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W J McGEE, *Editor*

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CONTENTS.

ILLUSTRATIONS.

(63 *figures*.)

PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA.

Regular Publications.

The Society issues a single serial publication entitled Bulletin of the Geological Society of America. This serial is made up of *proceedings* and *memoirs*, the former comprising the records of meetings, with abstracts and short papers, lists of Fellows, etc., and the latter comprising the longer papers accepted for publication. The matter is issued, soon as practicable after acceptance, in covered brochures which are distributed at once to Fellows and exchanges.

The publications are sold to Fellows and the public in full volumes as well as in separate brochures. The volume prices are, to Fellows a variable amount, depending on the cost of the volume (volumes 1 and 2, $4.50 each); to libraries, $5.00 per volume; and to the public ten dollars ($10) per volume. The brochure prices are given below.

Volume 1, covering the work of the Society from its organization to the end of 1889, is complete. It comprises the following brochures:

Brochure.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
Organization, Proceedings of Toronto Meeting, and Papers read at Toronto. J. J. Stevenson, *Secretary*	1–86	1	1–12, 1–7	$1.40	$2.75
Origin of the Rock Pressure of Natural Gas in the Trenton Limestone of Ohio and Indiana. Edward Orton	87–98	------	------	.15	.30
Notes on the Surface Geology of Alaska. I. C. Russell	99–162	2	------	.90	1.80
Note on the Pre-Paleozoic Surface of the Archean Terranes of Canada; The Internal Relations and Taxonomy of the Archean of Central Canada. A. C. Lawson	163–194	------	------	.40	.80
Structure and Origin of Glacial Sand Plains. W. M. Davis	195–202	3	1–4	.20	.40
The Pre-Cambrian Rocks of the Black Hills. C. R. Van Hise	203–244	4, 5	1–5	.80	1.60
Orographic Movements in the Rocky Mountains. S. F. Emmons	245–286	------	------	.50	1.00
On Glacial Phenomena in Canada. Robert Bell	287–310	------	------	.30	.60
On the Pleistocene Flora of Canada. Sir William Dawson and D. P. Penhallow	311–334	------	1	.35	.65
The Value of the Term "Hudson River Group" in Geologic Nomenclature. C. D. Walcott	335–356	------	1	.30	.60
Some Results of Archean Studies. Alexander Winchell	357–394	------	1–12	.55	1.05
Post-Tertiary Deposits of Manitoba and the adjoining Territories of Northwestern Canada. J. B. Tyrrell	395–410	------	------	.20	.40
Sandstone Dikes. J. S. Diller	411–442	6–8	1–8	.90	1.75
Tertiary and Cretaceous Deposits of Eastern Massachusetts. N. S. Shaler	443–452	9	------	.20	.40

Brochure.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
The Stratigraphy of the "Quebec Group." R. W. Ells	453–468	10	------	$0.30	$0.55
Some additional Evidences bearing on the Interval between the Glacial Epochs. T. C. Chamberlin	469–480	------	------	.15	.30
The Cuboides Zone and its Fauna; a Discussion of Methods of Geologic Correlation. H. S. Williams	481–500	11–13	------	.45	.90
The Calciferous Formation in the Champlain Valley. Ezra Brainerd and H. M. Seely. With a Supplement on the Fort Cassin Rocks and their Fauna. R. P. Whitfield	501–516	------	------	.20	.40
Proceedings of the New York Meeting. J. J. Stevenson, *Secretary*. (With Index, Title-page, List of Contents, etc., for the Volume	517–593 i–xii	------	------	1.25	2.45

Volume 2, covering the work of the Society for the year 1890, is now complete. It comprises the following brochures:

Brochure.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
Proceedings of the Semi-Annual Meeting held at Indianapolis. J. J. Stevenson, *Secretary*	1–30	------	1–2	$0.35	$0.70
The Cuyahoga Shale and the Problem of the Ohio Waverly. C. L. Herrick	31–48	1	------	.25	.45
The Structure of a Portion of the Sierra Nevada of California. G. F. Becker	49–74	------	1–13	.35	.65
Phosphate Deposits of the Island of Navassa. E. V. D'Invilliers	75–84	------	1	.15	.30
A Last Word with the Huronian. Alexander Winchell	85–124	------	1–3	.45	.90
The Nickel and Copper Deposits of Sudbury District, Canada. Robert Bell; with an appendix on The Silicified Glass-Breccia of Vermilion River, Sudbury District. Geo. H. Williams	125–140	------	1–4	.20	.40
The Overthrust Faults of the Southern Appalachians. C. Willard Hayes	141–154	2–3	1	.30	.55
The Structure of the Blue Ridge near Harper's Ferry. H. R. Geiger and Arthur Keith	155–164	4–5	------	.20	.40
Note on the Geological Structure of the Selkirk Range. G. M. Dawson	165–176	------	1	.15	.30
Graphic Field Notes for Areal Geology. Bailey Willis	177–188	6	------	.20	.35
Antiquities from under Tuolumne Table Mountain in California; Notes on the Early Cretaceous of California and Oregon. G. F. Becker	189–208	7	1	.30	.60
The Relation of Secular Rock-Disintegration to Certain Transitional Crystalline Schists. Raphael Pumpelly	209–224	------	1–4	.20	.35
The Geotectonic and Physiographic Geology of Western Arkansas. Arthur Winslow	225–242	8	1–9	.35	.65
Glacial Lakes in Canada. Warren Upham	243–276	------	------	.35	.70

Brochure.	Pages.	Plates.	Figures.	Price to Fellows.	Price to the Public.
Stratigraphy of the Carboniferous in Central Iowa. CHARLES R. KEYES	277–292	9–10	------	$0.30	$0 55
The Chazy Formation in the Champlain Valley. EZRA BRAINERD	293–300	11	------	.20	.35
The Petrography and Structure of the Piedmont Plateau in Maryland. G. H. WILLIAMS; with a supplement on A Geological Section across the Piedmont Plateau in Maryland. C. R. KEYES	301–322	11	1–5	.35	.65
Tertiary and Post-Tertiary Changes of the Atlantic and Pacific Coasts; with a note on The Mutual Relations of Land-Elevation and Ice-Accumulation during the Quaternary Period. JOSEPH LE CONTE	323–330	------	1	.15	.25
On the Lower Cambrian Age of the Stockbridge Limestone at Rutland, Vermont. J. E. WOLFF	331–338	------	1–2	.15	.30
Composition of Certain Mesozoic Igneous Rocks of Virginia. H. D. CAMPBELL and W. G. BROWN	339–348	------	------	.15	.30
The Cinnabar and Bozeman Coal Fields of Montana. W. H. WEED	349–364	13	1–2	.30	.60
On the Recognition of the Angles of Crystals in thin Sections. A. C. LANE	365–382	14	------	.35	.70
The Geology of Mount Diablo, California. H. W. TURNER; with a supplement on The Chemistry of the Mount Diablo Rocks. W. H. MELVILLE	383–414	15	------	.40	.80
Two Belts of Fossiliferous Black Shale in the Triassic Formation of Connecticut. W. M. DAVIS and S. W. LOPER	415–430	------	1–3	.20	.40
Mesozoic and Cenozoic Formations of Eastern Virginia and Maryland. N. H. DARTON	431–450	16	1	.30	.55
On the Triassic of Massachusetts. B. K. EMERSON	451–456	17	------	.20	.40
Glacial Grooves at the Southern Margin of the Drift. P. MAX FOSHAY and R. R. HICE	457–464	18	1	.25	.45
Post-Pleistocene Subsidence versus Glacial Dams. J. W. SPENCER	465–476	19	------	.20	.35
On the Geology of Quebec and Environs. H. M. AMI	477–502	20	------	.35	.70
The Comanche Series of the Texas-Arkansas Region. R. T. HILL	503–528	------	------	.30	.55
Carboniferous Fossils from Newfoundland. Sir J. WILLIAM DAWSON	529–540	21–22	------	.35	.65
A proposed System of Chronologic Cartography on a Physiographic Basis. T. C. CHAMBERLIN; with The Geological Dates of Origin of certain Topographic Forms on the Atlantic Slope of the United States. W. M. DAVIS	541–586	------	1–6	.50	1.00
Variations in the Cretaceous and Tertiary Strata of Alabama. D. W. LANGDON, JR	587–606	23	------	.40	.80
Proceedings of the Washington Meeting. J. J. STEVENSON, *Secretary*. (With Index, List of Contents, etc., for the Volume.)	607–662, i–xiv	------	------	.80	1.60

Irregular Publications.

In the interests of exact bibliography, the Society takes cognizance of all publications issued either wholly or partly under its auspices. Each author of a memoir receives 30 copies, and is authorized to order any additional number at a slight advance on cost of paper and presswork; and these separate brochures are identical with those of the editions issued and distributed by the Society. Contributors to the proceedings also are authorized to order any number of separate copies at a slight advance on cost of paper and presswork; but these separates are bibliographically distinct from the brochures issued by the Society.

The following separates of parts of Volume 2 have been issued:

Editions uniform with the Brochures of the Bulletin.

Pages	31– 48, plate	1— 30 copies.	January	12, 1891.
"	49– 74,	130 "	"	16, "
"	75– 84,	30 "	"	29, "
"	85–124,	200 "	February	9, "
"	125–140,	260 "	"	7, "
"	141–154, plates	2, 3—105 "	March	3, "
"	155–164, "	4, 5— 80 "	"	3, "
"	165–176,	200 "	February	11, "
"	177–188, plate	6— 30 "	March	3, "
"	189–208, "	7—155 "	"	3, "
"	209–224,	280 "	February	20, "
"	225–242, plate	8—130 "	March	4, "
"	243–276,	80 "	"	7, "
"	277–292, plates	9, 10—180 "	"	24, "
"	293–300, plate	11— 30 "	"	25, "
"	301–322, "	12— 60 "	"	24, "
"	323–330,	50 "	"	24, "
"	331–338,	60 "	"	25, "
"	339–348,	60 "	"	24, "
"	349–364, plate	13— 30 "	"	25, "
"	365–382, "	14—130 "	May	6, "
"	383–414, "	15—130 "	April	3, "
"	415–430,	130 "	"	14, "
"	431–450, plate	16— 80 "	May	5, "
"	451–456, "	17—230 "	"	13, "
"	457–464, "	18—330 "	"	9, "
"	465–476, "	19—205 "	"	6, "

Pages 477–502, plate	20—130 copies.	May	5,	1891.
" 503–528,	130 "	"	7,	"
" 529–540, plates 21, 22—130	"	June	3,	"
" 541–586,	100	July	13,	"
" 587–606, plate	23— 55 "	"	13,	"

*Special Editions.**

Pages	2– 6†—200 copies.	January 17, 1891.	Without	covers.
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"	25–30 — 30 "	" " "	"	"
"	611— 30 "	August 5 "	"	"
"	615–630 –300 "	July 23 "	"	"
"	635— 30 "	" " "	"	"
"	636— 30 "	" " "	"	"
"	638— 30 "	" " "	"	"
"	638–639— 30 "	" " "	"	"
"	639— 30 "	" " "	"	"
"	640–642— 30 "	" " "	"	"
"	645–652—200 "	August 3 "	"	"
"	ix–xi—200 "	" 5 "	"	"

* Bearing the imprint ["From Bull. Geol. Soc. Am., Vol. 2."]
† Fractional pages sometimes included.

ERRATA.

All contributors to Volume 2 have been invited to send in errata found in their contributions, and the volume has been scanned with some care by the Editor. The following errata, deemed worthy of notice, have been detected:

Page 56,	line 12	from	top (in cut);	*for* "N." *read* S. S. W.
140	" 7	"	bottom	" "dentrification" " devitrification.
144	" 10	"	"	" "northwest" " northeast.
209	" 6	"	top	" "1891" " 1890.
222	" 4	"	bottom	*substitute* † 7th Ann. Rep. Geol. and Geog. Surv., 1874, p. 211.
"	" 3	"	"	" ‡ Rep. Chief of Engineers for 1876, pt. 3, p. 394.
290	" 8	"	"	*for* "*ANTHROPODA*" *read* *ARTHROPODA*.
318	" 10	"	top	" "well" " well as.
331	" 2	"	"	*after* "LIMESTONE" *add* AT RUTLAND, VERMONT.
346	" 11	"	"	*for* "along only" *read* only along.
346	" 22	"	" (III);	*add foot-note* Analysis by G. W. Hawes, Am. Jour. Sci., 3d ser., vol. IX, 1875, p. 185.
354	" 18	"	" (in cut);	*for* "Whin — 25′" *read* Whin — 10′.
428	" 18	"	"	" "*auguilliformis*" " *auguiliformis*.
457	" 3	"	bottom	" "Azhtabula" " Ashtabula.
460	" 21	"	top	" "stream and" " stream, and.
478	" 7	"	"	" "St. Cyr" " Saint-Cyr.
482	" 21	"	"	" "*Lituites nudatus*" " *Trochoceras halli*.
506	" 16	"	bottom	" "upper half" " white band.
515	" 12	"	"	" "*pedernalis*" " *peruvianus*.
518	" 17	"	top	" "except" " except perhaps.
522	" 9	"	bottom	" "Archean" " alleged Archean.
521	" 12	"	top	" "Eocene débris" " Comanche débris.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 1-30 JANUARY 3, 1891

PROCEEDINGS OF THE SEMI-ANNUAL MEETING HELD AT INDIANAPOLIS AUGUST 19, 1890.

J. J. STEVENSON, *Secretary.*

CONTENTS.

SESSION OF TUESDAY, AUGUST 19.

The Society met in the State House, Indianapolis, Indiana, at 10.30 a. m.; Vice-President Alexander Winchell in the chair.

The Secretary reported the election of the following Fellows:

GEORGE H. BARTON, B. S., Boston, Mass. Instructor in Geology in Massachusetts Institute of Technology; now engaged in Glacial Geology; has done work on U. S. Geological Map of Massachusetts, and in various areas of special investigation; has published numerous papers in scientific journals.

HENRY M. CHANCE, M. D., Philadelphia, Pa. Geologist and Mining Engineer; engaged in private practice; was for many years Assistant on 2d Geological Survey of Pennsylvania; has published numerous volumes, maps, and memoirs.

CHARLES R. KEYES, B. S., Baltimore, Md. Paleontologist; has published papers on Paleontology in Davenport Academy of Natural Science; Essex Institute; American Journal of Science; American Geologist; American Philosophical Society; American Naturalist.

J. A. K. LAFLAMME, M. A., D. D., Quebec, Canada. Professor of Mineralogy and Geology in University Laval, Quebec; associated for five years with Geological Survey of Canada; has published text book of Mineralogy, Geology, Botany; memoirs in Proceedings of Royal Society of Canada.

LAWRENCE M. LAMBE, Ottawa, Canada. Graduate of Royal Military College of Canada; Artist and Assistant in Paleontology on Geological Survey of Canada since 1884.

FRANK LEVERETT, B. S., Madison, Wisconsin. Assistant Geologist, U. S. Geological Survey; has been engaged since 1886 in tracing terminal moraines of Michigan, Illinois, Indiana and Ohio; has published papers on glacial topics in A. A. A. S., and in Wisconsin Academy of Science.

JOSUA LINDAHL, A. M., Ph. D., Springfield, Ill. State Geologist of Illinois and Curator of the State Museum; edited Vol. VIII. of Illinois Geological Survey Reports; has published papers on Geology in American Naturalist; his other publications have been on Zoology.

WALDEMAR LINDGREN, Washington, D. C. Assistant Geologist, U. S. Geological Survey; engaged in Mining Geology; has published in American Institute of Mining Engineers; Tenth Census of U. S.; California Academy of Sciences; Bulletin of U. S. Geological Survey.

PETER MCKELLAR, Fort William, Canada. Has been engaged in Geological exploration, north of Lake Superior, during 25 years; was Assistant on Geological Survey of Canada; has published several important papers.

WILLIAM B. POTTER, A. M., E. M., St. Louis, Mo. Professor of Mining and Metallurgy in Washington University; President of American Institute of Mining Engineers; formerly Assistant on Geological Surveys of Ohio and Missouri; has published many papers.

WILLIAM NORTH RICE, A. M., Ph. D., LL. D., Middletown, Conn. Professor of Geology in Wesleyan University; has published numerous papers in American Journal of Science; Science; Bulletin of National Museum, and other journals.

RALPH S. TARR, Austin, Texas. Assistant Geologist on Texas Geological Survey; has been engaged on study of glacial deposits in New England; has published in American Journal of Science and American Geologist.

The Secretary announced the appointment of a committee to collect and to prepare a plan for the collection and preservation of geological photographs. This committee, consisting of Messrs. J. F. Kemp, W. M. Davis, and J. S. Diller, has begun work and issued a circular.

There being no other business before the Society, the printed programme was taken up. The first paper was—

THE APPOMATTOX FORMATION IN THE MISSISSIPPI EMBAYMENT.

BY W J MCGEE.

(Abstract.)

The Appomattox formation was defined and, as developed in the middle Atlantic slope, was briefly described early in 1888,* and its southern extension in the Carolinas, Georgia, Alabama, and southeastern Mississippi was described at some length during the present year.† As set forth in these publications, the formation is a series of obscurely stratified and frequently cross-bedded loams, clays, and sands of prevailing orange hues, with local accumulations of gravel about waterways; the materials varying somewhat from place to place, but always in the direction of community of material between the formation and the older deposits upon which it lies; while as a whole the formation retains so distinctive and strongly individualized character-

* Am. Jour. Sci., 3 Ser., Vol. XXXV, pp. 328–30.
† Am. Jour. Sci., 3 Ser., Vol. XL, 1890, pp. 15–41.

istics as to be readily recognized wherever seen. It occupies the greater part of the coastal plain in the southern Atlantic and eastern Gulf slopes, and overlies unconformably the Miocene, Eocene and Cretaceous formations ; and it is in turn unconformably overlain by the Columbia formation. In its typical development within this area the deposit is frequently flecked and streaked with white ; and it becomes gravelly toward waterways, and also differentiates into stratified beds of sand and clay toward the coast. The pebbles in the gravelly portions are of rocks forming the terranes traversed by the rivers along whose lower courses they are accumulated, and so differ from river to river ; the bulk of the loam is evidently composed of residuary sands and clays such as exist in greater or less volume along the same rivers ; and the white material by which the deposit is flecked and streaked is in considerable part a kaolin or clay apparently resulting from decomposition of feldspar, which forms an element in the Piedmont crystallines overlapped by the coastal plain formations.

During the present season the formation was studied in some detail in western, central and northern Mississippi, and in western Tennessee and Kentucky; and it was also recognized and casually studied in southern Illinois, as well as on the other flank of the Mississippi embayment in central Arkansas. Within this region the formation was found to display certain peculiarities in composition and structure which vary from place to place in a significant way, and also to exhibit a notable increase in volume.

In northern Louisiana and the contiguous portion of Mississippi the formation is a loam similar to that of southeastern Mississippi and Alabama, save that the prevailing color is brick-red rather than orange and that it is frequently pebbly, the pebbles consisting mainly of subangular and rounded fragments of Paleozoic chert. The thickness of the formation here was not accurately determined, but is apparently less than that attained further northward ; and as usual it has been profoundly eroded. It is commonly overlain by the Columbia formation up to altitudes of 250 feet or more. In central Mississippi the Appomattox loams and sands commonly form the surface over a considerable zone parallel with the Mississippi, but dip beneath the Columbia deposits toward the bluffs of that river and along its larger tributaries. Here the deposit is thicker, more sandy, and more frequently gravelly than to the southward ; and moreover it displays a differentiation of materials in the vertical direction : the upper third is a fairly homogeneous brick-red or orange sandy loam, sometimes gravelly ; the middle third a similar loam or sand of like color interstratified with thin lenses of white silicious clay ; while the lower third is an irregularly stratified bed of silt, clay and sand. Exposures of 40 to 60 feet are not uncommon, and the full thickness of the formation probably exceeds a hundred feet ; but as usual it is deeply dissected and sometimes completely removed along the waterways. In northern Mississippi and in western Tennessee and Kentucky the vertical differentiation commencing in the first-named state is well defined, and the formation becomes a definitely tripartite one. (1) The upper member is a fairly uniform brick-red sandy loam locally charged with pebbles, perhaps in such number as to transform the mass into a gravel bed ; sometimes it is cross-stratified, and it may be flecked and streaked with white, as in the more easterly localities ; and, as in these localities, exposed surfaces frequently display the distinctive semi-glazed aspect resulting from alteration of the contained iron. Over the terranes of the more ferruginous Eocene formations this member, and indeed the entire formation, is exceptionally rich in iron ; the gravels are sometimes so firmly cemented as to form puddingstones, the sands are locally lithified, and plates and nodules of sand ironstone are common. (2) The middle member may be a nearly pure snow-white silicious clay, but more commonly consists of alternating layers of such clay and brick-red loam like that of the upper member. This silicious clay sometimes contains well-preserved leaf impressions and other plant fossils. It is largely used in the manufacture of pottery in northern Mississippi, western Kentucky, and particularly in western Tennessee. (3) The basal member is commonly made up of irregularly stratified lead-colored or gray silicious clay (less pure than that of the middle member), red or brown sand, gray silt, etc. The middle and lower members commonly merge insensibly, as do the upper and middle members in most sections; but sometimes a sharp division plane demarks the upper loam and the subjacent clays, the clay strata are truncated as if by erosion, and pellets and lenses of the clay are incorporated in the overlying loam. This relation suggests unconformity; but it probably represents nothing more than a common type of transition from slack-water deposits to the products of stronger currents. From the Big Black river to the Ohio the brick-red loams and sands and the attendant gravel beds form the surface over a zone 20 to 50 miles broad lying east of the limits of the newer Columbia formation, though they have been deeply and widely trenched by all of the larger rivers. The thickness of the formation at Holly Springs, Mississippi, and La Grange, Tennessee, is about 200 feet, while the artesian borings at Memphis indicate a thickness of no less than 485 feet for the middle and lower members. North of the Ohio, in southern Illinois, the formation is a pebbly red loam or sand, sometimes distinctly stratified. In central Arkansas, notably at Little Rock and about Malvern, pebbly, red loams, undoubtedly representing the same formation, are occasionally found overlying the glauconitic Eocene sands and the older formations alike, and are overlain in turn by a series of deposits correlated with the Columbia formation of the east. The pebbles here are distinctive, those of Malvern in particular consisting chiefly of rounded and subangular fragments of novaculite.

A significant feature of the Appomattox formation in the Mississippi embayment is the enormous aggregate volume of gravel. East of the Mississippi the pebbles composing this gravel are commonly subangular or rounded fragments of chert, largely derived from the Sub-Carboniferous of the interior basin but partly from the Silurian and other strata. The distribution of this gravel, as well as the distribution of the formation in general, indicates that during the period of deposition of the formation the Tennessee river embouched directly into the Mississippi embayment of that period not far from what is now the northeastern corner of Mississippi. Another significant yet somewhat puzzling feature of the formation in its northern portion is found in the great beds of fine-textured and often snow-white silicious clay intercalated in the middle member and in the flecks and streaks of like material found throughout the loam of the upper member. It would seem possible, if not probable, that the greater part of this distinctive material consists of disintegrated chert, which was conveyed into the slack-water estuary anterior to the transportation of the non-decomposed chert by the stronger currents attending the close of the Appomattox period; so that the resemblance of the white markings to those in the eastern extension of the formation appears partly fortuitous. Still another significant feature of the formation is the accumulation of plant remains within it in northern Mississippi and western Tennessee and Kentucky. The fossils collected during the present season have not yet been studied, but the specimens collected by Safford and Loughridge have been examined by Lesquereux and Ward. It should be observed, however, that the age indicated by the few fossils thus far identified is hardly consistent with the voluminous evidence of stratigraphic position.

The known geographic distribution of the formation has been materially extended by the season's work. Originally it overspread the entire state of Mississippi, save a few hundred square miles in the extreme northeastern corner, mantled western Tennessee to and commonly a score or more miles beyond the Tennessee river, covered western Kentucky nearly or quite to the Cumberland river, and extended across the Ohio fifty miles or more into southern Illinois; and the isolated remnants west of the Mississippi on the White, Arkansas and Washita rivers indicate a still wider extension westward. But, as in the territory previously studied, it has been extensively invaded by erosion, cut through along the larger waterways and trenched by the smaller, to such an extent that somewhere between thirty and seventy per cent. (and probably between forty and sixty per cent.) of its original volume was carried into the Gulf. In the axis of the Appomattox estuary, however, the formation was sometimes buried beneath newer deposits, and remains intact to afford artesian waters, as at Memphis, Greenville and other points. The hypsographic distribution of the formation in the Mississippi embayment ranges from 50 feet or less above tide on Thompson bayou (near Bayou Sara) to 500–600 feet over the plateau extending northward from Grand Junction, Tennessee, and to over seven hundred feet in the isolated outliers between the Tennessee and Cumberland rivers about Tennessee Ridge. The observations concerning stratigraphic relation and the inferences as to age made during previous years are sustained and corroborated by the season's work. The formation rests unconformably alike upon the (probably Miocene) Grand Gulf deposits and upon the Eocene and Cretaceous strata of the coastal zone, as well as upon the margin of the Paleozoic terrane in Tennessee, Kentucky, Illinois and Arkansas. The distinctive materials found in the Mississippi embayment only reflect the rock composition along the upper river and its tributaries in the usual manner; the enormous increase in thickness is no more than proportional to the vast volume of the great river; and nearly all of the extensive erosion by which it is characterized occurred anterior to the deposition of the Columbia formation, as is the case further eastward.

The deposits of Mississippi now referred to the Appomattox formation were first described by Professor Eugene W. Hilgard, the able expounder of southern geology whose comprehensive grasp of isolated details and clear insight into complex relations excite the wonder and admiration of his followers, and whose interpretation of a most obscure record was so complete that later students have modified his reading only in minor points; and the same series of deposits in western Tennessee was described even earlier by another eminent pioneer among American geologists, Professor James M. Safford.

The results of the season's work raise a question of nomenclature. In 1856 the red and orange sands of western Tennessee, now correlated with the Appomattox formation, together with certain other deposits, were described by Safford, designated the "Orange Sand group," and referred to the Cretaceous.* In 1860 Hilgard adopted the same designation for the extensive sand and gravel deposits of Mississippi, including those now set apart and correlated with the Appomattox of Virginia together with some others, and referred the whole to the Quaternary.† Subsequently Safford modified the definition of his original group by excluding its lower portion, and at the same time substituted the name "La Grange group" for the series thus defined, pointed out its distinctness from the "Orange Sand" of Hilgard, and referred it doubtfully to the Eocene.‡ Loughridge has recently adopted Safford's later designation for the greater part of the same series as developed in western Kentucky (excluding "the superficial

* Geological Reconnoissance of Tennessee, pp. 148, 162.
† Geology and Agriculture of Mississippi, pp. 3, 4.
‡ Geology of Tennessee, 1869, pp. 150, 166, 424.

beds of sands"—the upper member of the foregoing paragraphs), and referred the deposits doubtfully to the later Tertiary, though "strongly inclined to believe * * * that they are the lowest of the Quaternary stratified drift;"* while Safford, in a quite recent publication, apparently still further modifies the definition of the La Grange and refers it to the highest part of the Tennessee Tertiary, and moreover applies the term "Orange Sand" to a superficial formation assigned to the Quaternary,† probably the "Bluff Gravel" of the 1869 report.‡ Under the law of priority it would seem just to restore one of the early designations. But there are certain adverse considerations of sufficient weight to merit statement: (1) The definition of the "Orange Sand" has never been clear; it was originally applied by Safford to a certain series of deposits, was subsequently applied by Hilgard to a series different as a whole though identical as to one member, was still later reäpplied by Safford to a distinct deposit, and has been used in a lax and irregular manner by other geologists. (2) In no case does the definition of the "Orange Sand" by geologists who have used the term correspond with that of the Appomattox formation; for Safford's original "Orange Sand" included one of the older formations, while his later "Orange Sand" is a wholly post-Appomattox deposit; Hilgard included under the term not only the deposits now set apart, but also the newer gravels intercalated between the loess (or loam) and Port Hudson—the Bluff Gravel of Safford—as well as various older gravels of which a part are now assigned to the Potomac (Tuscaloosa) formation; and other users of the term have employed it in equally discrepant ways. (3) The name "Orange Sand" appears to have been originally applied, and certainly has been commonly used, rather as a descriptive term than a specific appellation; and, moreover, it is by many geologists considered desirable to employ only connotative formation names in which the principal element is geographic and indicative of the locality of typical development. (4) While the definition of the "La Grange" as given by Safford in 1869 agrees with that of the Appomattox, the deposits were adjudged Eocene instead of late Pliocene, as indicated by stratigraphic position. (5) Although the locality from which the La Grange was originally named was at that time a flourishing city, it has since, in consequence of war, the building of railroads and other vicissitudes, shrunk to a small village, with an uncertain tenure of life beyond the present decade.

This question of nomenclature would appear to be one upon which the Geological Society of America might well pass, and it is raised in the hope that it may be freely discussed and, if practicable, definitively settled by this representative body of American geologists.

The paper was discussed by J. M. Safford, C. H. Hitchcock, E. W. Claypole and W J McGee.

This paper was followed by a brief communication on—

THE REDONDA PHOSPHATE.

BY C. H. HITCHCOCK.

Redonda, a volcanic island situated between Nevis and Montserrat, lat. 16° 55′ N., long. 62° 13′ W., is one of the Leeward islands of the Caribbean sea. It is one

* Geological Survey of Kentucky: Report on Jackson Purchase Region, 1888, pp. 7, 52.
† Agricultural and Geological Map of Tennessee issued by the Commissioner of Agriculture, etc. (J. M. Safford, State geologist), 1888.
‡ Geology of Tennessee, 1869, p. 432.

of a continuous line of volcanic islands, beginning with Saba, at the northern end and continuing through St. Eustatius, St. Christopher (or St. Kitts), Nevis, Redonda, Montserrat, Guadeloupe and Dominica, and probably farther. Volcanic activity is still displayed in St. Christopher, Montserrat and Guadeloupe.

Redonda is about one mile long and one-fourth as wide, and its extreme apex is 975 feet above the sea level. Most of it is surrounded by a cliff, never less than 500 feet high and reaching to the very top on the western side. The lower cliffs seem to have been formed by the wearing action of the waves, connected with the falling down of loosened fragments by gravity. The cliff is practically inaccessible except by means of the bucket attached to a wire tramway. Multitudes of sea birds nest upon these rocks; and because of the guano accumulated from their droppings, the island was occupied for the gathering of fertilizers. After the removal of the true guano a phosphatic mineral immediately succeeded it in depth. This mineral was named *Redondite* (shortened to *Redonite*) by the late Professor C. U. Shepard.* It contained, according to him, phosphoric acid, 43.20%; peroxide of iron, 14.40%; alumina, 16.60%; water, 24.00%; silica, 1.60%; lime, 0.57%. He perceived the strong contrast between this mineral and all other known guanos and phosphates, and noted its similarity to *barrandite.*

The following are a few analyses selected from a large number made for the English company owning the island:

P_2O_5	42.90%	38.30%	41.00%	40.20%	38.20%
F_2O_3	8.25	11.50	10.50	5.20	16.60
Al_2O_3	24.75	21.00	19.50	24.80	13.40
H_2O	22.00	20.00	23.00	24.20	24.80
	97.90	90.80	94.00	94.40	93.00

The rock of the island is a lava much like basalt, occurring in sheets resembling strata, and having a dip outwards from the center upon three sides. Many of the sheets are separated by thin and rough porous masses resembling the Hawaiian "aa." At several localities a friable tufa or ash, with breccias, is found to occupy large fissures in the lava. The thicker beds display well the concretionary or columnar structure. The phosphate, called by the miners "crust phosphate," is found to encircle the concretions or spherical nodules, occupying the spaces between them. Imagine a stone wall made of large and small stones cemented together, and the place of a large stone to be often taken by the cement, and let this structure be demolished and the cement gathered into a pile by itself. Then the stones will correspond to the spherules and the cement to the phosphate, and the mining is precisely like the tearing down of a wall. The rock is first shattered by blasting, and the phosphate is picked out by hand and carried to the pile awaiting shipment. Mining commenced at the apex of the island, and the mineral has been gathered from several acres of surface, proceeding northeastwardly. There seem to be at least two sheets carrying the mineral, which are separated by an ash-vein. For ease of working, only the more superficial masses are saved. Several of the bunches have been forty feet wide and deep; and when of these dimensions they suggest the bonanzas of the silver veins. It is also probable that the phosphate is accumulated along a northeasterly line very much like a vein of metallic sulphuret, but with an absence of walls.

* Amer. Jour. Sci., 2nd Ser., Vol. XLVII, 1869, p. 428; also Vol. L, 1870, p. 96.

It was discovered early in the exploitation of the ground that the most solid lava masses covered abundant phosphate. Captain Harding, the superintendent, received permission to test this view by running a short tunnel from near his office, at the south end of the island, beneath the most compact ledges known to him. Hardly a fathom of excavation was required to develop abundant supplies of the phosphate. At the inner end of this tunnel—say thirty feet long—the air moves from within outwards against the prevailing trade-wind. The rocks are somewhat fragmental and the rubble is coated with a white incrustation which proves to be a phosphate, probably of alumina, as there is no lime present. This discovery led to the conclusion that the abundant thin white coatings between the lava layers all through the island consist of phosphate, instead of gypsum, as hitherto supposed. The phosphate was also discovered by us at the extreme southern point of the island, at the water's edge, as well as near the northern end. In fact, there is more or less of this mineral disseminated through the volcanic mass everywhere upon the island except in the ash.

The phosphatic mineral exists in several distinct compounds, which are readily recognized. The "agate" and "crust" varieties carry about forty per cent. of phosphoric acid and twenty-four per cent. of water. Red varieties of different shades carry twenty-seven and twenty-four per cent. of phosphoric acid, and the iron oxide increases at the expense of the alumina. With the diminution of the acid there is also a loss of water, ranging down to sixteen per cent. The lowest grade of all is a reddish earth, full of grains or nodules of the redondite, carrying ten or twelve per cent. of phosphoric acid. This may be compared to soil covering the ledges.

Our researches have not been specially directed towards a study of the peculiarities of the several grades of phosphate, but rather to their origin. The present chemical combination is evidently not the original one. The existence of phosphatic nodules suggests conditions similar to those required in the separation of limonite from inferior grades of iron ore. It does not seem possible that these phosphates can have been derived from the droppings of birds, which have saturated the rocks by infiltration; nor is it easy to see how they can have been derived from phosphate of lime, such as occurs at Sombrero, Navassa, Aruba, and many of the small islands of Central America. Their hydrated character leads to the belief that they were originally anhydrous, receiving water from the saturation of the rock with rain. If the mineral was originally anhydrous lime phosphate, one might imagine the absorption of the lime by sulphuric acid produced through oxidation of the volcanic sulphur to constitute gypsum, which was leached out subsequently. But the nearly complete absence of lime renders this view of its disappearance problematical.

Only one or two other similar occurrences of this redondite are known. May it not be possible that there was a volcanic outburst through a bed of the lime phosphate, and that in some way alumina and iron replaced the lime? Is it possible that the mineral was disseminated through the lava in a gaseous condition? The scarcity of this form of phosphate and its occurrence in small volcanic islands makes some such view possible.

There is still another possible view: There is one known phosphuret—Schreibersite—found in meteors. Originating beyond the earth's atmosphere in the absence of oxygen, this combination is practicable; but if a similar compound were brought to the surface by an igneous ejection it would soon become a hydrous phosphate. The existence of iron not to be distinguished from meteoric masses is well known in the Greenland basalts, and it is generally conceded that it has originated in the earth and not from extra-terrestrial sources. Why may not this redondite have come up from below as a phosphuret, which has since changed its character through oxidation and hydration?

The discovery of this mineral in a volcanic rock recalls the presence of apatite in Archean granites, Paleozoic diabases and other massive rocks, which are assuredly of igneous origin. Our studies into the soils of New Hampshire led us to refer the origin of the small percentage of phosphorus found in them to the decay of the underlying granites carrying microscopic crystals of apatite rather than to any organisms of modern times.* If phosphates may occur in the ancient crystallines as original minerals, it is reasonable to believe that similar compounds might be found in recent lavas.

The dealers in fertilizers will be pleased if we can refer them to any new source of phosphates. Hitherto no one has thought of searching for phosphates in volcanic rocks. As they so greatly resemble decayed rocks or ferruginous earths, observers may have overlooked them in volcanic regions. With attention now directed to the possibility of finding phosphates in lava, future explorers may make important discoveries in regions now regarded as valueless for economic purposes.

Professor N. H. Winchell: I should like to inquire of Professor Hitchcock if there is any objection known to him to considering this peculiar phosphatic deposit the result of leaching from ordinary phosphate or guano. I understood him to describe the substance as embracing masses, large and small, of the rock of the island, in a manner similar to that in which mortar embraces stones in a stone wall, and that much of the island is composed, at least superficially, of loose rocks thus cemented together. Those volcanic islands may date back to Tertiary or Cretaceous times. They naturally would always have been the roosting and breeding places for aquatic or other fowls. At the same time the region of volcanic activity is one of copious rains—rains that are often saturated with acids that characterize volcanic regions. Such acid waters would act powerfully on the native guano, and would dissolve and remove any lime that it contained. The residue would be carried downward and deposited by the drainage among the loose stones that composed the mountain side, and would even permeate the scoriæ and insinuate itself between successive lava flows. On analysis it would be found to resemble that which Professor Hitchcock has presented.

Professor Hitchcock: The phosphate is not found in the loose stones or tufa deposits, but in close connection with solid basaltic lava. The so-called stones are properly examples of the columnar structure so common in lava, but the concentric masses are spherical rather than cylindrical in shape, and the enclosed minerals do not bear more marks of infiltration than do the feldspar crystals of porphyry or the chrysolite in basalt. Guano would have been too limited in amount to have equalled the many thousand tons of the visible phosphate. Mr. P. T. Cleve, of Sweden, describes the lava of the Windward islands, including Redonda, as of Quaternary age, and the fires have hardly died out yet.

Further remarks on the communication were made by E. W. Claypole and A. S. Tiffany.

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* Geology of New Hampshire, Part IV, 1878, p. 94.

A recess was then taken until 2.30. p. m., after which the following paper was read:

THE CONTINENTS AND THE DEEP SEAS.

BY E. W. CLAYPOLE.

(*Abstract.*)

An opinion has become current of late among geologists that the main features of the relief of the earth's surface—the ocean abysses and the continental masses—are aboriginal. Those who have adopted this doctrine hold that all the variations that have occurred in the outlines of land and water have been caused by oscillation in what they call "the border of the ocean" where the water is comparatively shallow. The conversion of a deep ocean into land or of land into deep ocean has never, they maintain, taken place.

It is the purpose of this paper to examine the bases on which this opinion rests in order to discover whether or not they are trustworthy.

The doctrine itself may be a reäction from the opposite extreme advocated about forty years ago by Edward Forbes. This able but perhaps too zoological geologist ordered the continents about in a fashion that is rather surprising. With the highest respect for one who did so much for science, I may yet be allowed to insist that he carried too far the doctrine of instability, as some in the present are tending too far in the reäction.

The original suggestion came apparently from Darwin, who writes in his "Origin of Species" (edition of 1860, p. 357):

> "I do not believe that it will ever be proved that within the recent period continents which are now quite separate have been continuously or almost continuously united. Several facts in distribution seem to me opposed to the admission of such prodigious geographical revolutions within the recent period as are necessitated on the view advanced by Forbes."

Following him came Professor Dana, who inculcated the same doctrine in stronger terms in his "Manual" (edition of 1874, p. 738):

> "The earth's crust rises over large areas into plateaus or continents, leaving a depressed area of much larger extent occupied by the ocean. These plateaus show by their position that they were the parts of the crust that first stiffened, and that the oceanic basins are due to a subsequent consolidation of the areas which they occupy, the attending contraction carrying them below the level of the previously solidified continental areas."

The new doctrine has been strongly defended and as strongly opposed; but in order to examine its merits it will be best to consider in order the chief arguments advanced in its support.

There will be no advantage in discussing the fundamental hypothesis of Professor Dana, because it is purely an hypothesis and has nothing to support it. It may be true or false, but neither can be proved.

The condition of the problem is this: A land-area equalling about one-fourth part of the surface of the globe rises above the water-level to the average height of one-fifth of a mile. The remaining three-fourths of the surface is sunk below that level to the average depth of two miles. The depression of the ocean-bed therefore below the sea-surface is in capacity thirty times as great as the elevation of the land above it. The continents are comparatively insignificant masses lying but little above the water and capable of being submerged (excepting a few peaks) by a slight submergence. Were the whole land planed down to a level it would be covered with water to the depth of at least a mile.

(*a*) One of the arguments advanced in support of the doctrine of permanence is that no example of elevation sufficient in amount and extent to convert an ocean-abyss into land or of depression sufficient to change a continent into a deep ocean can be brought forward.

It is quite true that most of the *recent* changes that geology has revealed are not excessively great in amount. Some of them, however, reach high figures. It is generally admitted that during the later Pliocene period a land communication existed from Scotland through Färöe and Iceland to Greenland, and perhaps to North America. Such a communication implies the upheaval of the bed of the north Atlantic to the amount of 350 fathoms over a long distance, and to double that amount over the deep trough lying between Färöe and Iceland. A change of level of 3,500 feet almost within the human era is scarcely an argument for great stability.

But without lingering over intermediate dates, let us review the Tertiary period as a whole and see what it tells us of subsidence and elevation. During the Eocene and Miocene ages a vast mediterranean sea extended over southern-central Europe into Africa and southern-central and eastern Asia. In it were deposited the great nummulitic and other limestones, reaching a thickness of 15,000 or 20,000 feet. At that time, therefore, this area was one of subsidence to at least the extent of 2,500 fathoms, or the depth of the present Atlantic.

Yet this sea completely disappeared from geography during the Pliocene era, and but for its deposits its very existence would be unknown. Its whole area has been lifted above sea-level, and in some places, owing in part to corrugation, the *Nummulites* may be collected at the height of 10,000 feet in the Alps and at 16,500 feet in Thibet, indicating a change of level of 4,000 fathoms, equal to the profoundest depth of the existing oceans.

Nor is this a solitary or a specially strong case. On the northern slope of the Himalayas was deposited an almost continuous series of strata, ranging from the Silurian to the Cretaceous. Disturbance followed, and on the disturbed beds the nummulitic limestones already mentioned were laid down. The inference is legitimate that this part of central Asia was a marine area during most of the time from the Silurian to the Eocene. Yet on this very area now stands the loftiest country in the globe (Thibet), a high, bleak plateau, measuring about 1,500 miles by 350 and covering half a million of square miles, the average elevation of which is about 15,000 feet above the sea. Neglecting the depth of the sea from which it emerged, here is evidence of the elevation of a large area to an amount equalling all but the deepest parts of the Atlantic

Passing over for the present the arguments that may be drawn from the European chalk, let us consider the American Cretaceous strata. In some places these reach a thickness of 10,000 feet and on them lie 4,000 or 5,000 feet of Tertiary beds, indicating a subsidence of the basin in which they lie to the extent of 2,500 fathoms. Yet much of this depression has been recovered, and now Cretaceous rocks are found at a height of at least 4,000 feet in California and even higher in some parts of the Rocky Mountains.

But we may take a glance yet farther back in time: During the Mesozoic era a great depression took place over an area including the sites of London and Paris, which bears the name of the Anglo-Parisian basin, and in it the whole series of Mesozoic rocks was deposited, exceeding, according to D'Orbigny, 15,000 feet in thickness.

Probably no single section includes the whole, but there can be little risk of over-estimate in setting the depression at 10,000 feet. Of this a great part has been again elevated so as to stand above sea-level.

In the same manner a large area in the western states of America, at present very imperfectly known, consists of Mesozoic strata many thousand feet in thickness, indicating depression to an equal amount; but these same beds have since then been elevated, and some of them now form the summits of peaks rising 14,000 feet above the sea (Dana).

Looking now across the gap that separates Paleozoic from Mesozoic time, without stopping to inquire into its great significance in connection with the subject, we find a striking illustration in the well-known depression in what is now the eastern states. The facts are familiar. Suffice it to say that in that region a subsidence set in early in the Paleozoic era and continued nearly or quite to its end, carrying down the old surface to a depth in some places of not less than 40,000 feet, or 8 miles. So far as it is possible to measure this area, its length was at least 2,500 miles and its breadth not less than 300, and in some places two or three times as great. Yet a great part of this has been filled and much of it reëlevated to the height of hundreds of feet above the sea.

Similar testimony comes from the Paleozoic rocks on the other side of the Atlantic. The sections there are of even greater thickness, and indicate immense depression and subsequent recovery as clearly and as extensively as do those of the western world.

Looking back to a yet earlier date, the Vindhya range in India supplies a remarkable example. There an enormous mass of pre-Silurian rocks lying on disturbed earlier ones indicates a subsidence of not less than 14,000 feet, and subsequent filling and elevation without alteration or disturbance. All this occurred in pre-Silurian times, and the vast unfossiliferous series of the Vindhyan has existed in the same state ever since (save for the effects of erosion), a monument to a subsidence equal to the depth of the Atlantic basin which has been filled and lifted into a now ancient continental area.

(*b*) A second argument urged on behalf of the opinion here under consideration is that no deposits are known among the strata resembling those now forming at the bottom of the deep seas. Up to a certain extent there is some force in this statement. It may be true that nothing exactly like the singular deposits revealed by the recent deep-sea exploration has been met with in the crust of the earth. These consist chiefly of two kinds of material—the ooze, mostly calcareous, of the less depths up to 2,500 fathoms and, below that limit, a fine red clay with nodules of manganese. The former is composed of minute foraminiferous shells and the latter of volcanic and cosmic matter. Regarding the former, it may be said that there is no valid objection to ascribing the chalk to a similar origin. Such material indicates distance from land rather than deep water at the time of its deposition, and the ooze of the Atlantic ranges from 2,500 up to 500 fathoms, and even here it could not be formed unless the surface layer, where the rhizopods live, were favorable to their development.

Regarding the latter—the real deposit of the deep sea—we may remark, in the first place, that it is by no means certain that we cannot match these abyssal deposits among the strata. Without urging the case of the chalk, there are other materials which very closely parallel some of them. Professor Nicholson says in his recent "Manual of Paleontology" (p. 75):

"It cannot be safely asserted that we have no ancient representatives even of the 'abyssal clays' of the oceans of the present day. On the contrary, it seems very possible that certain of the sediments of such old systems as the Cambrian and Ordovician were formed at great depths, and that they represent the modern abyssal clays." "This is particularly the case with some of the fine-grained muds, red, brown or green, which occasionally form a conspicuous feature in the Cambrian and Ordovician series. Such muds are not only singular for their extraordinary barrenness in fossils, but there is good ground for thinking that they have been formed by the decomposition of volcanic matter, while they commonly exhibit dendrites of manganese."

The deposits above 2,500 fathoms not unfrequently consist largely of radiolarian and diatomaceous oozes, and these may be paralleled by similar deposits among the older strata. Haeckel regards the well-known "Barbadoes earth" as a deep-sea deposit, and states that many of the radiolarians of that island are to-day unchanged in the radiolarian ooze of the deep Pacific ocean.

But, setting these considerations on one side, there are some others. The lack of what we should at once call deep-sea deposits among the strata may have been due to the shallowness of the waters and be rather an evidence of the absence of ocean abysses than of their permanence. This, if not a probable explanation, is at least possible, and the more so when we reflect on the comparatively small portion of our seas over which the deep-sea deposits prevail. Again, it may result from our ignorance of the contents of the rocks over a large part of the globe; and we must also bear in mind the fact that such deposits must be in most cases quite thin. Away from land-wash, and dependent for their accumulation on volcanic and cosmic supplies, they cannot be heavy. Were it otherwise, and had the abysses existed from the beginning, they must have been long ago filled up. Moreover, the "Challenger" results have shown us that fossils have been lying on the bed of the sea in some places ever since the Eocene era without being buried. At one haul of the dredge there were brought up 600 shark teeth, 100 ear-bones of whales, and 50 fragments of bone; and many of these specimens are identical with fossils found in the Eocene strata—*Carcharodon megalodon*, for example. In this instance the deposition must have been exceedingly slow.

Further, in the discussion of this subject we might, if space allowed, dwell on the fact that the red clays do not indicate deep water, except in a sea peopled with calcareous organisms. Apart from this, they prove merely distance from land. According to the "Challenger" reports, blue and green muds are forming around the land to the depth of about 500 fathoms. Outside of this limit, therefore, in a sea not thickly peopled with foraminifera, the deposits should resemble those of the deep sea.

It might further be urged that strata so excessively thin as in many cases these abyssal deposits must be might easily be eroded or concealed during the elevation of the deep basin in which they were formed.

Yet once more it will not be wise to proceed on the assumption, as do the advocates of the permanence theory, that the present conditions of the globe have always prevailed. Indeed some are so strongly of an opposite opinion that they do not hesitate to assert that the present climates of the earth are quite exceptional, and that a very different state of things existed in past ages at the poles not only transitorily (of which there is no doubt) but even permanently. Now in this case the present condition of the bottom of the deep sea with its cold currents cannot have been the lasting one, and it would be unsafe to infer that the same deposits that are now and have been forming there during the later geological eras were laid down during the earlier and especially during the Palæozoic days.

(*c*) A third argument, and one on which great stress is laid in defense of permanence, is the alleged absence from all true oceanic islands of the stratified rocks of which the continents largely consist. It is even asserted that with one or two insignificant exceptions all these are volcanic.

On this point it is difficult to acquit some of the extreme advocates of the theory of the charge of reasoning in a circle. Whenever a case is quoted of sedimentary rock at a great distance from the main land, and with deep water intervening, they assert that it is not, for *that very reason*, an oceanic island. Though it may be rather difficult exactly to define what shall constitute an oceanic island, it is easy to quote examples of what must be such islands, if the term is to mean anything at all, in which, nevertheless, stratified rocks occur. Let us mention a few:

It is scarcely necessary to linger over the oft-quoted case of the Seychelles—a granite group separated from Africa by a channel 2,000 fathoms deep; or on the various islands of the East Indian archipelago, some of which are certainly entitled to the name. Less frequently cited perhaps are New Caledonia, between which and Australia lies a channel 700 miles wide and 2,000 fathoms deep; New Zealand, 1,200 miles from Australia, with 1,000 fathoms of water between them; the Falkland islands, 500 miles from the South American continent, and South Georgia, 800 miles farther still, in the same direction, and yet containing rocks of clay slate. But perhaps the strongest case of all is that of Kerguelen land (the Desolation island of Captain Cook), midway between the Cape and Australia, and 2,000 miles from both, yet containing sandstone and coal and, according to Sir Joseph Hooker's by no means surprising statement, a flora of immense antiquity.

Furthermore, in the same direction it may be urged (though our limits allow little more than the suggestion) that the scarcity of such islands is only what should be expected under the circumstances. Sink the continent of North America to the depth only of 1,000 fathoms, and what would remain above water to tell that it had existed? Not a single spot in all the eastern and midland region would be visible. The western mountainous area would in places be dry. But sink it to the depth of the Atlantic, or to 2,500 fathoms, and nearly everything would be lost. Not a peak of the Rockies, with one or two doubtful exceptions, would remain above water, and those would be volcanic. A few of the Mexican volcanoes also would survive. It is scarcely surprising therefore that so few except volcanic islands can be found in the present oceans, even if they should be the sites of sunken continents. Their scarcity cannot be employed as a strong argument in favor of permanence.

(*d*) The fourth of the leading arguments urged in support of the doctrine of permanence is drawn from the distribution of animals and plants. Instead of enlarging on this as intended, I cannot do better than make a few extracts from the address recently delivered by Mr. W. T. Blanford, president of the Geological Society of London, in which the subject has been treated in a masterly manner.

Mr. Blanford assumes as a proposition whose truth from the biologic standpoint is axiomatic that New Zealand was formerly connected with Australia, and that the Solomon islands were also connected with New Guinea. He then discusses at some length the affinity of the Malagasy flora. Here, though rejecting the hypothetical "Lemuria" of Tertiary times, he thinks that the well-marked oriental element in the Mascarene fauna and flora requires the existence at a late Tertiary date of large intermediate islands, and is quite prepared to give his adhesion to the doctrine of continuous land at an earlier era. I cannot here repeat his argument in full, but he lays great stress on the significant flora that existed in later Paleozoic time from Australia to India and southern Africa, and remarks that a great continent including all these three seems more in accord with facts than Mr. Wallace's view "that fragmentary evidence derived from so remote periods is utterly inconclusive."

Mr. Blanford's long experience in India enables him to point out some facts that strongly support the views which he expressed several years ago and to which he still adheres. He shows that while the Cretaceous marine beds of northern India contain many species found in Europe, that of southern India contains very few forms indicating the existence of a land barrier separating the seas. The Trichinopoly fauna, he says, recurs in Assam 1,200 miles to the northeast and in Natal 4,000 miles to the southwest, and "it appears almost a necessary inference that these points were on the south coast of a tract of land that extended across the Indian ocean." His views have since been confirmed by Neumayr and Duncan.

Mr. Blanford also discusses at some length the evidence in favor of a connection between South America and Africa, dwelling especially on the fact that two families of fresh-water fishes are found only in South America, New Zealand, Tasmania and southern Australia. He inclines to the belief in an earlier connection between southern Africa and South America, and evidently deems a "southern continent," with considerable northward extensions, a probability. It is obvious that such a change would at once explain the facts already mentioned of the occurrence of stratified rocks in the Falklands, South Georgia and Desolation island.

There are other arguments which might be brought forward, but they can be only mentioned. For example, the immense Paleozoic deposits in eastern North America and in western and northwestern Europe are far too large to have been supplied from any existing Paleozoic land. The increasing thickness of the former to the eastward and northward, and of the latter to the west and northwest, are strong indications that their origin must be sought in that direction. Accordingly, in this region—that is, in the area of the present north Atlantic—not a few geologists are inclined to place a Paleozoic continent which has since disappeared, but which was then the quarry whence came the material that has built up these massive strata on both sides of the Atlantic.

It is hardly necessary to point out, in conclusion, that if the Archean rocks are, as generally regarded, only metamorphosed sediments, their presence below the Paleozoic strata must prove that all the surface over which they are known to occur was at the time sea-bottom. As this will include all the portions at present known, it is clear that much wider changes are indicated by this fact than even those above quoted. Apparently as we go back in time the evidence of depression and elevation becomes more and more clear and strong—a result which is quite in harmony with what might be anticipated.

In the present condition of the evidence it seems, therefore, unwise to hold with any confidence the doctrine of the permanence of the ocean-basins and of the great continental masses. The future may bring to light new facts and stronger support, but what is now attainable warrants much distrust.

On the whole it is probable that depression and elevation result from causes which we cannot at present reach, and that both occur without any apparent continuity or localization. When we review the innumerable changes of this kind that have taken place in almost every known part of the world we are more inclined to regard the ocean depths as those parts of depressed areas which, being situated out of the reach of the land-wash, have never been subject to deposition and consequent filling. If we may infer from what we observe, it appears probable that whenever such areas by any change are brought within the reach of the waste of a shore-line and buried beneath thick sediment, reëlevation sets in and they are converted into land, there being seemingly a connection between sedimentation and elevation.

On this view the depths of the ocean may be the result not of a general subsidence over the whole area at once but of many small and local subsidences which have run into one another. This would also agree with its extremely irregular shape. Such local subsidences are in harmony with what we know has occurred. If the channel of Mozambique between Africa and Madagascar has sunk 1,000 fathoms since middle Tertiary days, apparently without affecting the adjoining land to any great extent (and many similar cases could be quoted), there is nothing contrary to probability in believing that the same thing has happened elsewhere and repeatedly, or in regarding the oceans as the result of many such changes rather than as aboriginal features of the earth's surface.

AKRON, OHIO, *August* 15, 1890.

The paper was discussed by C. H. Hitchcock, J. J. Stevenson and E. W. Claypole.

The next paper was entitled—

THE CUYAHOGA SHALE AND THE PROBLEM OF THE OHIO WAVERLY.

BY C. L. HERRICK.

The paper was discussed by H. S. Williams, E. W. Claypole, I. C. White, A. S. Tiffany and C. L. Herrick. It is published elsewhere in this volume.

The next communication was on—

THE TACONIC ORES OF MINNESOTA AND OF WESTERN NEW ENGLAND.

BY N. H. WINCHELL AND H. V. WINCHELL.

The communication was discussed by C. H. Hitchcock and N. H. Winchell. It is printed in full in the American Geologist, vol. vi, 1890, pp. 263–274.

This paper was followed by—

WHAT IS THE CARBONIFEROUS SYSTEM?

BY H. S. WILLIAMS.

(*Abstract.*)

The confusion which arises from a lack of precise definition as to the constitution and limitation of the Carboniferous system has led to the preparation of this paper.

The earliest English author who appreciated the importance of grouping certain rock formations with the Coal Measures to form what now is called a system was W. D. Conybeare.* The German geologist Werner and the school of geologists that followed him called the Coal Measures the "Independent Coal formation" or "Steinkohlengebirge." Conybeare subdivided the "Transition and Secondary formations"

* Conybeare and Phillips, Outlines of the Geology of England and Wales. London, 1822.

of Werner into orders, and his medial order was called the "Medial or Carboniferous order." Here were included "the rock formations which ought to be considered together with the Coal Measures." In his classification these formations were, "I. The Coal Measures, II. The Millstone grit and shale, III. The Carboniferous or Mountain limestone, IV. The Old Red Sandstone."* His "Super-medial order" included all the rocks from the Coal Measures to the Tertiary; substantially what we now call Mesozoic. His "Sub-medial order" was the "Grauwacke" of Werner.

Conybeare prominently notices that the formations of the Medial or Carboniferous order are the rocks which form the Pennine (spelled by him "Penine") range of mountains in northern England. He carefully defines the position and structure of the range and proposes the retention of the name Pennine, which was first applied to it by the early Roman inhabitants of the island. Other exhibitions of Carboniferous rocks are mentioned by him, but here alone he found the whole series represented; and the rocks of the Pennine range were the typical rocks of the system which Conybeare defined.

In Hughes' "Geography of British History" (London, 1863) we find the Pennine range defined as "applied by general consent to the extensive range of high ground stretching south from the Cheviot hills to the district of the Peak in Derbyshire, about 170 miles in length," stretching "from the border of Scotland southward to the valley of the Trent" (p. 20). It is composed "entirely of rocks belonging to the Carboniferous series" (p. 22).

H. B. Woodward, in his "Geology of England and Wales" (1887), page 149, describes this range as "a faulted anticlinal of lower Carboniferous rocks, supporting on the east the coal fields of Northumberland, Yorkshire and Derbyshire, and on the west the Lancashire and Cheshire coal fields." As was pointed out by Conybeare, the rocks of this range not only contain the typical series of rock formations to which he applied the name "Carboniferous order," but each of the members of that system.

De la Beche (1831–1833) followed the classification of Conybeare, but dropped the term "medial" as a synonym. John Phillips (1837) adopted the name Carboniferous, with "system" instead of "order," in the same sense as proposed by Conybeare; and Murchison, in "The Silurian System" (1839) made classic the names "Silurian system," "Old Red system," "Carboniferous system," "New Red system," and "Oolitic system."

After these authors, geologists in general have adopted the name Carboniferous system for one of the great groups of rocks composing the grand geologic column.

All of these early English authors were in unison in distinctly excluding the rocks afterward (in 1841) called "Permian" by Murchison, and at that time going under the names "New Red sandstone" and "Magnesian limestone," "Saliferous system" and "New Red system."

Conybeare, De la Beche, and John Phillips agreed in including the upper Old Red sandstone in the Carboniferous system, while Murchison after them (in 1839) separated from the Carboniferous the lower member as a distinct system. On page 169 of his "Silurian System," he says that he "applied the name 'Old Red system' to the old red sandstones of previous writers in order to convey a just conception of their importance in the natural succession of rocks, and also to show, that as the Carboniferous system in which previous writers have merged it * * * is surmounted by one red group, so is it underlaid by another."

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* *Ibid.*, p. 335.

Thus all four of these early authorities in English geology agree in their definition of the original Carboniferous system, which is that of the series of rocks typically represented in the Pennine range of England, and not fully represented in any other one section of England.

When we seek to determine the precise definition of the Carboniferous system, we are led directly to the typical section in the Pennine range first clearly defined by Conybeare and afterward adopted as the typical section by the founders of geologic science in England, and afterward by correlation recognized as the standard section of the Carboniferous system throughout the world.

The section of this typical Pennine Carboniferous system consists of, first, the upper part of the Old Red sandstone resting upon lower beds of Old Red sandstone, unconformably about the Cheviot hills, or upon the Cheviot volcanic series, or upon Silurian rocks, as in Northumberland. The second formation, resting conformably upon the first, is the "Mountain or Carboniferous limestone." The third member of the series is the "Millstone grit and shales;" the fourth, the "Coal Measures," including the familiar coal fields of Lancashire and Cheshire, of Yorkshire, Northumberland and Derbyshire. These latter are terminated, where contacts are seen, by the New Red sandstone, in some places apparently conformably but generally unconformably.

The system in this Pennine range was evi lently terminated both below and above by geologic disturbance of greater or less extent, furnishing natural delimitations, thus peculiarly fitting it for a stand rd of geologic definition.

An analysis of the standard schemes in geologic classification shows us that a *system* is a series of rock formations whose stratigraphic order and lithologic composition are thoroughly well expressed in some definable geographic region, and whose fossils indicate a continuous biologic sequence, more or less distinctly broken at its lower and upper limits from contiguous formations.

Thus a typical system has definite geographic position, geologic delimitation, and biologic definition.

The Silurian system in Wales and western England, the Devonian system of South and North Devonshire, the Jurassic system of the Jura mountains, are examples, and no less perfect is the Pennine carboniferous system of the Pennine range of North England; to which the unsatisfactory name of Carboniferous has been so long applied.

While so much is true of the standard or typical expression of a geologic system, it cannot be expected that any system will offer precisely the same features in other regions of the world or on other continents:

1. Because the composition, the size of particles, and the order and thickness of deposits are all determined by conditions that are geographically dissimilar, a geologic system can have but one typical geographic position.

2. Because the geologic events, such as elevation of land, breaking of strata recorded in faults, and volcanic eruptions, do not take place either uniformly or simultaneously in different parts of the earth, it is certain that intervals or breaks in sedimentary formations will not be uniform for separate regions.

3. Because organisms in the past cannot be regarded as having ceased to carry on the ordinary functions of life and reproduction, all the breaks in the sequence of organisms, all the sharp lines distinguishing the faunas or floras of one formation from those of a preceding or following formation, are local and not universal.

To apply these reflections to the present case, it will be seen that the settlement as to which is the typical section upon which the Carboniferous system was founded will greatly facilitate all attempts to determine the limits of the system in other regions. It is evident that the typical section is the section exhibited in the Pennine range; and as the name Carboniferous is a misnomer geologically, since we now know that carbon or coal bearing rocks are not confined to the system generally so called, and as the name does not indicate the geographic position of the typical section, it is believed that the adoption of the name "Penninian system," or "Pennian system" (the latter being preferable), may be of advantage to the science.

This Pennine carboniferous system may be defined, as to *geographic position*, as the rock formations of the Pennine range of northern England and equivalent formations in other parts of the world.

In *geologic delimitation* the Pennine system begins with a red sandstone and terminates with the upper rocks of the Coal Measures.

In *biologic definition* its first marine fauna is that of the Mountain limestone, and its final fauna and flora are those of the Coal Measures. The brackish fauna of the Old Red sandstone had not ceased at its opening, the characteristic Permian fauna and flora had not appeared at its close.

Whatever may prove to be the correlation between the Old Red sandstone and the Devonian system, the definition of the Pennine system is explicit in including fishes, such as *Holoptychius*, characteristic of the Old Red sandstone of Murchison, and is as explicit in the exclusion of the Devonian marine fauna above which its earliest marine fauna belongs.

The rocks and faunas of what was later called the Permian system are definitely excluded by the original author from the Pennine carboniferous system. The problems of the Devonian Old Red system and of the Permian system must be discussed on their own merits: this original section of the Carboniferous has its relations to each clearly defined.

In correlating our American rocks, the recognition of the Pennine carboniferous system as typical settles for us several disputed questions.

The Paleozoic along the Appalachian and eastern border region will find the limits between Devonian and Pennine carboniferous in the following positions: The Chemung marine fauna is strictly Devonian; the brackish water fish fauna of the Catskill is as strictly Pennine. Hence the red rocks of the Catskill formation of New York, the Ponent, Umbral, and Vespertine formations of Pennsylvania, belong to the Pennine carboniferous.

When, as in western Pennsylvania and Ohio, the species of the Carboniferous, or Mountain limestone fauna of England, appear to follow the marine Chemung, the line should be drawn between them for a strict correlation. On passing westward the formations called Waverly, Marshall, Kinderhook, Chouteau, containing, as they do, a fauna distinctly related to the Carboniferous limestone fauna, must be placed in the Pennine carboniferous system.

In Kansas and Nebraska and other localities where the upper Coal Measures gradually assume species of the type described from the Russian Permian, the problem of correlation is definite. Both the stratigraphy and the biologic evidence indicate that there is no sharp division between the representative of the Pennine carboniferous system and that of the Permian system. The division line here must be arbitrarily drawn, and the fact that a system is a local series of formations and not a universal subdivision of the geologic time scale, becomes evident. It is in such cases that the paramount importance of the determination of the geographic position of the typical representative of a system is seen, and the only way to make this apparent to all is by the association of the geographic name with the system.

The paper was discussed by W J McGee, E. W. Claypole, C. L. Herrick, A. Winchell and H. S. Williams.

A recess was then taken until 7.45 p. m.

After reässembling in the evening the Society listened first to—

THE GEOTECTONIC AND PHYSIOGRAPHIC GEOLOGY OF WESTERN ARKANSAS.

BY ARTHUR WINSLOW.

The memoir was discussed by I. C. White, J. C. Branner and W J McGee. It is published elsewhere in this volume.

In the absence of the author, the following paper was then read by Mr. W J McGee:

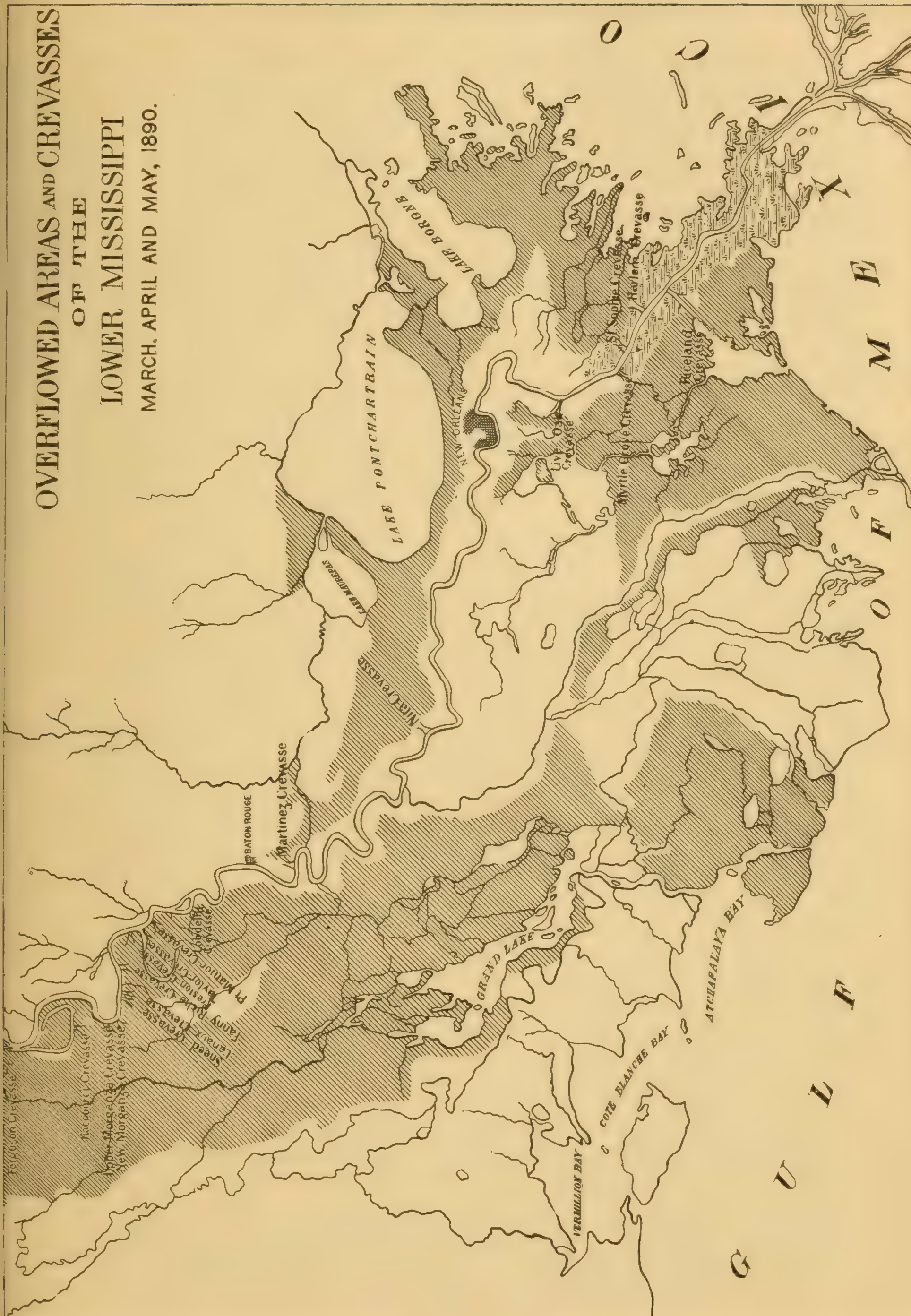
THE NITA CREVASSE.

BY LAWRENCE C. JOHNSON.

The Nita plantation is about two miles above Convent station, on the L., N. O. and T. railway, and the landing of the same name on the Mississippi river. It is opposite the head of Blind bayou, a sluggish affluent of Amite river which joins it before reaching Lake Maurepas, after, in a sense, draining the back swamps of that region (fig. 1). This sluggishness of current in Blind bayou and neighboring waterways should be borne in mind as explaining the length of time before the back swamps were filled up and the lakes reached by the flood, despite the extraordinary force of the current (15 miles an hour) at the Nita crevasse. The first break began March 13, 1890; yet it was not until March 22, nine days later, that the water came through the south pass of Manchac (the bayou or strait connecting Lake Maurepas with Lake Pontchartrain), and two weeks more passed before Lake Maurepas overflowed the lowlands to the northeastward sufficiently to threaten the track of the Illinois Central railway; and it was not until April 13, or a month after the break, that this railway was covered so deeply as to stop the running of trains. The water now quickly spread over the whole of the flat country from the 28-mile post north of New Orleans to the 46-mile post, or to within one and a half miles of Ponchatoula station, and trains ceased to pass over this line till June 23. The greatest height attained here by the river water was only eight and a half feet above mean tide, or the ordinary low-water stage of Manchac.

Ordinary maps do not show the well-known fact that the banks of the river, of the bayous, and of lakes Maurepas, Pontchartrain and Borgne are higher than the back swamps immediately adjoining, and that the Mississippi river at the Nita crevasse is (by estimate) twenty-one feet above the swamps about Lake Maurepas. It is reasonable to suppose that in locating the Illinois Central railway the highest ground was selected; yet until surveys were actually made it was not suspected that the lowest ground is not the banks of Manchac, nor yet the quaking bogs to the south of it, but the apparently firm land of the "pine meadows" or prairies to the north, between the bayou and Ponchatoula.*

* It is a pleasure to acknowledge the courtesy of Captain Mann, superintendent of the Illinois Central railway, in furnishing data relating to altitudes as well as many facts connected with the late overflow.



OVERFLOWED AREAS AND CREVASSES
OF THE
LOWER MISSISSIPPI
MARCH, APRIL AND MAY, 1890.
LAKE PONTCHARTRAIN
LAKE BORGNE
LAKE MAUREPAS
NEW ORLEANS
BATON ROUGE
Martinez Crevasse
Nita Crevasse
Live Oak Crevasse
Myrtle Grove Crevasse
St. Sophie Crevasse
Riceland Crevasse
Sneed Crevasse
GRAND LAKE
ATCHAFALAYA BAY
COTE BLANCHE BAY
VERMILLION BAY
G U L F   O F   M E X I C O

FIGURE 1.

By reason of the low level of this region with respect to the Mississippi at the Nita plantation, many industries suffered. These industries were not only those of the plantations on the river, but those of two railways, the Illinois Central and the Louisville, New Orleans and Texas (known as the Mississippi Valley road), whose aggregate losses must have been very large; and not these alone, but many minor industries of gardens and "truck farms," of lumber and shingle mills, and of other enterprises which had grown up on the bayous in late years of apparent security, and which suffered in most cases total wreck. Still more important and more immediately to our purpose was the industry which had developed rapidly on Mississippi sound, under the liberal laws of the state of Mississippi, of canning and shipping fish and oysters. It is only in the last six years, or since the final closing of the Bonnet Carré crevasse, that oyster planting has assumed such large proportions in the sound; yet large plants have been established, and it is estimated that three to four thousand men, women and children are employed in the canning factories, besides a thousand others, with two hundred sailing vessels and small boats, engaged in fishing and in planting or collecting oysters.* This industry has now suffered the penalty due to want of foresight, or to parsimony and negligence. With this great industry, so easily protected yet so grossly neglected, it is not intended to deal specifically; yet to it is due the credit of exciting close observation of the facts recited below.

According to parties on the coast during May and June the color and taste of the water was affected as far east as Pascagoula, some declaring the change perceptible even as far as Grant's pass, the entrance to Mobile bay. Old fishermen announced that they could perceive an eastward current on the surface beyond Ship island. After southerly and southeasterly winds became prevalent the main current seems to have been diverted into the channels immediately east and west of Cat island, and this is the region in which most of the damage was done. On both sides of Cat island and along the edges of the Chandeleur group lie the main oyster reefs, this being the choicest ground for oyster planting, and there were other grounds near the mainland and even in the tide-water inlets or bayous all along the sound as far east as Mobile bay. With the influx of fresh and muddy water all the plantings were destroyed or very greatly injured as far eastward as the end of Ship island. Farther east no actual destruction of the oysters has been discovered up to this date, although the water was freshened and the fish were driven out for a time. Towards the last of June, as the fresh water diminished and the tides resumed their sway, the fish began to return.

Why and how were these effects produced?

It was not merely because of the freshness of the water that expelled the fish and destroyed the oysters; it was the presence of the mud discoloring the water, which clogged up the gills and other branchial appendages. Some fishes are able to indure more of the floating foreign matter than others; marine species, accustomed to a clear medium, are actually destroyed by a very moderate quantity of silty material suspended in the water passing through their branchiæ; and this is true also of other marine creatures upon which they depend for food.

Besides the injurious effects of the disseminated river mud which, according to all the witnesses, was manifested in oysters collected in the latter part of April by a sickly hue and unpleasant flavor and by small pellets of silty matter or discolored mucus

* Mr. George H. Dunbar, of the firm of G. W. Dunbar's Sons, New Orleans, has furnished much exact information concerning this industry and the effects of the recent flood upon it. Accurate information was courteously given also by W. H. Hardy, president of the Gulf and Ship Island railway, and reliable testimony as to the structure of the coast islands and sea bottom was obtained through the kindness of Major Whenery, lately chief engineer of the Northeastern railway.

gathered in the folds of the mantle and between it and the shell, the bars or reefs throughout the region were within a month actually silted over and buried, some of them several inches deep, in the fresh material from the crevasse. From May 24 to May 30 railway parties working in the vicinity of Gulfport, who were in the habit of seining for fish in the sound, found the firm, sandy beach bottom, the delight of bathers, covered by a brown yellowish ooze; and instead of red-fish, pompano, sheepshead and Spanish mackerel they caught only catfish and buffalo—inhabitants of muddy inland lakes—with a few scattering mullets.

Tracing the waters back to their source, their work may be better understood.

At the break the immediate action was destructive. Except where there was little or no current there was no deposition of sediment, although in the wake of stranded houses and other obstructions elongated banks or ridges of sand and mud were formed, and these included many fragments of the wrecked houses and mills. In one case many iron implements were found embedded in the sand and silt with leaves, sticks and other debris. A part of this silty sediment, but with less and less of sand, was deposited eastward along the bayous and timbered bottoms between the crevasse and Lake Maurepas. On the large flat prairie or pine meadow towards Ponchatoula, the water, deep as it was, left no sand, but only a fine, impalpable, yellowish or bluish-brown clay, such as constitutes the basis of the pine meadows from Ponchatoula to Escatawpa river.

The bed of the sound itself does not seem to have been affected during recent years by the various inundations and the constant contributions from the rivers—that is, there is no proof of filling up; there seems to be the same stiff blue clay, overlain by ocean sand, that was first reported; the same average depth; the same shelving bottom, sloping gulfward about 3 feet to the mile for the 12 to 15 miles of its width. Yet the filling-up goes on. The river contributes its clay, to be covered by the tides with sand, regularly, slowly, from year to year; but at an equal pace with this goes on a subsidence, slowly, steadily; and for no recent historical period can we exactly measure the rate. We can observe that the oldest shell heaps of the aborigines were of *Gnathodon* shells, with some fresh water and land mollusks; we can see that the bases of the shell heaps have sunk below tides now and probably 10 to 15 feet below the shore elevation of the beginning; we can cut into these and find some of them 10 to 20 feet deep, and observe that, above the brackish water *Gnathodon* remains, later occupants of the camps have piled 8, 10 and 12 feet of oysters and conchs, proving that latterly the salt tides have reached farther up the rivers and bayous than when the settlements were first located and the inhabitants lived mainly upon the fresh and brackish water mollusca; but as to the time in years, there is wanting a common standard of measurement. The time was so considerable that the fresh-water shells are mostly crumbled to powder; the *Gnathodon* shells are much decayed, and only the more enduring shells of *Ostrea* remain as sound as ever. So sound and abundant are these that, without much apparent diminution, the shell heaps have furnished material for streets and roads and quicklime for the cities and settlements of the coast from the first occupation of this region until recent transportation facilities rendered northern lime cheaper than the older wood-burnt supplies. Similar evidence of subsidence, even to a greater degree, on Mobile bay was thought worthy of notice by Professor Tuomey.* Such facts are not uncommon in other parts of the world, but the subject is only incidentally of interest in connection with the matter in hand and need not be pursued further.

*2nd. Bien. Rep. Geol. Survey of Ala., 1855 (1858), p. 148.

The coastal sands, or Biloxi sands, as the deposits of the strip immediately adjoining the salt water of Mississippi sound are called, represent now, by reason of modern subsidence, a remnant only of their former extent. The strip varies from zero to a width of several miles, stretching, as usually understood, from the Rigolets (or mouth of Pearl river) to Mobile bay. Evidently it once reached out gulfward beyond the present bounding chain of sea islands—that is, if the coast sands be separated from the underlying clays, of which they in fact seem to be only a continuation; and they are so, but with a sufficient variation in genesis and material to warrant division; and the deposits were separated by a considerable lapse of time also, though the period was not long enough to permit a change in the fauna of the region affected. Borings at Biloxi, at Pass Christian, on Pearl river near the mouth, and at other places disclose these Biloxi sands to a thickness of 80 or 100 feet. At Ocean Spring the deposit may be regarded as wanting, while at Scranton the excavation at the railway tank reached the water-bearing clays at 30 feet, and in the overlying sands and marsh mud of this depth were found shells of *Venus mercenaria*, and, it was reported, specimens of the familiar fiddler crab, *Gelasimus vocans* (or *pugilator*).

The Biloxi sands consist essentially of thin alternating layers of sand and yellowish brown or blue clay, similar to the deposits now in process of accumulation upon the floor of the sound. In geologic age they evidently represent the beginning of the present or the close of the past. They were unquestionably formed after the mouth of the great river pushed beyond the highlands of Baton Rouge, and when the "passes" were probably about where New Orleans now stands around the great Crescent bend—after the evolution of representatives of lakes Maurepas and Pontchartrain, and when Manchac was the permanent high-water outlet of the main river. If this were not the case; if the Biloxi sands had been deposited at a time when there was a greater divergence of the northern waters eastward and when Manchac was the main outlet, the results would have been essentially similar, but on a grander scale.

There was, indeed, an era during which the Mississippi embouched through Manchac, and during which the action was so much grander and so different in character as to require a different consideration. During this era there were formed what may provisionally and for convenience be called the Pontchartrain clays. As already indicated, the method of action was essentially similar to that concerned in the building of the coast sand formation during tho Biloxi period, and similar to that displayed by the comparatively insignificant agency of the Nita crevasse. Hence, although the Pontchartrain clays extend farther inland than the Biloxi sands, or to the edge of the rolling lands of St. Tammany and even to the foot of the gravelly hills of Mississippi and Alabama, as well as up the large estuaries of Pearl and Pascagoula rivers, the bluffs, excavations and artesian borings reveal a like sequence of sands and brownish or yellowish-blue clays under a thick coat of clay which forms the water-holding pan of the "pine meadows."

The topmost layer of the Pontchartrain clays, when tempered by sand or silt, upon the banks of bayous and rivers is not unsuitable for making brick, though it is generally too tenaceous for such use; in fact, it is locally called "pipe clay," from which it really differs; and it differs also from the brick clay or loam on Amite and Tangipahoa rivers, with which it is often confounded. Although this uppermost clay bed is from ten to fifty feet thick in the "pine meadow" region, it contains no fossils, so far as yet discovered; but it conceals and overlies sands in which excavations have brought to light stumps and logs and, in a few places, marine shells. One general charisteristic of this formation is that it contains abundant water for the supply of wells, in which the water often rises considerably and sometimes, in low places, overflows.

It would appear that during the earlier part of the period of deposition of the Pontchartrain clays the great river embouched, in high-water stages, at the last bluffs or in the vicinity of Baton Rouge, or perhaps as far up as Port Hudson, and, then as now, the current seems to have tended eastward along the coast. From the topmost layers at both these localities the date of the period may be definitely fixed in geologic chronology as that of the glacial period; for there may be seen a modification of loess identified by position and stratigraphic continuity with the calcareous and fossiliferous loess of Natchez and Vicksburg; and by like continuity the same loess may be identified and traced eastward indefinitely, though thinning out at the same time to constitute the brick loams of the lake parishes and Pearl river. No fossils are found in this modification of the loess any more than in the Pontchartrain clays, and for a similar reason, this reason being exemplified in the recent break at Nita, with the attendant displacement of a distinctive fauna. Beneath the loess and corresponding loams lies the type and homologue of the Pontchartrain clays, viz., the "pinnacle sands" and brownish clays with calcareous "puppets" so well exposed at Port Hickey, Port Hudson and Bayou Sara. These represent the Port Hudson formation of Hilgard, and indicate the Pontchartrain clays to be equivalent to the Port Hudson.

It is interesting to note that no fossils have been discovered near the axis of development of the Pontchartrain clays along the old coast line extending southeastward from Baton Rouge, except in the very lowest silts where lie the remains of the forests overwhelmed by the glacial floods. At the most eastern and southern extension of the formation, however, where the icy and muddy currents mixed with the warm waters of the Gulf, marine shells would naturally be looked for; and in fact artesian well borings have brought up remains of living marine mollusca in many places. These borings show the clays to have a thickness of about 100 feet.

And thus the Nita crevasse, with its floods of muddy water seeking an outlet directly into Mississippi sound, and with the destruction or displacement of aquatic life over a large area, illustrates an episode in the development of the lower Mississippi region such as has been enacted more than once in the past, and illustrates at the same time the manner in which the development of the region has been accomplished. In all the series of events and deposits, from the first stages of the Port Hudson and Pontchartrain to the uppermost clays of these formations and the sands and gravels at the base of the loess, to the stages of the loess at Bayou Sara, of the loam at Port Hickey and Baton Rouge, of the brick clays on Amite and Pearl rivers, and of the Biloxi sands, down to the effects of the Nita crevasse, the method, the system and the agent have been but one; the dates of action and doubtless the degrees of energy have varied, but the source of the material and power has always been and is to-day the same—the great river from the north.

The next paper on the programme was the following:

AN OLD LAKE BOTTOM.

BY L. E. HICKS.

Primitive structural forms are so generally replaced by forms of erosion upon the land surfaces of the earth that it is a matter of some surprise to encounter a truly primitive and unmodified surface of construction. Especially in the region of the

Great Plains of North America, where the slope is considerable and the beds soft, one might suppose that the rivers would have already spread a network of tributary ravines over the whole surface, notwithstanding its recent emergence. If they have not done so it must be on account of some peculiarity in the form of the surface which has resisted their approaches; and it will appear in the sequel that such is really the case.

The rivers of the Plains are hard at work scoring down the great sheets of sediment over which they flow. In no other part of the world are the waters so burdened with silt. Given unlimited time for these rivers to cut away at the face of mother Earth and they will reduce her featuree to the precise topographic type which prevails in countries geologically old, where the rivers have been long at work. Every part of the surface will be brought under the chisel of that untiring sculptor, flowing water, and consequently every part of the surface will become a part of the valley of some river. Each little depression will lead out to a larger one, that into another still larger, and so on to the great trunk lines of continental drainage, and finally to the ocean. Wherever the rain may happen to fall it will find an open path to the ocean—a path for the rain made by the rain. That is the fundamental type of water sculpture.

Not only will the rivers take possession of the whole surface, but they will cut it all down to base level. Towards the accomplishment of this enormous labor they have just made a beginning—in some places not even a beginning. Their ultimate task is to cut down the whole surface to base level, but they have not yet taken possession of the whole surface. Great stretches of table-lands are yet independent of their dominion. In regions of erosion the water-shed is a line. On this side the rain-drop falling may run off to the Atlantic; on that side its twin drop falling may run off to the Pacific. On the plains the water parting, instead of being a line, bulges out here and there into a broad band. It splits into two lines and loops around a space which does not belong to the valley on either side. Here falls a drop which runs off to the south; yonder, a score of miles away, falls a drop which runs off to the north. Between lies a broad table-land, where the rain may sink into the earth, and by subterranean ways ultimately get into some river, or it may be evaporated and return to the heavens; but the one thing which rain persistently does everywhere else—that is to say, run along the surface in ravine, creek, river, to the ocean at length—that one thing it persistently refuses to do on these table-lands.

Some notion of the peculiarities of surface which cause this unusual behavior of the water may be obtained from the stereogram presented herewith, illustrating a portion of the surface in the western part of Custer county, Nebraska. A sort of regular or persistent irregularity is apparent. In contrast with the ordinary landscape there is a striking absence of *leading lines*. There are valleys, but they lead nowhere; there are basins, but they have no outlet; there are ridges and hills, but they have no continuity and no definite arrangement. Every depression soon bumps up against a hill; every hill slopes off into a hole.

The general level is well maintained over a considerable area. The higher points are so equal, so numerous and so close together that they form a level sky-line when viewed from a little distance; but from these summits down to the bottoms of the "lagoons" may be fifty or seventy-five feet. The roads, following section lines, cross hills and valleys in endless succession. In other regions one may make the distinction of traveling "across the country" or not, according as he follows the valleys or takes them transversely. Here there is no choice; it is "across the country," no matter what direction is taken.

All of the elements of composition are curves. The horizontal planes and sharp angles of water-sculpture are conspicuously absent. The hills are low domes, the basins have the same form inverted. There may, indeed, be a level space at the bottom, but that is a secondary modification. The sloping sides of the lagoons are grass-covered and wash but little, yet enough is carried down to make notable accumulations when reinforced by the remains of a luxuriant vegetation induced by the rich soil and abundant moisture. As much as twenty feet of soil has been observed in some of these lagoons.

Here we see the natural reservoirs for the storm waters of the plains. In some of them water remains throughout the year; in almost all it is easily reached by digging

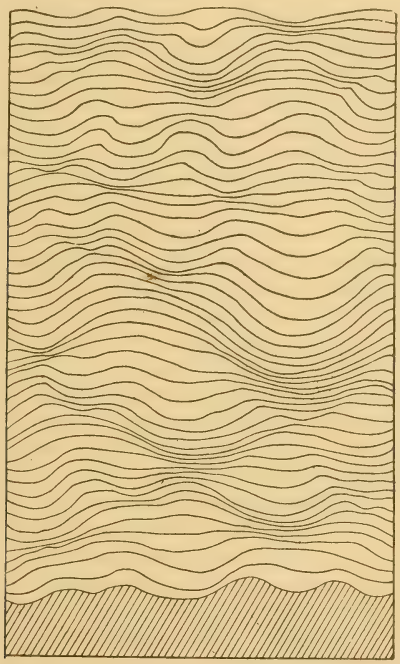


FIGURE 2.—*Stereogram of a portion of the surface of Custer county, Nebraska.*

Scale, horizontal 8 inches = 1 mile, vertical 1 inch = 600 feet.

A cistern is often dug in the bottom of a lagoon, and, being covered to prevent evaporation, it preserves the collected storm waters for household use. Still more frequently a supply for animals is obtained by simply deepening the basin with plow and scraper. The economic value of these natural storage basins has brought them into general notice, and accounts for the fact that they have a popular name. This name, "lagoon," is closely restricted to the depressions on the rolling surface of the high, grass-covered table-lands. I have never heard it applied to the numerous closed basins among the sand hills or the "kettle holes" of the drift.

Lagoons occur over a wide region east of the Rocky Mountains, where the rivers have not invaded and modified the old lake bottom. They are more numerous in

Custer county, Nebraska, than in any other locality which has come under my observation. Here there may be a score of them to the square mile. In other parts of the Great Plains they are few and widely separated. They vary from one acre to fifty acres in area.

Are there no outlets whatever for the surface flow of water from these depressions? There may be, but the moment that occurs the type is destroyed. The outlet deepens to a ravine, the ravine to a cañon, the cañon opens into a valley, and so on to the sea; the primitive surface of construction has been captured and converted into a surface of erosion. This process is constantly active. The chisel of water-sculpture is forever hacking away at the remnants of the table-lands. Their edges are gashed with fresh ravines, and here and there a cañon pierces the very heart of the plateau.

But the resistance to the encroachments of water-sculpture is considerable, and the manner of resistance is obvious. So long as the lagoons are not filled to the brim there is no chance for any "wash" to get a start. Should there be a great increase of the rainfall, so that precipitation should exceed evaporation, the lagoons would fill up and overflow, and the table-lands would rapidly melt away. Their preservation is therefore good evidence of constancy in climatic conditions during the whole period since this lake bottom became dry. At least it is conclusive evidence that there has been no great variation in the direction of increased rainfall, though there may have been greater aridity. These curious structural forms constitute a sort of weather record which runs far back into the past. It was dry enough when Lake Cheyenne was spilled out of its bed by upheaval to evaporate the remnants of that lake in the lagoons, and it has since been dry enough to keep them from filling and overflowing. They even give us a glimpse of the climate which prevailed in a period far more remote, as we shall see when we inquire into their origin.

To this question of the origin of the lagoons the most queer and contradictory answers, ranging all the way from wallowing buffaloes to spouting volcanoes, may be elicited from the old settlers. The generic relations of the lagoon type are clear enough: it is a structural form unmodified by erosion. But among structural forms is this an example of the sedimentary, the igneous, the coralline, the glacial, or the eolian type, or is it a combination of some of these? The title of this paper implies that it is sedimentary. But sedimentation tends to produce horizontal planes. If there are exceptions, such as torrential cones and sloping beaches, they have obviously no application to the case in hand. Yet the materials displaying this structural form are indubitably lake sediments—Tertiary marls. Their unique form must, therefore, have been influenced by forms of surface already in existence when this region became a lake. None of the familiar accidents of upheaval, tilting, folding or faulting to which horizontal sediments are subject will account for such forms as these. Igneous action produces lofty cones, craters, geyser basins, dikes, bosses, laccolites, and sheets of extruded lava which may present considerable irregularities of surface. Some of these igneous forms of construction, if they were mantled over with a sheet of lake sediment, might give a result something like the lagoons and rounded hills of the table-lands of Custer county, but there is no reason to suspect that any sort of igneous agency has been concerned in the matter. The hint contained in the identity of the popular name, lagoon, with that which designates a prominent type of coralline structure is only misleading. The promiscuously irregular forms of the glacial drift are more promising. Hillocks, kettle holes and morainal lakes might possibly assume a facies not unlike the forms in question, at least with the help of a thin cover of fine sediment; but the region is clearly beyond the recognized limits of glaciation, and no drift is found either on the surface or beneath it.

We come, then, by the method of exclusion to the eolian type of construction, and we soon find that, apart from the objections lying against other hypotheses, the suggestion that we have here an example of the influence of a preëxisting surface shaped by the action of the wind has much to commend it. The materials of wind construction are drift-sand and dust. The latter does not produce topographic forms of much magnitude, and, in this discussion at any rate, may be disregarded. Drift-sand is, however, an element of construction which produces important topographic results upon the Great Plains at the present time, and it has probably been as busy in previous geologic cycles as it is now.

The fundamental type of a single sand hill is a half cone lying upon the flat side, its base concave, facing the prevailing wind and forming a "blow-out," and its elongated apex stretching off to leeward. A succession of these overlapping upon each other gives a serrated ridge running parallel with the prevailing wind. Shifting winds give cross-ridges which shut in sections of the troughs lying between the ridges first formed and produce closed basins. In a region of newly formed sand hills the ridge-and-trough structure parallel with the direction of prevailing winds is distinctly visible, but where the sands have been long tossed about by shifting winds the leading lines are obscured, the ridges are cut through by fresh blow-outs, and these may be found facing in all directions.

Such a surface mantled over with lake sediments would present the same forms which we see upon the table-lands. The sharpness of the serrations would be mellowed down to graceful curves, the closed basins would form the lagoons, and the whole surface would present gentle and irregular undulations, reminding one of chopping waves, after the violence of the storm has passed, arrested and fixed in mid-ocean. The well sections show much sand beneath the surface marl of these table-lands, and, upon the whole, there is good reason to believe that this interesting topographic type is the combined result of eolian and sedimentary processes The character of the climate during the last period of emergence preceding the lake period may therefore be inferred to have been similar to that now prevailing in the same region. The hypothesis of pre-existing sand hills is only intended to apply to regions of constantly recurring and closely packed lagoons, such as we find in the western part of Custer county. The isolated depressions of other regions may be due to some of the numerous accidents which produce lakes and ponds.

It may be objected to this hypothesis that in the progressing subsidence which produced the Tertiary lake the sand hills would be leveled down by wave-action on the shore. This result would certainly follow the progressive encroachments of a lake which had already attained considerable dimensions, but in the first stages of its formation in the center of the depressed area wave-action would be very slight; the waters would quietly rise above the sand hills, leaving them and the closed basins between them undisturbed, except that slight rounding off and softening of their sharper features which, being still further mellowed down by a light covering of lake marl, produces the gentle undulations which characterize the table-lands. Custer county is, if not in the very center of the old Lake Cheyenne at the time of its greatest expansion, at least well removed from its shore-line.

We have also other distinct evidences that the encroaching lake did not level all before it. Old valleys of erosion, obscured, indeed, but not concealed by the newer sediments, stretch for miles across the table-lands where now no stream flows. It is true that these would be more difficult to obliterate than the sand hills, but their preservation is nevertheless significant. Whatever weight they may have as evidence of the gentle advances of the lake waters over the rough, wind-tossed and water-sculptured surface of the plains, they possess an interest of their own as evidence of a long period of emergence before the last submergence. The rivers had time enough to cover the surface with their lines of erosion even more completely than the surface is covered at the present time. The channels now occupied by rivers show, here and there, marks of preëxisting channels, and those which are still unoccupied remain over to the credit of the older drainage system.

All this series of events falls within Tertiary time. The older drainage system of which I have spoken wrought upon Tertiary beds, and the erosion thus produced makes the later Tertiary unconformable with the earlier. We have here the evidence of cycles of emergence and submergence, of arid and humid epochs, of wind-swept plains and ancient rivers, of structural forms invaded by agents of erosion and again reconstructed—all within the limits of Tertiary history. In order to ravel completely the tangled threads of this history it would be necessary to pass in review the events accompanying the upheaval of the Rocky Mountains, perhaps also the physical history of regions more remote. That does not, however, belong to this discussion. I have merely aimed to decipher the geological record so far as to discover a probable cause for the peculiar structural forms which have escaped destruction simply by reason of their peculiarities. I have reached the conclusion that they are the result of sedimentation upon a surface previously shaped by the action of the winds. In other words, the lagoon type is a combination of the sedimentary and eolian types of conformation.

The last paper on the programme was—

ON THE RECOGNITION OF THE ANGLES OF CRYSTALS IN THIN SECTIONS.

BY ALFRED C. LANE.

The paper is published elsewhere in this volume.

The Committee on Photographs presented a report of progress which was accepted, and the committee was continued.

The Society then adjourned.

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THE CUYAHOGA SHALE AND THE PROBLEM OF THE OHIO WAVERLY.

BY C. L. HERRICK.

(*Read before the Society August* 19, 1890.)

CONTENTS.

INTRODUCTION.

It is not my purpose to enter into a discussion of the opinions which have from time to time been advanced with reference to the age and homologies of the so-called Waverly formation of Ohio. This has been done *in extenso* by A. Winchell* and by Newberry and Orton in the various reports of the Ohio Geological Survey.

Neither is it necessary to repeat in detail the reasons for regarding the Waverly as a highly composite (and hence unnatural) rather than a simple element in the series, for it is hoped that the paleontological and stratigraphical evidence presented in the papers published in the Bulletin of Denison University, the American Geologist and elsewhere by the writer and his associates during the last few years may serve to sufficiently demonstrate this. The study has been so prolonged and minute that its results

* Proc. American Philosophical Society, vol. XI, 1870. pp. 385-416.

may be relied upon to justify the statement, once for all, that at least three well-marked divisions must be recognized in the Ohio Waverly. These divisions must always rest chiefly upon paleontological evidence, although their approximate limits are formed by two bands of conglomerate which apparently represent periods of exceptionally rapid oscillation.

To us the great interest centering in a careful paleontological study of the Waverly lies in the fact that the disturbances referred to were neither violent nor extensive enough to seriously interfere with the peaceful evolution of types. From the end of the Corniferous to the beginning of the Coal Measures in Ohio a quiet, shallow sea was the rule and local fluctuations or perturbations the exception. The result of this long period of quiet is a marvelous record of the slow changes in life which bridges over the interval between mid-Devonian and early Carboniferous times. Although the number of species found in any one horizon is, with perhaps two exceptions, rather small, the aggregate in the Waverly is considerable. Should an attempt be made to collate all species reported from Ohio a considerable allowance would certainly need to be made for duplication, while, on the other hand, it is certain that the resources of our Ohio fauna are by no means exhausted.

The proper way to contribute to the ultimate elimination of the disturbance and ambiguity introduced by the vague descriptions and meager data of some of the earlier writers has seemed to be the systematic description *with figures* of such species as are actually found at the various typical exposures upon well-defined horizons. It certainly is true that in a case like the present one, in which much, nay, all, depends on the ability to recognize beyond doubt each stratigraphical horizon by means of its fossils, and in which lithological peculiarities are so nearly valueless, no pains can be excessive when applied to the correlation of local cotemporaneous faunas.

The necessity of repeating much of the work done previously grows out of the absence of figures of fossils and (worst of all) of minute data as to position, locality, etc. So long as the belief prevailed that the Waverly was essentially homogeneous, it was thought sufficient in the majority of cases to say from "the Waverly group of Ohio," "the Marshall group of Michigan," or "the Kinderhook of Illinois." This is very much as though one should locate a fossil in the "Silurian group of New York."

It is thus only that the writer hopes to apologize for having entered a field which properly belongs to the paleontologist, and very probably failing in many cases to identify the species previously described. Accordingly the effort has been made to locate every species described, both stratigraphically and geographically, so minutely that its exact position may be subsequently determined. Hence, even though changes in the nomenclature employed may be rendered necessary by reïdentification of the species previously de-

described, we have ventured to hope that such changes would but slightly impair the usefulness of the attempt to refer our species to definite horizons and thus form the basis for correlation and generalization. In this attempt we have been reasonably successful and feel confident that, with a dozen species of well-preserved fossils from any given stratum, the stratigraphical position can generally be determined within a few feet.

Reference to current discussion as to the limits of the Carboniferous system may seem necessary, but in the light of recent revelations the search for a hard and fast line of demarkation between Devonian and Carboniferous seems futile. For our own part, the convenience of the time-honored nomenclature and the application of the law of priority outweigh all other considerations yet advanced, unless the whole Sub-Carboniferous group be dropped and the Paleozoic be restored to its primitive simplicity—Silurian, Devonian, Carboniferous—with only a single series of coördinate terms included in each; in which case one might let the Berea grit form the base of the Carboniferous.*

The General Stratigraphy.

About the Ohio Waverly the sequence has proved quite simple in central Ohio, but curious misapprehensions have been perpetuated up to the present moment. While Professor Andrews was the first to distinguish the great mass of shales, freestones and conglomerates previously confused with the Carboniferous conglomerate, he introduced so many elements of error that his discovery was nearly unfruitful. To Professor Orton belongs the credit of first distinctly differentiating on purely stratigraphical grounds the Cuyahoga shales from the typical Waverly of central and southern Ohio. And we may claim the task of carrying out (though quite independently) the minuter subdivision and correlation of the several horizons in the southern part of the Waverly domain. It was a great misfortune that Dr. Newberry's studies of the Waverly were so largely restricted to and based upon the northern exposures which, as we shall see, contain only a poor one-third of the series. The most recent discussion of the problems here touched upon is that contained in Professor Orton's volume VI of the reports of the Geological Survey of Ohio. It will, therefore, be convenient to summarize the results of our work by reference to that report, and it will, of course, be understood that this reference is not in the nature of criticism, but rather to facilitate comparison with the most conservative and adequate basis for an understanding of the Waverly which up to this time exists.

The Bedford Shale.—This argillaceous bed has been considered the base of the Waverly, and is so constant and, in southern and central Ohio, so dis-

*Cf. the suggestion of Professor Williams in the present volume, p. 19.

tinct lithologically that, as Professor Orton says, "there is not a stratum in our geological column that can be followed across the state in more easily demonstrated identity than this."

Another statement of that author requires modification in view of our discovery (published about the same time) of abundant evidences of life in the shale. This statement is the following:

"In the lower beds of the Bedford shale fossils are, in northern Ohio, at a few points, abundant. They are of pronounced Sub-Carboniferous character, comprising *Syringothyris typa*, *Hemipronites crenistria*, *Chonetes logani*, *Orthis michelini*, *Spiriferina solidorostris*, and others of like association. None of these fossils have been reported south of the lake shore." *

In 1888 we found at Central College, near Columbus, in the lower part of the Bedford shale, an abundant fauna of evident Devonian habit, including about twenty species, at least half being closely allied to or identical with Hamilton species and with no admixture of strictly Waverly species. At the same place we traced such species as *Strophomena rhomboidalis* and *Atrypa reticularis* to a point above the Berea grit. Subsequently the same association of fossils was found in the middle Bedford of Chagrin falls, Cuyahoga valley, and elsewhere. Even in the typical locality at Bedford *Macrodon hamiltonæ*, *Microdon bellistriatus*, *Leda diversa*, *Palæaneilo constricta* and *Chonetes scitula* are found 40 feet below the Berea grit. It is true that the forms identified by Newberry, and upon which the Carboniferous age of the Bedford has been maintained, do occur associated with *Macrodon hamiltonæ;* but, so far as observed (and I think I have seen most of the specimens), they are thus associated in the bands of flags intercalated with the shale and not in the shale itself. However that may be, out of the list quoted, *Syringothyris typa* and *Spiriferina solidirostris* are the only species which could carry conviction; the others are either too widely distributed or too closely allied with Devonian types to be positively identified from crushed and imperfect specimens. As to the *Syringothyris*, after careful examination I incline to think it distinct from the species characteristic of the middle Waverly, while it is very rarely found in the shales 100 feet above the Berea. The generic assemblage also counts for nothing, for Professor James Hall has shown that *Syringothyris* is certainly not a Carboniferous genus but arises in the Devonian. Again, such well-known Devonian forms as *Strophomena rhomboidalis* and *Atrypa reticularis* rise to the summit of the Cuyahoga shale.

The lithological character of the Bedford deposits changes as it passes eastward and assimilates with that of the Erie, so that where the Cleveland shale loses its distinctive features the two merge insensibly.

While we may dissent from Professor Orton's classification of the Ohio shales in some respects, enough has been said to prove that if we are to look

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* Rep. Geol. Survey of Ohio, vol. VI, 1885, p. 34.

for a definite lower boundary of the Waverly it must be found in the Berea grit, which, as so well shown by Orton, is a sharply limited and easily recognizable horizon throughout Ohio. If, however, it can be proved that the original application of the term Waverly was primarily to the Bedford shale, whatever else was also included, we are placed in an awkward predicament not wholly without parallel in the history of geological progress.

Lithologically and faunally, I repeat, the affinities of the Bedford are certainly with the underlying shales rather than the shales above the grit.

The Berea Grit.—We have nothing to add to Orton's admirable account of this distinctive bed, which forms the next element in the column, except to note the occurrence of the Devonian forms already mentioned in the upper courses and the immediately overlying shales.

The Berea Shale.—This term is conveniently applied to the thin band of bituminous shale above the grit and perhaps should not be extended (as the writer has done in a previous paper) to the gray and blue shales above. In southern Ohio it varies from fifteen to twenty feet in thickness and is little more than two feet thick at Chagrin falls. It is typically exposed in the Cuyahoga valley, but its fossils at that place extend upward to the flags which form the "Big falls of the Cuyahoga," thus justifying from the standpoint of paleontology the attempt to extend the application of the name. The fossils are mostly *Lingula* and *Discina* of several species, but *Chonetes*, *Productus* and other forms also occur.

The Cuyahoga Shale.—Using this term, in the sense in which it was employed by Professor Orton, for the 100–150 feet above the Berea shale, we here encounter one of the surprises of our study. As is well known, Dr. Newberry applied the term Cuyahoga shale to the whole series of strata filling the interval between the Berea grit and the Chester limestone. I have sufficiently shown that this use is impossible, because of the fact that at least three important formations are included and confused. In central Ohio it is easy to recognize these horizons and to determine approximately their limits. In 1888 Professor Orton, on stratigraphical grounds, determined that the entire series as exposed in the Cuyahoga valley lies below the reddish and yellowish freestones and conglomerates constituting our divisions II and III and his Logan group. He makes the natural error, however, of concluding that "as here limited it is, for the most part, very poor in fossils," suggesting that "the fossils with which the Cuyahoga shale has been credited have been largely derived from the division next to be described"—*i. e.*, the Logan group.

Until the summer of 1890 I have had little opportunity to examine carefully the exposures in Cuyahoga county, and have refrained from attempting to complete the correlation. Last summer (1889) Mr. Cooper was commissioned to examine the exposures in Richland, Wayne and Summit counties, and extended the exact knowledge as far as Lodi and Burbank;* but there still remained the problem of the Cuyahoga shale proper, and with the solution of this rested the raveling of the strange snarl which has so long puzzled geologists. The very simple solution of the problem suggested by Orton seemed cut off by the results of Mr. Ulrich's study of the bryozoa from Lodi, Bagdad, Richfield and other localities within the area occupied by the Cuyahoga shale. Mr. Ulrich, after describing forty-one species, finds 41 per cent. of the number identical with those identified by him from the Keokuk and Burlington of Illinois. Inasmuch as these species were known in several cases to also occur in shales only fifty feet below the Carboniferous conglomerate at Cuyahoga Falls and the large fauna at that place had not yet been studied, we felt that his conclusions had much weight, especially in view of the fact that undoubted Keokuk and Burlington strata occur in central and southern Ohio within the one hundred feet immediately below the Coal Measures.

The work of the present season has happily set the general question quite at rest, and will doubtless shed a flood of light on the affinities of the crinoids of the Cuyahoga which have caused so much discussion. Their curious resemblances to the Devonian species and the strange commingling of Carboniferous characters can no longer be regarded as abnormal. Regarding the bryozoa, it must be remembered that the Kinderhook has thus far produced few bryozoa, and the bryozoan fauna of the Chemung is yet to be discovered. At what time the Burlington bryozoa appeared and what their range in time may have been remain to be seen. A large supply of bryozoa may be found in the Keokuk and Burlington of southern Ohio, but they must be studied microscopically when the rocks are first broken open, as they are too fragile to bear transportation. The mistakes which have prevented a proper paleontological understanding of the Waverly consisted in the belief that the uppermost part of the Cuyahoga shale, the lower part of the Waverly in central and southern Ohio, and the Bedford shale are unfossiliferous.

We have been so fortunate as to discover a rich fauna within 15 feet of the conglomerate at Cuyahoga Falls and extending 50–60 feet below. This also occurs at Akron (in spite of the assurance of numerous collectors who have stated that the shales are positively barren)†. The most remarkable storehouse of fossils is derived from calcareous and ferruginous concretions containing galenite and blende. These occur 50 feet below the Millstone grit at Cuyahoga Falls and Akron. They occur at Richfield, Bagdad, Lodi, Ashland county, Moot's run, Licking county, and even in Scioto county, on the Ohio river. In short, they indicate a practically constant horizon from

*See his report, Bul. Denison Univ., vol. V, 1890, pp. 24–34.
†Professor Claypole informs me that he had also noticed this fossiliferous horizon at Akron.

the extreme northern to the southern limits of the state, which is not only constant in lithological character and in the main elements of the fauna but also in its stratigraphical relations when referred to the Berea grit as a base line, in spite of slight local modifications, which have value as representing zoological and geological stations simply. Evidence can be given on this point which is absolutely conclusive. In the first place, a careful instrumental survey has correlated the horizons stratigraphically beyond possibility of error. On these grounds alone we can positively assert that the Cuyahoga shale as represented in the northern tier of counties is identical with that part of the Waverly lying below conglomerate I—*i. e.*, below the undoubted actual equivalent of the Kinderhook of central Ohio. The fossiliferous horizons of Granville, Newark, Rushville and Winchell's division 4 on the Ohio river are all above the top of the Cuyahoga. Mr. Cooper and myself have traced the limits of division II by means of the conglomerates and associated fossils along a line emerging from beneath the Coal Measures apparently not far from Seville, passing between Wooster and Burbank, southeast of Ashland, west of Independence, west of Granville and Newark, east of Lancaster and west of Rushville to the Ohio river near Buena Vista. But the evidence which is beyond suspicion is that derived from the fauna. The large assemblage of fossils derived from Moot's run, Licking county, is sharply distinguished from anything found in the remaining Waverly in central Ohio. Very few of these species occur elsewhere in the series. The specimens hitherto derived from the upper part of the Cuyahoga were from the shales and were curious depauperate forms baffling identification; but the recently discovered fauna of the concretions from the same horizon reveals a large series of familiar forms sharply characteristic of the Moot's run and Lodi horizon. These forms include, besides many others, the following species:

1. *Pterinopecten shumardianum.*
2. *Edmondia sulcifera.*
3. *Phaëthonides spinosus.*
4. *Crenipecten cancellatus.*
5. *Proëtus præcursor.*
6. *Fenestella herrickana.*
7. *Spirifer marionensis.*
8. *Spirifer tenuispinatus.*
9. *Productus newberryi.*
10. *Pterinopecten cariniferus.*
11. *Athyris ashlandensis.*
12. *Terebratula inconstans.*
13. *Crenipecten cooperi.*

The Waverly Shale.—The stratum so termed by us is lithologically similar to the Cuyahoga shale, and, being confined to central Ohio and occupying a thickness of only 40 feet immediately below conglomerate I, might be ignored in our enumeration were it not for the fact that it contains a large number of species found also in Michigan and Illinois. Its fossils have been found thus far only in Licking and the adjoining counties. The term is perhaps unfortunate, and for convenience this shale might be merged with our division II, from paleontological resemblance, though continuous with the Cuyahoga shale stratigraphically and resembling it lithologically.

The Kinderhook.—With this section (our division II) we enter the group of olive and yellowish freestones and conglomerates called by Professor Orton the Logan group. The term was originally applied to our division III, to which it should apparently be restricted.

Even Professor Orton fails to distinguish the conglomerates which in typical sections sharply limit the middle Waverly. The local thickenings in these conglomerates have caused more trouble than any other feature of the Waverly. The band of characteristic fossils lying beneath the second conglomerate, *Sanguinolites obliquus, Allorisma winchelli, Prothyris meeki*, etc., is, fortunately, very persistent and well limited, even when the conglomerate is absent, having been traced from Sciotoville to the northern exposures in Wayne county.

The Burlington and Keokuk.—These formations are in part, at least, represented by the 200 feet or so which lie beneath the Chester and are very fossiliferous in some localities. Unfortunately the beds referred to the Keokuk are usually removed by erosion and if not are seldom well exposed. They are characterized by a deep red color and a great abundance of fossils which, though often well preserved, can rarely be removed from their matrix. *Phillipsia meramecensis, P. serraticaudata* and *Spirifer keokuk* are among the characteristic fossils.

Summary.—The general results of our study may be summarized as follows:

1. The Berea grit is the natural floor of the series, the Bedford shale having its faunal relations decidedly with the shales of the Devonian below.
2. The Bedford affords a striking exemplification of the doctrine of colonies,* and that portion lying to the southwest beyond the western limits of the Erie retained a fauna derived from the Hamilton long after this fauna had perished to the eastward.
3. The Cuyahoga shales (including the whole series above the Berea so far as present in the Cuyahoga valley) is divisible into three minor sections, the uppermost of which is characterized by a vast abundance of fossils, which are especially well preserved in calcareous or ferruginous concretions, is a constant and almost unvarying horizon, extending from Lake Erie to the Ohio river. The Cuyahoga proper is never more than 200 feet thick, and forms a transition zone, with a prevailing Devonian habitus.
5. The upper portion of the Waverly is quite distinct from what precedes in fauna, and contains an undoubtedly lower Carboniferous assemblage.

* It is suggested by Williams that this term can only be used in a modified sense.

6. None of the larger divisions of the Carboniferous of the west are entirely unrepresented in Ohio.
7. The transition is nevertheless so gradual that we have an instructive illustration of the evolution of one age from the preceding with neither catastrophe nor annihilation.
8. There is an opportunity to trace the geographical variations in a species as distributed over a great area, and to observe the evolution of new types therefrom.
9. The entire thickness of the Waverly is not far from 700 feet, though the highest consecutive section measures only 670 feet.
10. The Cuyahoga fauna bears an unmistakable resemblance to the so-called Sub-Carboniferous of Belgium, especially that of Etage I, the limestone of Fornai.

In the present state of our knowledge of the stratigraphy of Missouri it is perhaps hazardous to attempt to parallelize Ohio and western horizons, but if, as Professor Calvin states, the Chouteau and therefore also the Lithographic limestone are faunally lower than the Kinderhook at Burlington, we may easily regard the Cuyahoga shale as the eastern equivalent of the series including these limestones, the shales included, and possibly also the shales below extending to the deep-blue shales superposed upon the Black shale which here, as elsewhere, affords a well-marked horizon.* Professor Safford offers a hint which seems to open the way for extending the generalization into Tennessee as well.

Representative Sections.

The following representative sections derived from the northern and southern exposures in the state, respectively, may be offered in illustration of the stratigraphical correlations suggested. The figures are all actual measurements, there being no composition of different partial sections, and are as nearly accurate as need be.

*A small *Phillipsia*, practically indistinguishable from our *P. serraticaudata*, has been received from the lower Burlington beds of Louisiana, Mo.

Cuyahoga Valley and Bedford.	Thickness.	*Portsmouth.*	Thickness.
Carboniferous conglomerate	70 ft.	Carboniferous conglomerate, fire-clay, or Chester limestone	2–10 ft.
This entire series is absent in the northern tier of counties to the base of Conglomerate I.		Sandy freestone and reddish sandstone, with Keokuk fossils, *Phillipsia meramecensis*, etc.	35 ft.
		Yellow or grey freestone and shales, with Burlington fossils, *Crenipecten crenistriatus*, *Grammysia ovata*, *Spirifer biplicatus*, *Spirifer striatiformis*, *Schizodus newarkensis*	200–215 ft.
		Massive freestone, usually with some bands of conglomerate; *Productus arcuatus* (conglomerate II)	50 ft.
		Immediately below the conglomerate lie bluish or greenish and very soft shales, with *Prothyris meeki*, *Sanguinolites obliquus*, *Allorisma winchelli*	90 ft.
		Freestone representing the quarry rock of central Ohio, containing *Crenipecten winchelli*, etc	20 ft.
		Shales of same series.	
		Freestone, the lower courses of which represent conglomerate I of central Ohio; variable in thickness; entire series	70 ft.
The fauna of this horizon is not here represented.		Shales	50 ft.
Cuyahoga shale, with *Spirifer marionensis*, *Phaëthonides spinosus*, *Proëtus præcursor*, etc.	50 ft.	Shales, with *Spirifer marionensis*, *Phaëthonides spinosus*, and many other fossils	50 ft.
Concretions with same fauna.		Flags	20 ft.
Shales	40 ft.	Concretionary shales, with *Productus newberryi*, *Spirifer marionensis*, etc. Variable in thickness.	
Flags and shales, with *Productus newberryi*, *Allorisma cuyahoga*, *Discina newberryi*, etc.	35 ft.	Flags of Buena Vista	25 ft.
Berea black shale	10–15 ft.	Berea black shale	15 ft.
Berea grit	45 ft.	Flags, Berea grit	30–40 ft.
Blue to green Bedford shale	45 ft.	Blue to green Bedford }	Thickness variable.
Flags	10 ft.	Red Bedford }	
Soft fossiliferous shale	25 ft.		
Flags	10 ft.		
Cleveland shale.			

The Fauna of the Cuyahoga Shale.

The following list of common fossils from the Cuyahoga shale is not only very incomplete, but doubtless contains many identifications requiring verification as soon as a revision of the published species from the same horizon in Michigan and Illinois shall make this possible. It will, however, give a fair idea of the assemblage of forms under consideration. The numerals affixed indicate in a general way the known geographical distribution as follows: (1) localities on the Ohio river; (2) localities in central Ohio, chiefly in Licking county at Moot's run; and (3) exposures within the northern tier of counties:

CRUSTACEA.

Phaëthonides spinosus, Her. (1, 2, 3).
" *immaturus*, Her. (3).
" *lodiensis*, Meek (3).
" *consors*, Her. (3).
Proëtus minutus, Her. (2).
" *præcursor*, Her. (2, 3).
Dalmanites cuyahoga, Claypole (3).

LAMELLIBRANCHIATA.

Allorisma cuyahoga, Her. (3).
Avicula (?) *recta*, Her. (3).
Crenipecten cooperi, Her. (2, 3).
" *subcardiformis*, Her. (2).
" *cancellatus*, Her. (2, 3).
Conocardium alternistriatum, Her. (3).
Ctenodonta iowensis, W. and W. (?) (2, 3).
Ctenodonta sp.
Cypricardinia scitula, Her. (2, 3).
Edmondia sulcifera, Her. (1, 2, 3).
Leptodesma ortoni, Her. (2).
" *nasutus*, Her. (= *hector*, H. (?) (2, 3).
Lyriopecten nodocostatus, Her. (2, 3).
Macrodon striato-costatus, Her. (cf. *parvus*, W. and W.) (2, 3).
Mytilarca fibristriatus, W. and W. (1).
" *occidentalis*, W. and W. (2).
Palæaneilo marshallensis, Win. (2).
" (?) *ohioensis*, Her. (2).
" *consimilis*, Her. (2, 3).
" *ignota*, Her. (2, 3).
Palæaneilo sulcatina, Her. (2).
Promacra truncata, Her. (2).
Pterinopecten shumardianus (1, 2, 3).
" *cariniferus*, Her. (2, 3).
" *ashlandensis*, Her. (2, 3).
" *lætus*, Hall (2).
Schizodus harlamensis, Her. (2).
Sphenotus contractus, Hall (2).
" *fragilis*, Her. (2).
" *media*, Her. (2).

GASTEROPODA.

Bellerophon sp.
" *perelegans*, Win. (2 ?).
Conularia gracilis, Her. (2).
" *micronema*, Meek (2).
Cyclonema levenworthanum (?) (2).
" *strigillatum*, Her. (1, 2, 3).
Loxonema sp. (1, 2, 3).
Naticopsis sp. (1, 2, 3).
Orthoceras sp. (2, 3).
Platyceras paralium, Win. (1, 2, 3).
Platyceras sp.
Pleurotomaria textiligera, Meek (3).

BRACHIOPODA.

Athyris lamellosa, Lev. ? (2).
" *ashlandensis*, Her. ? (1, 2, 3).
Atrypa reticularis, Hall (3).
Chonetes logani, Nor. and Pratt (2).
" *scitula*, Hall (2, 3).
" *tumida*, Her. (2, 3).
Crania hamiltonæ, Hall ? (2).
Cyrtina acutirostris, ? (2, 3).
Hemipronites crenistria, Phil. (?) (1, 2, 3).
Lingula atra. Her. (3).
" *membranacea*, Win. (3).
" *melie*, Hall (3).
Discina newberryi, Hall (3).
Productus shumardianus, Hall (2).
" *concentricus*, ? Hall (2).
" (*Productella*) *lachrymosus*, Hall (2).
Productus (*Productella*) *speciosus*, Hall (2).
Productus raricostatus, Her. (2).
" *newberryi*, Hall (1, 2, 3).
Rhynchonella contracta, Hall (1, 2, 3).
" *sappho*, Hall (1, 2, 3).
Rhynchospira ashlandensis, Her. (1, 2, 3).
Spirifer marionensis, Shum. (1, 2, 3).
" " var. *centronotata*, Win. (3).
Spirifer tenuispinatus, Her. (2, 3).
Spiriferina sp. (2, 3).
Syringothyris cuspidatus-typa, Win. (2, 3).
Syringothyris sp. (2, 3).
Terebratula inconstans, Her. (1, 2, 3).

The crinoids and bryozoa need not be specially catalogued, as nearly all of the species described from the Ohio Waverly are derived from this group.

Notes on New and Little-Known Waverly Fossils.

This opportunity is embraced to add a few notes upon Waverly species hitherto overlooked or imperfectly described.

PHAËTHONIDES SPINOSUS, HERRICK.

(*Plate* 1, *fig.* 13.)

A large series of specimens collected by Mr. Cooper and myself indicate that the species was very abundant and widely distributed during the period represented by the shales of Moot's run and Lodi. The species likewise occurs in the very upper Cuyahoga at Cuyahoga Falls and Akron. In the shales we found for a long time only the depauperate form described by us as *Phaëthonides immaturus*. Examination of the recently discovered fauna of the concretions of the same horizon revealed many specimens of the type. Since then intermediate stages have been encountered and typical examples of *P. spinosus* have been found at Lodi, Akron and Cuyahoga in the shales. The fine example figured was derived from the same horizon in Scioto county less than 50 feet above the Berea. The name *Phaëthonides immaturus* may lapse, but upon what form *Phillipsia lodiensis* may have been founded remains to be seen. Collectors are generally agreed that the species as characterized by Meek does not occur at Lodi or elsewhere on that horizon. The evidence is strongly suggestive that the specimen forming the basis of the species was imperfect and distorted. It will also be very interesting to rediscover the *Dalmanites* described by Professor Claypole from this horizon.

Phaëthonides spinosus is reported from Missouri, though I have not seen specimens.

PHILLIPSIA (?) CONSORS, HERRICK.

(*Plate* 1, *fig.* 12.)*

Additional specimens seem to indicate that the numerous pygidia upon which this species chiefly rests do not belong to the same species as that represented by the associated glabellæ, but that the latter pertain to immature or slightly variant forms of *Proëtus præcursor*, the resemblance to which was noted in the original description. Pygidia obtained at Akron and Lodi can be identified certainly with that species, though the glabellæ exhibit minor points of difference which may perhaps be correlated with the small size. The glabella of *P. consors* being, therefore, unknown, it cannot be at present determined whether it represents a *Phaëthonides*, as is quite possible, or a *Proëtus*.

Figure 12 (plate 1) gives a greatly enlarged view of the pygidium of *P. præcursor* as seen in the shales 40 feet below the Carboniferous conglomerate at Cuyahoga Falls.

PHILLIPSIA MERAMECENSIS, SHUMARD.

(*Plate* 1, *fig.* 14.)

This, for the purpose of determining the stratigraphical equivalence of the upper part of the Waverly, is one of the most important species. Until recently the only specimen seen was that figured in the Bulletin of Denison University, volume IV, plate I, fig. 6, which was derived from an isolated exposure immediately below the Chester. More recently other specimens have been found in Scioto county which are derived from the uppermost layers of the Waverly. Some slight variation is observable, but the smooth surface, evenly rounded ribs, and almost obscure margin prevent confusion with other forms. It does appear, however, that *Phillipsia serraticaudata* becomes gradually modified, in passing from lower to higher strata, in the direction of this species.

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* Bulletin Denison University, vol. IV, 1888, p. 53.

CYTHERELLA UNIONIFORMIS, SP. N.

(*Plate* 1, *figs.* 8–10.)

Carapace elongate, subovate, acutely rounded behind, the greatest prolongation above the middle; anterior margin oblique at an angle of 120° with the hinge nearly straight; hinge-line nearly straight; ventral margin a gentle curve; valves similar, gently convex, slightly compressed posteriorly, abruptly deflexed anteriorly. In the cast a ridge appears nearly parallel to the anterior margin, from which the surface descends abruptly to the margin. The ridge terminates in a conical projection (indicating a pit in the interior of the valve which may or may not have a corresponding external elevation), from which a faint ridge passes obliquely backward toward the superior margin. Muscle pit large, nearly central, and surrounded by a nearly circular ridge. Greatest width near the middle. Length (.04 ± mm.) about 1.7 times the width and about 2.5 times the thickness.

This species is very abundant in the upper layers with *Phillipsia meramecensis.* Another entomostracon is figured on plate 1 (fig. 11), the description of which is reserved. A considerable number of species of *Cytherella* are in our collections from other horizons of the Waverly series, but the present species is the most characteristic and widely distributed. The same or a very similar species occurs in the upper layers of the Cuyahoga shale.

LEPTODESMA NASUTUS, HERRICK.*

(*Plate* 1, *fig.* 6.)

This species, briefly indicated in an earlier publication,† proves to be widely distributed, though nowhere common upon the horizon of the concretionary zone of Moot's run. The right valve figured is from Burbank, Ohio, and differs in no obvious respect from the corresponding valve of the Chemung species quoted. On the other hand, other specimens connect it with *L. ortoni* from a somewhat higher horizon.

LEIOPTERIA CUYAHOGA, SP. N.

(*Plate* 1, *fig.* 7.)

Species of small or medium size, subrhomboidal, oblique, subfalcate; body narrow, compressed, produced posteriorly, sharply elevated at the post-umbonal ridge, forming an angle of 30° with the hinge-line; height equal to less than two-thirds the length; basal margin gently curved, posterior margin sinuate; byssal sinus moderate; left valve sharply elevated at the post-umbonal ridge, sloping to the ventral margin by a very flat curve; hinge straight, shorter than posterior prolongation of the body; wing de-

* Cf. *L. hector*, Hall.

† Bul. Denison Univ., vol. IV, 1888, p. 29.

pressed, concave; ear small, obtuse, convex; surface ornamented by about thirty sharp, equidistant striæ, which are nearly obsolete on the wing. Length, 23 mm.; height, 10 mm.; length of wing, about 10 mm.

This pretty little species occurs at Cuyahoga Falls, 50 feet below the Carboniferous conglomerate. A few specimens of a similar, if not identical, form were also found at Moot's run, Licking county.

CONOCARDIUM ALTERNISTRIATUM, HERRICK.

(*Plate* 1, *figs.* 1–4.)

Several imperfect specimens of this fine species were found by W. F. Cooper at Wooster in shales 60 feet below conglomerate I. The fossiliferous zone is on the same stratigraphical level as that at Moot's run, Licking county, and, like that layer, is characterized by calcareous concretions frequently filled with perfectly preserved fossils.

The characteristics differentiating *C. alternistriatum* from other Waverly species are chiefly the distant flat-topped ribs and distinctly bifaceted surface. The species also attains a larger size than the others reported from Ohio. Unfortunately no perfect specimens have been obtained. Among the fragments of this familiar form at Wooster was found a nearly perfect small individual with surface characters of *C. alternistriatum.* As the specimen is undistorted and retains the shell with even its original brown color in places, it has been carefully figured. The chief difference between this specimen and the specimens of *C. alternistriatum* thus far seen is in the structure of the posterior prolongation. The shell is exfoliated over this region, but the cast exhibits coarse, rounded ribs very unlike the remainder of the surface. In *C. alternistriatum* the posterior facet of the lateral surface is covered with finer and more numerous plicæ than the anterior, while here the conditions seem reversed. Length from beaks to posterior extremity, $\frac{1}{3}$ in.; extreme length from antero-ventral to postero-dorsal extremity, $\frac{1}{2}$ in.; greatest breadth, 1-33 in.

The species figured is in some respects like *C. meekanum,* Hall, but seems quite distinct. It is much more oblique, and is more distinctly compressed posteriorly. Without definitely deciding upon its specific relations, the figures are given for subsequent comparison.

Another species of *Conocardium* is present at the same place in the same stratum, which in surface characters resembles *C. pulchellum.*

SPIRIFER PSEUDOLINEATUS, H.?

(*Plate* 1, *fig.* 18.)

The *Martinia* group is very difficult, and although we have at least three nominal species from the Waverly they are by no means well distinguished.

S. tenuispinatus, Her., from the Cuyahoga, nearly resembles *S. setigerus* of the Chester, but is more rhombic in outline. The form we have compared with *S. hirtus* is quite different and is from the Kinderhook. The specimens of the present species so far seen are from the sandstone of the upper 35 feet of the series at Portsmouth and elsewhere, and, though much smaller than the western types, agree with the Keokuk species better than either of the others noted. The enormous curved spines are well shown in the figure. (It may be added that all the Keokuk species found in Ohio are smaller than their western representatives from limestone strata.)

CYPRICARDINIA (CF. SCITULA).

(*Plate* 1, *fig.* 15.)

This species is figured because of its close resemblance to the form described from Moot's run, in the lowest one hundred feet of the Waverly—*i. e.*, the Cuyahoga shales. The beautiful little shell occurs sparingly in the concretions of Richland beds also.* The form figured herewith occurs in the upper 35 feet of the Waverly in Scioto county, and would thus seem to be upon the horizon of the Keokuk or upper Burlington, and is associated with fossils of that age. It differs from the types of the species quoted in the less prominent beak, more uniformly arched anterior margin, and less obliquity of the posterior margin. In surface characters and general appearance the two are very similar, and it seems at present unwarrantable to attempt to separate them.

SPIRIFERINA SPINOSA, HALL.

(*Plate* 1, *fig.* 19.)

While possibly a distinct variety, the little form occurring rather abundantly on the uppermost horizon of the Waverly appears more closely allied to the Chester species than either of those common beneath that level.

DISCINA MAGNIFICA, SP. N.

(*Plate* 1, *fig.* 17.)

The largest of our specimens of the Carboniferous genus *Discina* was found by W. F. Cooper in freestone a few feet above conglomerate II, at Hemlock Falls, Ashland county, and also upon the same horizon at Wooster. It is, therefore, upon the same stratigraphical level as *Orbiculoidea* (?) *pleurites.*

Upper valve oval, elliptical, or nearly circular, usually with the sides somewhat straightened; beak exactly one-fifth the length from the dorsal margin;

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*Bulletin Denison University, vol. IV, 1888, p. 38.

convexity greatest a little in front of the beak, the region from that point to the front elevated; surface marked by relatively strong concentric ribs; structure of shell unknown; lower valve flat or slightly concave.

Our specimens are all casts, and none of them preserve the structure of the lower valve. There is no species with which it could be confounded. Dimensions of one individual: length, 52 mm.; width, 50 mm.; beak from front, 11 mm.; of a second individual, 50 mm., 46 mm. and 11 mm.; and of a third, 48 mm., 47 mm. and 11 mm.*

* Bulletin Denison University, vol. V, 1889, p. 28.

Description of Plate 1.

New or imperfectly known Fossils from the Ohio Waverly.

Figures 1–4—Four views of a nearly perfect specimen of *Conocardium* for comparison with *C. alternistriatum*, Herrick. From concretionary shales of the Cuyahoga division at Wooster. Greatly enlarged.

Figure 5—A minute specimen of *Nucula* sp. From the Cuyahoga shales, drawn with the camera lucida and much enlarged.

Figure 6—*Leptodesma nasuta*, Herrick, from Burbank, Ohio, to illustrate the similarity of the right valve with that of *L. hector*, Hall.

Figure 7—*Leiopteria cuyahoga*, sp. n. From the concretionary shales of the Cuyahoga valley, 50 feet below the Millstone grit.

Figures 8–10—Three different specimens of *Cytherella unioniformis*, sp. n., highly magnified. From the upper layers (Keokuk) of Scioto county, Ohio.

Figure 11—Unidentified Ostracode from same place.

Figure 12—Fragment of the interior of pygidium of *Proëtus præcursor*, Herrick, from Cuyahoga Falls. Complete heads of the same species have been found at this locality since the drawing was prepared, making its presence certain.

Figure 13—Pygidium of *Phaëthonides spinosus*, Herrick, from horizon of the shaly beds at Moot's run (Cuyahoga shale), in Scioto county, Ohio.

Figure 14—Pygidium of *Phillipsia meramecensis*, Shumard. From upper layers (Keokuk) of Scioto county, Ohio.

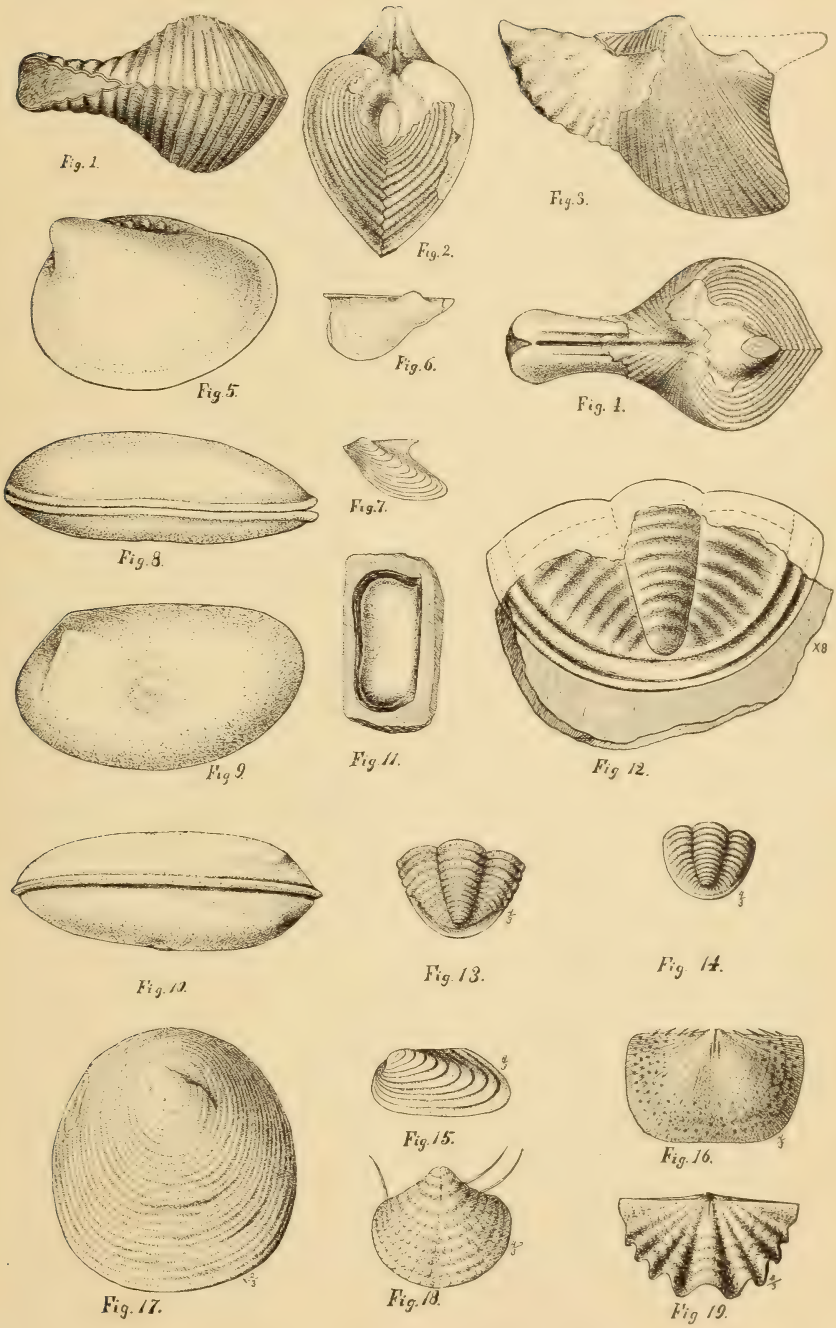
Figure 15—A close homologue of *Cypricardinia scitula*, from the Keokuk of Scioto county, Ohio, to illustrate the persistence of the type.

Figure 16—*Chonetes illinoisensis*, from the Keokuk of Scioto county, Ohio.

Figure 17—*Discina magnifica*, sp. n. From Hemlock Falls, Ashland county, Ohio, a few feet above conglomerate II. Two-thirds natural size.

Figure 18—*Spirifer pseudolineatus*, Hall. Locality and position the same as fig. 15.

Figure 19—*Spiriferina spinosa*, Hall. Locality and position same as the last.



NEW OR IMPERFECTLY KNOWN FOSSILS FROM THE OHIO WAVERLY.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 49-74. JANUARY 10, 1891.

THE STRUCTURE OF A PORTION OF THE SIERRA NEVADA OF CALIFORNIA.

(*Read before the Society December* 29, 1890.)

BY GEO. F. BECKER.

CONTENTS.

Summary of Observations.

Region studied.—During the past field season I have made studies of the structure of a part of the high Sierra with a view to elucidating the orogenic forces involved. My observations were made chiefly from the south fork of the Stanislaus river to the Truckee, a distance of about 80 miles, and covered a belt of some 30 miles in width immediately west of the eastern scarp of the range. The results are in some respects incomplete even for this limited area, but they appear to be of sufficient interest to justify a preliminary paper. During the field-work I did not find myself able to frame any hypothesis to account for the phenomena, although these were in some of their features singularly regular. This was in one respect advantageous, for it left me free from all bias in the collection of facts. On the other hand, it led to a failure to record minutely certain features of structure which I now believe capable of very complete explanation.

Rocks and Exposures.—The rocks throughout the area mentioned are chiefly granite and diorite, overlain in part by andesite and basalt. Excepting portions of the eastern slope of the range and the higher peaks, the whole area has been glaciated up to the summits of the passes and, as the glaciation is very recent, the rock is admirably exposed.

Fissures.—The granite and other granular rocks are intersected by fissures at short intervals. Sometimes these appear to be without any regularity; but much more often they are manifestly grouped in systems. A few square miles will be particularly characterized by horizontal fissures and here the granite mountains will appear terraced. In such cases vertical or diagonal fissures are always present, but are less prominent than the horizontal partings. In other areas the granite will be intersected by diagonal fissures usually dipping at about 45° and striking between northwest and north. These dip in both directions and divide the mass into horizontal columns. Much more frequent than any other fissure systems are vertical partings, and these are remarkably uniform in strike, almost always running either nearly north-northwest or at right angles to this direction. As a rule, where these vertical systems occur together, one of them is more strongly pronounced than the other, but sometimes the rock is divided into square columns, which look as if they had been cut and smoothed by stone masons. The prevalence and the strongly marked character of these vertical fissure systems led me to devote to them most of my attention. They are so common that one seldom travels more than a mile or two over granite without encountering them, and I estimate that they are distinctly developed in more than one-half of the area occupied by granular rocks.

Fissures of more than one kind appear in some cases to penetrate from the granite into overlying andesite, but the lava flows are for the most part very heterogeneous agglomerates, and when this is not the case they are apt to be columnar. They are, in short, in all respects ill adapted to the study of orogenic movements.

The Fissures are Fault Planes.—Though the fissures in the granite never gape and are usually only cracks, they are not mere partings or joints but true fault planes. In innumerable cases they show excellent slickensides and very often the amount of dislocation can be demonstrated. The faulting has been attended by intense compression, so that at some points the rock for an inch or two from the principal plane of motion has been sheared to a mass resembling slate. This is comparatively rare, but it is often manifest that, for some distance from a pronounced fisssure, lines of weakness have been developed in the rock at intervals of a quarter of an inch, or thereabouts. These lines grow less distinct as the distance from the fissure increases, and disappear a foot or two from the fissure.

Frequency of the Fissures.—In areas intersected by the vertical fissure systems the horizontal interval between the parallel planes is variable. Occasionally they are a couple of hundred feet apart, but this is rare. There can hardly be said to be an inferior limit to the horizontal intervals, for there is every gradation from almost microscopic frequency upwards. It seems possible, however, to distinguish two sets of fissures among members of a single parallel system. A portion appear to represent original fractures of the granite, while the mere act of faulting under strong compressive stress has produced a second set subordinate to the first, and of course parallel to them. An exact determination of the frequency of the primary fissures is impossible, but careful estimates on the ground led me to believe that the horizontal interval between them averages about five feet.

Age of the Fissures.—There are certain dikes of a highly feldspathic, nearly white, granitic rock which intersect the darker granites of the Sierra and the areas of metamorphic strata sometimes imbedded in the granite. Though the age of these dikes requires more investigation, I have reasons for believing it to be early Cretaceous. These dikes are more ancient than the fissure systems under discussion. There is much to show that California was in a very quiet condition from the Gault, or thereabouts, to the close of the

Miocene. Then trouble began again. The early Tertiaries of the Coast ranges were thrown into folds, the axes of which are nearly parallel to the coast, and the Miocene of the Great Basin was similarly affected. The main volcanic eruptions of the Sierra probably began at this time, or perhaps a little earlier. They continued throughout the Pliocene.

Since the fissuring and faulting of the granite amounts to a very great disturbance, which one can hardly suppose simply local, it is natural to refer them to the Pliocene. They were also connected with the andesitic eruptions. The dikes of andesite which are found near superficial masses of this lava, and which sometimes connect distant areas of andesite, follow the vertical fissure systems under discussion. This has been noted by Professor Reyer* and I have abundantly confirmed his observations in this respect. Even if the fissures were substantially older than the andesite, the intrusion of this rock must have caused renewed movements of the granite, and as a matter of fact the faults of greatest throw which I have found immediately adjoin intrusions of andesite along the fissures. A portion of the faulting is thus certainly referable to the period of andesitic eruptions, and I have as yet found no indication that the fissure systems under discussion antedate this period.

Absence of post-Glacial Faults.—It is well established that there have been recent faults in the Great Basin as far west as the eastern base of the Sierra Nevada, and post-glacial faults have also been reported from the higher portion of the range.† The area of glaciated surfaces is enormous, and I confidently expected to find many post-glacial faults, even if they had a throw of only a fraction of an inch. In spite of daily searches for many weeks, I was unable to make certain of any such movements. There are, indeed, cases in which dislocation of glaciated surfaces has occurred, but all the instances of this kind which have come under my observation appear distinctly superficial and due in all probability to the action of the frost, more or less assisted by alternations in temperature. I met with no cases that simulated post-glacial faults near the bottoms of cañons or where the rock was manifestly solid. At the very beginning of the investigation I became aware that in dealing with faults of small throw it is needful to be constantly on the watch for the dislocations of a merely superficial character which are so common in mountain ranges, and I have found proof of such movements in which surprisingly large masses of granite were involved. It is possible that I may have examined post-glacial faults without recognizing them, for much of the granite decomposes readily, and some comparatively recent faulted edges may have become rounded by decomposition; but if there has been post-glacial faulting in the area under discussion it has been of small amount.

* E. Reyer's "Theoretische Geologie," 1888, p. 537.

† Ibid., p. 538.

Throw of the Faults.—To determine the direction and throw of faults in granite is often (or perhaps usually) impossible, and I must confess with mortification that, prior to the present investigation, I have been over vast areas of granite in the Sierra and even studied the fissure systems without perceiving that, in this region, the faults can very frequently be determined to a tenth of an inch or less. The means of determining the faults under discussion depends upon the existence of the white dikes already referred to. These dikes (which are familiar to all visitors of the Yosemite valley) are distributed over the entire area dealt with in this paper, though they are much more common in some localities than in others. They are often extremely persistent and can sometimes be followed for a mile or more without sensible deviation or change of width. They are seldom more than three feet in width and are more often from half an inch to four inches wide. The welding between the dike-rock and the walls is commonly perfect, but the dividing line is as sharp as a pencil-mark. No doubt the distribution and direction of these dikes is systematic, but I have not yet found the key to the system. They seem to stand at all sorts of angles and are quite as often almost horizontal as in any other position. Their intrusion was accompanied by faulting, as a matter of course, and this can occasionally be directly observed; but there is no danger of confounding these movements with those on the fissures which form the subject of this paper, and which intersect the white dikes. The throw of the later faults is determinable where the white dikes are intersected, because the dikes are also faulted, and extremely minute motions are thus revealed.

The throw of the faults is, as a rule, so small that it might readily be overlooked, as indeed might be inferred from the very great frequency of the fissures. Suppose, for example, that the total faulting of a point on the range is one mile relatively to another point 200 miles to the southeast of it. Then the average faulting is one foot in 200 feet, or three-tenths of an inch in five feet, which, as nearly as I can ascertain, is the average horizontal distance of the faults. The faults observed are of this order, rarely exceeding three inches and often sinking to a quarter of an inch or less; only in the immediate neighborhood of andesitic intrusions have I detected throws amounting to from two to three feet. Slickensides are sometimes as well developed by the smallest faults as by the largest.

Large faults, however, are often simulated in this region. One frequently comes upon a vertical wall in massive granite from ten to fifty or more feet in height which shows manifest slickensides, and a casual observer would be apt to infer that the height of the wall was the throw of the fault. In most of the cases of this kind which I have seen I have been able to demonstrate by the course of white dikes that the real fault did not exceed a few inches. The explanation is that one or other wall of the fissure has been carried away either by ice or by frost. Sometimes this has occurred because one wall was divided into smaller fragments by the fissure systems and sometimes because its position exposed it in a greater degree to the action of the ice.

So infrequent are large faults that I soon came to suspect the character of any dislocation apparently exceeding a few inches, and in most cases I found that such appearances were referable to merely superficial action.

The horizontal movements on the fissures are of the same order as the vertical movements and I am unable to state from observation which on the average is the greater. Very often the exposures are such as to render only one of the movements determinable, and it appears that, just as the amount of vertical faulting on parallel fissures is variable, so too is the ratio between the vertical and the horizontal motions. In many cases, however, it can be shown that the two movements were not very different.

Rules of Faults.—Throughout the area here treated I have found not a single exception to the following rules of the faults on the two vertical fissure systems which strike respectively north-northwest to south-southeast and east-northeast to west-southwest, where the surface had undergone no superficial dislocation: 1, the northerly wall has moved upwards and westwards relatively to the southerly wall; 2, the easterly wall has moved upwards and southwards relatively to the westerly wall. These rules maintain their validity even when an exception might be looked for. The fissures which I call vertical are of course not absolutely so, for that would be impossible. Often they are so nearly vertical that the eye detects no deviation from a plumb line suspended in line with them; but sometimes there is a divergence of a few degrees in one direction or the other. One might then expect that the hade would always be to downthrow, but this familiar movement has taken place only when it was compatible with the rules just stated, and in other cases the hade is to the upthrow. I have been astonished to meet no exceptions to these rules. I should have supposed that variations in density, preëxisting fissures, and the like, would necessarily have induced local exceptions to any general rule. It may be that there are such exceptions, but I certainly failed to find any. To the north of the area here examined, in the neighborhood of Mt. Lola, there is another set of vertical fissures intersecting those for which the rules were given at angles of about 45°. The dislocations are there so complex that I did not succeed in systemizing them, and they may be found exceptional.

Inductive Examination of Dislocating Forces.

RELATIONS OF THE MOVEMENTS.

The various disturbances are so associated as to indicate that they took place simultaneously, and their uniformly systematic character over a large area suggests that they must have been due to some set of parallel forces pretty uniformly distributed with reference to the mountain mass. I shall therefore make an attempt to infer from the nature of the phenomena the character and direction of a system of forces such as would give rise to the fractures and faults actually observed. In doing so it will be most convenient to begin with the horizontal movements on the vertical fissure systems.

HORIZONTAL MOVEMENTS.

Resolution of Forces.—In figure 1 one of the small vertical prisms is shown in projection on a horizontal plane. The sides are oriented as if the top of the page were to the north, and the arrows show the directions in which the movements of adjoining columns have taken place. These arrows may also be considered as representing in direction and intensity the forces which have produced the motions of the neighboring columns. Regarded as forces, they form two couples which, as drawn, exactly balance one another; so that, though either couple alone would produce rotation, the two conjointly can produce no rotation, but only deformation of the mass regarded as elastic.

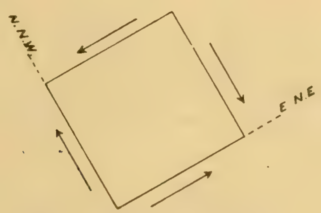


FIGURE 1—*Plan of vertical prism.*

It is quite possible that the couples actually involved in the dynamic action on the Sierra did not exactly balance, but if so the excess of one above the other must have produced an actual rotation about a vertical axis, and only that portion of the stronger couple which was exactly balanced by the weaker couple was employed in producing deformation and rupture of the mass.

The combination of two balanced couples is known as a simple shearing stress. It is possible for such a stress to exist alone, but, if it did so, it would be unattended by compressive action or by any horizontal or diagonal fissures. It is also difficult to see how the precise combination of forces needful to produce a horizontal shear by itself could have existed in a geological convulsion.

The slickensides and other evidences of great pressure in a horizontal direction indicate that the shear must have accompanied a thrust, and it is known that a simple compressive thrust involves shearing action. Now, when both the direction of the fissures and the direction of the relative motions along these fissures are taken into consideration, it can be shown that only a thrust acting at an angle of 45° to the fissures along that diagonal of the prism which strikes north-northeast to south-southwest would bring about the phenomena to be accounted for.

This I will proceed to show by a demonstration to be found in a somewhat modified form in treatises on elasticity, but which has not hitherto, to my knowledge, appeared in geological literature.

Analysis of a Thrust.—Suppose a cubical portion of the mass of granite of the Sierra, oriented as in figure 2*a*, to be subjected to a uniformly distributed pressure acting from the south-southwest, this pressure being opposed to a resistance in the opposite direction. Let the uniformly distributed pressure be represented by a single force P. This force P may be considered as

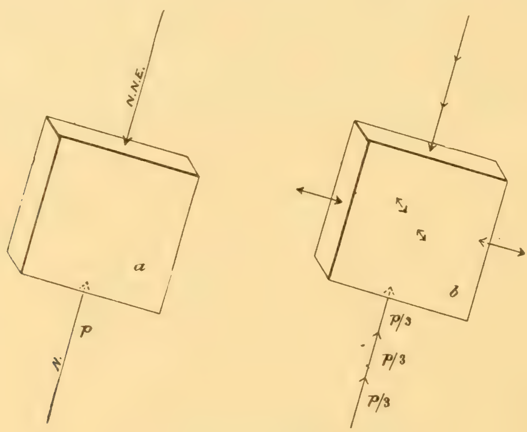


FIGURE 2—*Cube subjected to Thrust.*

divided into three equal parts, and one may also assume that other forces are applied to the cube, provided that these other forces exactly balance one another. Thus a normal traction $P/3$ may be applied to each of the lateral faces of the cube, provided that a lateral pressure $P/3$ is also applied to each of these faces. Such a system of forces is shown in figure 2*b*, and is exactly equivalent to the seemingly simpler system shown in figure 2*a*.

When the distortions of an elastic mass are small, the forces which produce them may be regarded as applied in any succession which is convenient. This is called "the principle of superposition of small stresses," which is applicable whenever the displacements produced are so small that all powers of these displacements higher than the first are so minute as to be negligible. It is only with such distortions that the mathematical theory of elasticity deals, as it is at present developed.*

* The theory of elasticity deals with such strains as occur in bridges, buildings, and machinery, not with deformations like those to be observed in masses of rubber or jelly. Suppose that an iron girder 100 feet long sags under a load to the extent of 1-20th of a foot; then the square of this flexure is 1-4,000,000th part of its length, which is inappreciably small relatively to the size of the mass.

In the case in hand, then, one may consider the effect of any portion of the forces shown in figure 2*b* by itself. Take, first, six forces, one on each face of the cube, all directed inwards and each equal to $P/3$. This group is shown in figure 3*a*, and, since each of the forces is supposed to be uniformly distributed over the surface, it is manifest that their effect will be to compress the mass without any alteration of shape. In other words, this group of forces represents a simple compressive stress, unaccompanied by distortion of figure.

There now remain eight forces, which may be separated into two groups of four. One of these acts in a plane parallel to $o\ x\ y$, as shown in figure

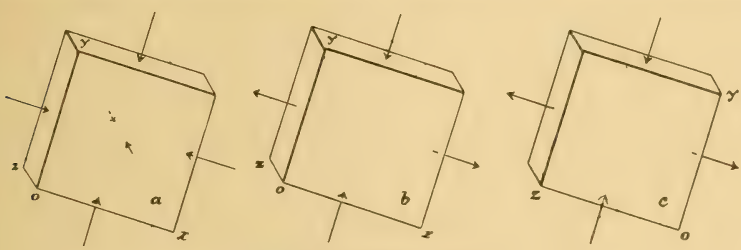


FIGURE 3—*Analysis of a Thrust.*

3*b*, and the other in a plane parallel to $o\ y\ z$, as shown in figure 3*c*. Thus the three diagrams of figure 3 show, in a segregated form, all the forces of figure 2.

The last two diagrams each show a pressure in one direction accompanied by an exactly equal traction acting at right angles to it. Now it was shown above that a pressure produces a cubical compression and, since traction is negative compression, a traction must produce cubical dilatation. Furthermore the compression produced by a given pressure is exactly equal to the dilatation produced by a traction of equal intensity. Hence no change of volume can be produced by the system of forces shown in figure 3*b* or 3*c*, and the effect of the system of forces, or the strain, must consist in a simple change of shape, *just as if the mass were incompressible.*

If the pressure of figure 3*b* were to act alone upon an incompressible cube of unit volume, it would diminish its height by an amount proportional to the pressure, according to the experimental result embodied in Hooke's law, "Ut tensio, sic vis," or strain is proportional to stress. Hence if n is a certain constant, called the modulus of rigidity, the force $P/3$ would shorten the unit cube by an amount $P/3n$. This contraction would be accompanied by an increase of the other dimensions of the mass, since the volume remains constant. Thus $o\ x$ and $o\ y$ would each be increased by a small quantity, say d, and the value of d is to be found from the equation—

$$1^3 = (1 - P/3n)\,(1 + d)\,(1 + d).$$

As was pointed out, the distortions are supposed to be so small that their squares may be neglected, and this is certainly the case with such material as granite; for suppose such a substance under pressure to undergo so great a linear contraction as 1 per cent. before rupture, then the square of this distortion would be only $\frac{1}{10000}$, which it would be very difficult to detect experimentally. Neglecting the distortions of the second order, the above formula reduces to—

$$2\,d = P/3n,$$

so that the elongation of $o\,x$ and $o\,z$ per unit length in consequence of the pressure is $P/6n$.

Turning now to the traction acting on the incompressible cube, it is evident that its effect is exactly analogous to that of the pressure with contraction substituted for elongation. Hence the traction will *decrease* $o\,z$ and $o\,y$ each by $P/6n$ per unit length. The line $o\,z$ is thus increased by the pressure and decreased by the traction in precisely the same proportion, or, in other words, this line is not affected in length by the system of forces represented in figure 3*b*.

Hence a compression $P/3$ accompanied by a traction $P/3$ at right angles to it, acting on a compressible cube, alters neither the volume of the body nor the length of lines perpendicular to the plane of the forces. The only effect is to diminish the height by $P/3n + P/6n = P/2n$ and to increase the breadth by the same amount.

Now the northeasterly and southwesterly forces of figure 1, if they could act alone (or if the mass were capable of deformation only in this direction), would tend to drag the mass into an oblique form, as shown in figure 4*a*, by shifting of layers. No change of area would accompany this distortion.

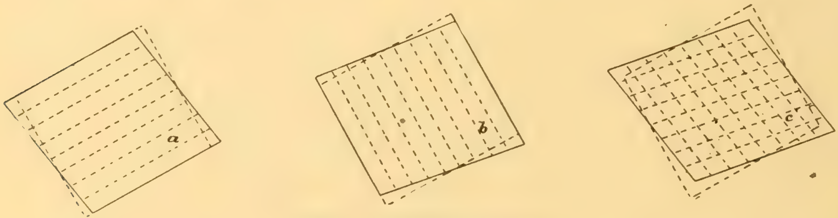


FIGURE 4—*Analysis of a Shear.*

Similarly the other couple would by itself tend to produce the distortion shown in figure 4*b*, again without change of area. Neither couple would have any tendency to change the volume. Acting simultaneously they would produce the distortion shown in figure 4*c*.

Thus the effect of the balanced couples of figure 1 is exactly the same as that of a pressure accompanied by an equal traction as shown in figure 3*b*, and these different diagrams are merely different methods of representing one and the same strain—a simple shear.

Result of a Thrust.—Collecting the results of the last few paragraphs, it appears that a simple horizontal thrust from the south-southwest will at least tend to produce three distinguishable effects : 1. A cubical compression upon which exactly one-third of the applied force will be expended ; 2. Two vertical sets of fissures, of which one will strike to the north-northwest and the other to the east-northeast ; 3. Two sets of inclined fissures striking north-northwest and dipping at 45°, one set to the east-northeast, the other to the west-southwest. On the vertical fissures the northwesterly wall would move in a southwesterly direction relatively to that opposed to it, and the northeasterly wall would have a relative motion towards the southeast. A thrust on a line striking at right angles to the direction assumed above would produce vertical fissures on the same surfaces, but it would also produce relative movements precisely the opposite of those observed. The hypothesis of a thrust in this direction is thus excluded. A thrust acting in any other direction would not produce vertical fissures striking either north-northwest or east-northeast, so that all such thrusts are also excluded. Thus, as previously stated, the observed conditions are fulfilled only by a thrust on a line striking north-northeast to south-southwest.

While this thrust will tend to produce the effects enumerated above, it by no means follows that all of these tendencies should be permanently traceable at any one spot. Solids such as granite offer great resistance to cubical compression and are almost perfectly elastic to this stress, so that when the pressure on the mass was relieved the fragments must have resumed their original volume. One can expect to find the tendency to cubical compression manifested only in slickensides and similar phenomena.

Were the granite ideally homogeneous in all its physical properties, were its surface a true plane, and were the thrust distributed with absolute uniformity, then all parts of the mass would reach the elastic limit at the same instant and all the fissures would form simultaneously. Of course, such ideal conditions could not actually prevail, and one should thus expect that in some localities one set of fissures would be developed either alone or in a preponderating degree, and that in other localities other fissure systems should predominate. Even in laboratory experiments, on the crushing of blocks of stone or metal, when all possible precautions are adopted to insure uniformity of conditions, the mass often yields only along a single plane. In the Sierra, on the other hand, at least two systems of vertical parallel fissures, as a rule, accompany one another, and they are often closely attended by associated inclined systems, dipping at 45°.

The vertical fissure systems I have studied with great care, as has been mentioned above, and their strike has been taken at almost innumerable points. I also noted the existence of the inclined fissures dipping at about 45° at many points, but, while in the field, I was under the impression that they were mere local irregularities, and I failed to take systematically minute notes of their strike. In some instances, at all events, the strike is very nearly north-northwest, and I am not aware of any exceptions. The inclined fissures are much less frequent than the vertical ones.

Conclusions as to horizontal Thrust.—On the whole, then, the vertical fissures, together with the character of the horizontal movements upon them and with the evident presence of compressive action, necessarily lead to the hypothesis of a thrust acting on a south-southwest to north-northeast line. This hypothesis also compels the inference that there must have been at least a tendency to the formation of two more sets of fissures, dipping at angles of 45°, and corresponding fissures have been observed. Thus the facts and hypothesis correspond, so far as is known, while further observations on the strike of the inclined fissures and on the relative movements of the walls of these fissures are requisite.

VERTICAL MOVEMENTS.

Resolution of Forces.—Turning now to the vertical movements, it will be remembered that on the vertical fissure system the northwesterly and northeasterly walls were found to have risen relatively to those opposed to them. If, then, one supposes a vertical section on a strike diagonally across the vertical prisms, or on a north-northeast to south-southwest plane, there will appear on this section parallel vertical lines, representing the corners of the prisms, as shown in figure 5.

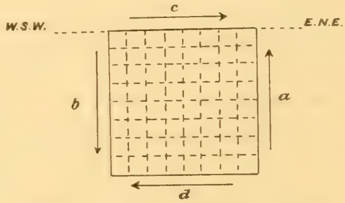


FIGURE 5—*Sectional elevation of Prism.*

Along these lines relative motion has taken place, as indicated by the arrows *a b*. These arrows show the relative direction of the forces, and may also represent their intensity. Unless they were balanced by a second couple they would produce a rotation instead of strain; and since the faulting is evidence of strain, there must have been a couple, *c d*, of equal intensity and opposed direction. The couple *c d* would tend to divide the mass into horizontal sheets, and the presence of horizontal partings in many parts of the area has been referred to. The vertical couple would tend either to produce the faulting actually observed on already existing fissures, or to produce fissures striking at right angles to the plane of the diagram; *i. e.*, west-northwest to east-southeast. Such fissures, if they exist in the area under discussion, have been overlooked, but were observed near Mt. Lola.

What Forces are indicated?—It is certain, then, that there has been such a shearing stress in action as is shown in figure 5, and the question is, How is it to be accounted for? It must arise in one of two ways. If it is a simple shear and not one feature of a compression, it has been caused by a vertical thrust opposed by a resistance not in a vertical line with it and represented by b or, what amounts to the same thing, it has been opposed by a vertical upward force not in the same vertical with it. These forces with a resistance to rotation represented by the couple c d would clearly give the observed result. On the other hand, if the shear is one feature of a compression, this must have acted downward at an angle of 45°.

Before making a choice between these hypotheses it is necessary to remember that the vertical and the horizontal movements took place simultaneously. This is proved by the scratches on the faulted surfaces, which are sensibly straight lines inclined to the horizon. They show that points originally in contact have moved apart in straight lines, or that the motions in a vertical and horizontal direction have been simultaneous. Hence, too, the forces acting on any particle were reducible to a single resultant, P, which acted either downwards from the south-southwest or upwards from the opposite point of the compass.

Any force P is resoluble into three components at right angles to one another, say X, Y and Z, and one may, if he pleases, take X and Y as horizontal and Z as vertical. The horizontal components may also be combined to a single horizontal resultant, say R, and when the effect of R has been determined it only remains to determine the effect of Z.

A vertical Couple.—Now in the preceding pages the direction and effect of R have been studied and only the vertical component Z remains. Hence an inclined force producing a compression accompanied by the shear of figure 5 is out of the question. Further, if Z were opposed directly by a resistance it would tend to produce four sets of fissures, all cutting the vertical at angles of 45°. Hence these vertical dislocations can be due only to the force Z acting against a resistance which is also vertical, but not in the same right line. This conclusion is of much importance, as will appear later.

The couple formed by the vertical force Z and the resistance tended to rotate the mass of the Sierra toward the Pacific ocean. It was opposed by a resistance to rotation so intense that hundreds of square miles of the territory were divided to an unknown depth into horizontal sheets of granite. Such action implies a vast expenditure of energy, and, since the distance through which relative motion took place was very small, the force which acted through the distance was also tremendous. The fact that in spite of this vast force the vertical fissure systems do not on the whole sensibly incline to the westward I shall discuss a little later.

Orientation of the Fissures.—I have shown that the existence of the vertical fissure systems attended by evidences of compression leads inevitably to the theory of a horizontal thrust, which is further confirmed by the occurrence of relatively rare fissures dipping at angles of 45°. Under appropriate limitations it should be possible to invert the argument and say that a horizontal thrust would produce the four fissure systems observed. But this is not immediately possible. Why should the vertical prisms not be replaced by others the axes of which would be perpendicular to the line of force, like those observed, but inclined to the horizon instead of vertical, dipping say to the east-northeast? Level surfaces cut the actual prisms in rectangles; they would cut the hypothetical prisms in rhombs.

Imagine a large cubical portion of the earth's mass with one face at the earth's surface subjected to a horizontal thrust evenly distributed over one of its vertical surfaces. This mass will resist distortion on account of its elasticity, but also because it is surrounded by other masses, and, further, it will, because of its weight, oppose any distortion which tends to raise the center of inertia. Now the horizontal thrust diminishes the volume and thus tends to lessen the opposition which surrounding masses offer to its distortion, but cubical compression of course leaves the weight wholly unaffected. Moreover, surrounding masses act only superficially on the large cube, while gravity is a "bodily" force acting on every particle alike. Hence when the mass is large, say of a volume of a thousand cubic miles, one would expect to find gravity a much more powerful obstacle to deformation than lateral confinement. If so, the mass would first yield in such a manner as not considerably to raise the center of inertia. Now the only way in which this could be accomplished is by shearing in a horizontal plane, which would tend to form vertical columns. This process, if carried out alone, would not raise the center of inertia at all.

Comparing this reasonable deduction with the facts, it seems to me that one may conclude with certainty that the vertical fissure systems were formed in that position and because gravity caused a greater resistance to fracture in every other direction than in this. This theory also explains the comparative rarity of the diagonal fissure system caused by the horizontal thrust.

The same theory has a bearing on the fissure systems formed by the vertical thrust. In this case horizontal partings could be produced without raising the sheets of granite, while the vertical fissuring and faulting by the vertical thrust component involved either the raising of a sheet against gravity or a downward movement into the underlying mass. When the vertical fissures and the horizontal fissures were once formed, the stress still present would be relieved rather by relative motion on these fissures than by the establishment of new ones.

Tilting of the Sierra.—The conclusion that an originally vertical system of fissures must have been formed in this portion of the Sierra leads to a means of judging whether it has been tilted towards the Pacific ocean. The tremendous couple which led to the vertical faults and the horizontal partings tended to produce such a movement. Had it effected a sensible rotation, however, the originally vertical fissures would now dip away from the coast; but my observations do not reveal such a dip. In a great number of cases I compared these fissures with a plumb-line without being able to detect any difference in direction even where they were exposed for a vertical distance of hundreds of feet. In other cases, indeed, the fissures are slightly inclined; but I observed no regularity in the direction of these divergences; they seemed to me due to local irregularities in the resistance of the rock.

Were such a tilting of the fissures observed, it might have taken place during the disturbances of which the fissuring itself was an early feature, or at any later period. I gathered some independent evidence that since the beginning of the glaciation of the region no such movement has occurred. Lake Tahoe appears to have been in existence since the earliest glaciation, since which time it has cut down its outlet about 300 feet; but the highest beaches which I have found are at sensibly the same elevation at the northern and southern ends of the lake and at its western side. The lake is now about 22 miles long and 12 miles wide, and its earlier dimensions were of course still larger. It thus forms an excellent self-recording levelling instrument. The highest terraces of the lake are nearly obliterated, but there are well marked intermediate benches which seem to be at uniform elevations above the present surface. It is possible that more exact measurements, such as I propose making, will reveal a difference of a few feet; but as the whole range is only about five times the width of the present lake, it seems to me impossible that the tilting should be considerable.

Erosion of the Gravels.—The hypothesis of the tilting of the range has been put forward by Professor Joseph Le Conte to account for the now well-known fact, recorded by Professor Whitney, that the modern rivers of the western slope of the range have eroded far below the level of the Pliocene streams in the beds of which the hydraulic gravels are found. It is therefore desirable for me to show that such erosion does not necessarily imply a movement inconsistent with the results drawn from my observations.*

* Professor Le Conte states "that the Sierra Nevada is a great crust block 300 miles long and 50 miles wide heaved and slipped on the eastern side, forming there a great fault of 15,000 to 20,000 feet vertical displacement, and that this took place at the end of the Tertiary accompanied by floods of lava. The evidence of this is found in the relation of the new to the old river beds. The rivers displaced from their old beds by the lava have since that time cut far deeper than before, although cutting far less time" (Amer. Journ Sci., 3d Ser., vol. XXXVIII, 1889, p. 261). On a previous occasion he recognized the fissuring of the high Sierra and its connection with volcanic phenomena, which again he ascribed to the elevation of the range (Amer. Journ. Sci., 3d Ser., vol. XIX, 1880, p. 190). In the same paper he says that he has observed many eruptive dikes in all the granite region above the lava flow, and these he regards as probably the roots of the flow (page 188). How the range could be tilted as a single block at the same time that its central portion was intersected by numerous fissures reaching down to volcanic foci does not seem to be explained.

The faulting studied in this paper has certainly increased the western slope of the range, for all the east walls of the fissures have risen relatively to the western walls. It must also have promoted erosion something as a westward tilting of the range would do. The influence of this distributed displacement on erosion must have been greatest where the fractional displacement was greatest, probably a little west of the present crest of the range. It must also have produced the greatest effect immediately after the faulting occurred. Now the faulting seems to have been contemporaneous with the eruptions, and to have extended throughout Pliocene times. Hence one would expect to find evidences of great erosion during the Pliocene, and particularly towards the crest of the range from which the surface material loosened by the fissures would be swept down to lower altitudes. One might plausibly infer that coarse gravels resting on relatively high slopes would result from such conditions. Now, independently of the fissure system, it is known that the Pliocene was a period of great erosion near the crest, and that enormous quantities of coarse gravel accumulated on the western flank of the range. Thus the faulting and the accompanying increase of slope are entirely consistent with other observations, but afford no explanation of the more recent deepening of the channels. In my opinion the effects of the faulting on the erosion of the range were exhausted during the Pliocene, nor does it seem to me that cañon erosion precisely like that observed would be produced by such faulting as forms the subject of this paper or by a tilting of the range as a single block. Uniform tilting would uniformly increase the grade of the streams flowing westward, and, as in the case of faulting, these would probably take up all the material they could transport high up towards the crest. This does not correspond to the phenomena to be explained.

While the modern rivers have eroded below the Pliocene channels, the deepening of the channels has taken place to a considerable degree only within certain limits of altitude. The plains of the great valley are as high or perhaps higher relatively to the mass of the range than at the end of the Tertiary, and the old and new channels substantially coincide in level when they reach the plains. In the higher mountains, too, the old and new water-courses seem coincident. Thus on the south fork of the Stanislaus, near the locality called Donnell's flat on the state map, columnar lava 40 feet thick occurs on the river bank and therefore close to the lowest portion of the valley. The top of the lava is covered with granite erratics, while the columns extend down to the level of the water as it stood in August last. This lava is thus of Pliocene age and the river, which is now only a few feet in depth, cannot have eroded more than two or three feet since that time. Several other similar cases occur within distances of ten miles from this point. In general in the glaciated region there is abundant evidence that the preglacial surfaces in the valleys or ravines were very little above those now exposed. It was the high exposures, peaks and cliffs, which furnished the moraines to be found at lower altitudes.

Thus the relation between the ancient and modern stream beds is that represented in the following diagram.

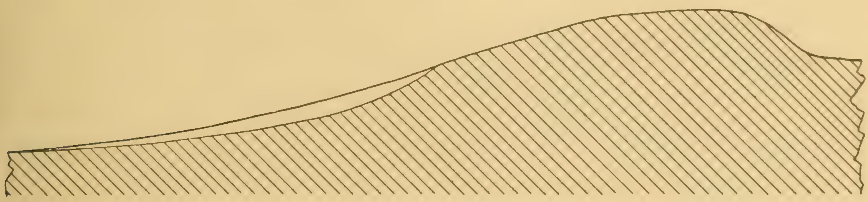


FIGURE 6—*Erosion by modern rivers.*

Erosion influenced by Ice Cap.—The climatic conditions affecting erosion during the Pliocene were very different from those which influenced it during the period of glaciation, and for this difference an allowance must be made. During the Pliocene there were no glaciers and probably little snow, if any. The rain must therefore have flowed down the mountain sides very rapidly, eroding them as it went. During the glacial period, on the other hand, the flats and valleys from 5,000 feet or less to the summits of the passes were deeply buried in ice and snow. The upper half of the range was thus protected from direct rain erosion, though subjected to the action of ice.

Some few geologists still believe that glaciers not only sweep their beds clear of loose rocks and soil and polish the solid underlying mass, but that they vigorously erode solid rock. In my opinion this theory is maintained in opposition to overwhelming evidence. Reference has already been made to some of the many facts indicating a trifling amount of erosion since a preglacial date in the higher part of the Sierra, and long before my examinations Professor Whitney reached the conclusion that the solid rock had been scoured rather than eroded by glaciers. It is more satisfactory, however, to observe what erosion modern glaciers actually effect than to infer what ancient ones accomplished. On this question Professor Albert Heim has no equal as an authority. A few of his conclusions, based upon his own fully described observations and confirmed by those of others, are as follows: "Advancing glaciers often leave even loose detritus undisturbed." This happens, he explains, especially where the glacial valley widens. "Under other circumstances, particularly in constricted valleys or where there are obstructions, the advancing glacier ploughs up the ground down to the solid rock;" but "it is only loose masses standing very much in the way which are pushed along by the glacier." "A glacier is unable to scour away even a small crag standing in its path." I have myself seen, in Switzerland, illustrations of all these statements. "So far," says Heim, "there is no proof whatever that these [Norwegian and Greenland] glaciers tear their ground moraines from rock in place." Finally, he concludes that "glaciation is equivalent to relative suspension in the process of valley formation."*

The action of the ice and snow fields on the Sierra during its glacial period was thus chiefly to protect the underlying rock from decomposition and erosion, and this action must have exerted an influence upon the erosion at lower altitudes. Imagine the range to-day to be covered with canvas down to 5,000 feet above sea-level. Then erosion could take place only below this level, and the only effect which erosion could produce would be to deepen the stream beds and cut steeper slopes than those which now characterize the topography. You may say that a canvas-covered range is highly hypothetical, but there are plenty of hills covered, if not with linen, yet with sheets of lava. The following diagram shows the outlines of two hills near Pence's ranch taken from photographs. They are near together, in the same formation, and the lower portion of each is composed of the same material,

FIGURE 7—*Lava-capped hill and bare hill.*

but one has a lava cap and the other has none. The unprotected portion of the lava-capped mass shows relatively very steep slopes, and one cannot doubt that if such protection were now added to the rounded hill its lower exposures would gradually assume contours similar to those of the mesa-topped butte.

The formation of the ice cap on the Sierra must have acted very much as the superimposition of a lava cap or a canvas cover would do on the rounded hill shown in the figure 7, or it must have produced an effect similar to that actually observed and indicated in figure 6. I do not think that the action of the ice cap can be pronounced quantitively insufficient to produce the observed effect. One has only to imagine this covering to have persisted for a sufficient time to produce any increase of general slope or any amount of cañon erosion. The great moraines form a rough index of the duration of the glaciers, and there is nothing seemingly unreasonable in supposing that while these vast masses were accumulating the observed cañon erosion might have taken place.

The subject may be regarded from a slightly different though nearly equivalent standpoint. During the Pliocene the waters flowing from the crest must have become loaded with detritus high up on the range and the coarsest portion of this load must have been deposited as soon as decreasing inclination or increasing width of the stream beds caused a slackening of

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*"Handbuch der Gletcherkunde," 1885, pp. 174–189.

the current, *i. e.*, along the lower half of the range where the auriferous gravels are found. The waters of the glacial period started from the ends of the glaciers at, say, 5,000 feet altitude with a very small load of finest detritus. They were consequently in a condition to take up detritus or to produce erosion at the same altitude at which the Tertiary streams were overloaded and deposited gravel.

The period which has elapsed in California since the glaciers disappeared is a very brief one, and the cañon erosion has no doubt been correspondingly small. The precipitation is of course also small relatively to that of the glacial period or of the Pliocene, and this explains the fact that in some cases cañon erosion is still apparently progressing. It is known that a falling stream erodes the deposits which it has made at high water; and it can be shown by appeal to observation as well as by simple reasoning that a relatively great rain-fall will tend to relatively great erosion of the upper part of a drainage system, while, *ceteris paribus*, a small rain-fall will expend most of its energy in eroding the lower part of the drainage.

As a final argument against the tilting hypothesis I may mention that there are preglacial gravels on the eastern slope of the range, *e. g.*, in the valley of the Truckee between Verdi and Carson. These gravels, like those of the western slope, show terraces, and the stream has cut through them to a depth of 100 or more feet. Tilting of the range as a rigid block 50 or 60 miles in width would of course diminish the eastern slope in the same proportion that it would increase the western slope, and if erosion were intensified on the latter it would be diminished on the former.

On the whole, then, I cannot concede that any important tilting of this portion of the Sierra has taken place at or since the post-Miocene disturbances.

Effects of the Fissures.

Effect of irregular Distribution.—A few notes may next be made with reference to the effects of the fissure systems on the course of events in the part of the Sierra here discussed. As has been mentioned, the distribution of fissures is not uniform. In many places one system or the other is highly and almost exclusively developed. Sometimes the rock is divided into very regular prisms of indefinite length, and again these are cut by horizontal partings into rectangular blocks. Finally there are areas in which the mass consists of polyhedral fragments.

The rate at which decomposition and erosion will take place clearly depends upon the frequency of the fissures of a system and the number of fissure systems developed in a given locality, for both erosion and disintegration vary with the amount of surface exposed per unit volume. Thus, where the granite is shattered into fragments of small size, disintegration will be rapid and heavy showers will move the blocks, while masses of large size will remain unmoved and decompose slowly. The patches and zones where the shattering has been relatively thorough will thus be carved into hollows and ravines, while the more solid parts of the mass will remain as hills or mountains.

Formation of Cañons.—The influence of these relations is very sensible in the Sierra and every step of the process can be traced on a large or small scale. The shattered zones commonly follow the direction of one of the main fissure systems, and so do many of the cañons, large and small; but the zones sometimes jump across from one set of fissures to another parallel set belonging to the same system, and so, too, do the cañons. Such zones also sometimes end abruptly—a fact due, no doubt, to variations in the composition of the rock. The cañons do the same.

Ice seems to have played a considerable part in clearing the cañons of fragments and in excavating shattered and decomposed patches, so that in a sense one must ascribe a large erosive effect to the glaciers; but the ice seems, nevertheless, to have been incapable of cutting into solid masses to any extent, or even into much fissured rock where little decomposition had preceded and where the blocks were tightly wedged together.

In many cases the glaciers have polished rock surfaces, the contours of which are so thoroughly characteristic of surface exfoliation, due to weathering, that no observer could doubt their character, and some of these surfaces are such that ice could not possibly have modeled them. Such evidence, together with that derived from the occurrence of glaciated lavas near the bottoms of the present cañons, indicates very clearly that the present system of cañons was established long before glaciation began, and probably during the warm and no doubt very wet Pliocene epoch.

In the area here dealt with there are gorges resembling the Yosemite valley in the most striking manner, though on a small scale, but so exposed as to show that their existence is due simply to local intensification of the shattering process. In one especially striking instance in the district known as Border Ruffian the gorge is on the east-northeast vertical fissure system, but the fissures are slightly inclined to the southward through some irregularity in resistance. Faulting has consequently produced irregular cross-fractures of the mass and reduced it to more than ordinarily small fragments. Weathering, water and ice have then done their perfect work and cut the mass down to the lowest possible level, leaving, however, the rocky floor exposed. The Yosemite, too, is on the same fissure system; the fissures there also are somewhat inclined, and the walls still show that the fragments are in part of unusually small size. The bottom of the Yosemite valley is occupied by alluvial deposits, but the floor of the deep alcove into which the Yosemite creek falls is solid rock. The Yosemite was once at least partially filled with ice, as was first pointed out by Mr. Clarence King. This has been questioned; but 18 months since I found a small amount of perfectly preserved glacial polish on the north wall. Ice, however, cannot have excavated this valley, for the moraines are of trifling extent, and facts enough have been adduced above to show that the glaciers of the Sierra have made no such cañons. If the fault system studied in this paper extends to the Yosemite, as the fissure system certainly does, the valley cannot be due to a local subsidence. On the other hand I can see no objection to the hypothesis that the shattered zone of rock was disintegrated and eroded in preglacial times, the process being completed by a glacier which left a small moraine near the entrance and thus converted the valley into a lake.

Formation of Domes.—Decomposition converts polyhedral fragments of granite into approximately spherical nodules found the world over; and I have on previous occasions examined the cause of the process, which, shortly put, is simply that the rate of decomposition varies directly as the surface exposed per unit volume. Similarly a prism of rock projecting from a surface is reduced to a more or less mammillary or dome-shaped mass. The following figure shows such a mass about five feet high near Dumont meadows, at a locality where the prismatic fractures are very pronounced.

In these instances examination makes it perfectly clear that the modelling is directly dependent upon the fissure systems from which decomposition has

FIGURE 8—*Weathered end of Prism.*

proceeded, and, as has been shown in the earlier part of this paper, the fissure systems are those to be expected in a mass which on a large scale is to be regarded as homogeneous. Thus these rounded forms are not due to anything like ball structure or flow structure.

From such little masses as shown in figure 8 to immense masses similarly modelled there is every possible transition, and the great domes of the Yosemite region seem to me simply the other end of the series. These, when their surfaces are perfect, show no fissures, and wherever cracks are formed in them rounding of the edges and corners made by the cracks commences at once.

The gigantic domes are found only near the Yosemite and to the southward, but there are domes of considerable size between the Truckee and the Stanislaus.

Origin of the Forces.

Thesis of a solid Earth maintained.—Thus far I have discussed the fissures, their immediate cause and their effects; but I have made no reference to the origin of the inclined thrust to which the existence of the fissures was traced. I now desire to show that this thrust can be satisfactorily explained, provided the earth be regarded as a solid mass of extremely high viscosity which would yield slowly to relatively moderate forces of constant terrestrial direction and long duration, but which would probably yield almost imperceptibly to any force of brief duration or rapidly changing direction.

Direction of Subsidence.—Without assuming any hypothesis as to the fluidity or solidity of the earth's interior, let it be assumed that the globe tends to a condition of hydrostatic equilibrium and that at one particular period of time it had reached such equilibrium. Now when the equilibrium is perfect, imagine a certain mass removed from the surface of one region, *A*, and piled upon some other region, *B* *.

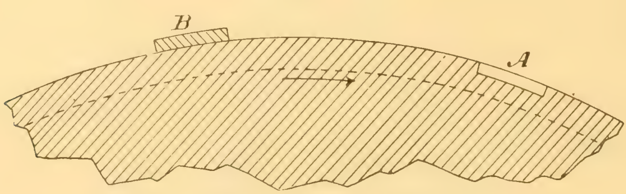

FIGURE 9—*Disturbance of terrestrial equilibrium.*

Then a tendency to reëstablish hydrostatic equilibrium would at once assert itself, and material would begin to flow from beneath *B* towards *A*. The mass at *B* would sink into the globe and the cavity at *A* would fill up.

Now let it be supposed that the earth's mass below the dotted line of the figure were a substantially perfect fluid. Then, as the fluid was displaced by the sinking at *B* it would flow over towards *A* by the shortest possible path. In doing so there would be a tendency to frictional resistance between the moving fluid and the supernatant mass. But the fluid being substantially a perfect one, the friction which its motion would induce would be

* Precisely this case does not occur in nature, but erosion produces results which are equivalent to it so far as the disturbances of equilibrium are concerned, as will be pointed out a little later.

substantially *nil;* for the ideal perfect fluid is the one which offers no resistance to a shear. Of course there is no such substance as a perfect fluid; but it is manifest that such a liquid as water under these circumstances would move with very little friction and exert only an excessively minute lateral pressure on the mass below *B*. Thus, if the earth's interior were of water-like fluidity, the mass under *B* would sink in a substantially vertical direction.

On the other hand, if the earth's interior were a viscous substance, like asphalt, the transfer of material from below *B* to *A* could not occur without overcoming great resistance. The viscous material would thus drag the mass underlying *B* with it towards *A* to a certain extent, and *B* would no longer tend to sink in a substantially vertical direction, but in a line of least resistance, inclining towards *A*. The angle which this line would make with the vertical would increase with the viscosity up to a certain limit.

It is important and very easy to determine a limit which this angle cannot surpass. The viscous resistance is a horizontal force due to a vertical pressure. Now this resistance certainly cannot exceed the pressure which excites it; in fact, it must always fall at least a little short of the pressure. But if one imagines the horizontal traction quite equal to the vertical pressure, the mass under *B* will move under the influence of two equal forces, one vertical and the other horizontal, and will therefore tend to sink at an angle of 45°. Thus, under no circumstances can the center of inertia of the mass at *B* tend to diverge from a vertical line more than 45°.

Experiments on Subsidence.—On the basis of these deductions I have made some rough experiments. Fancy a vessel containing some such substance

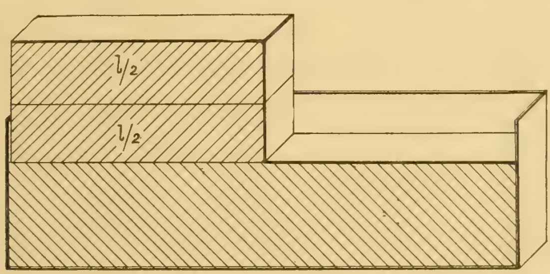

FIGURE 10—*Experiment on Subsidence.*

as hard tar with a level surface carrying a uniformly distributed load, *l*, and then let half of the load be removed from one half of the surface to the other. Then the conditions will be those represented in the diagram, figure 10. The load should now tend to sink into the mass in a slanting direction, if the argument presented above is correct, instead of subsiding vertically, as it would do in a perfect fluid. On trying this experiment with oiled asphalt and with coal tars I found that the weight did sink in the manner expected, so that the masses assumed a position about as shown in figure 11, the surface of the load remaining sensibly horizontal and the unloaded portion of the viscous mass being compressed laterally. It is also possible to measure the horizontal component of the force by attaching to the load a cord passing over a pulley and adding just enough weight to the vertical end of the cord to keep the load from diverging from simple vertical motion. With a tar which yielded to the pressure of the finger about as easily as the softest

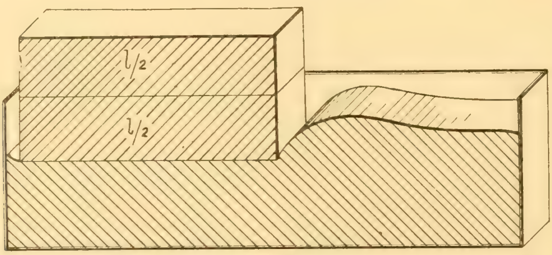

FIGURE 11—*Result of Experiment.*

India rubber, I found by this means that the horizontal traction was $7\frac{1}{2}$ per cent. of the load. The experiment was much too rough to make this percentage of any value except as showing that the horizontal traction, even in a very soft mass, is a considerable fraction of the weight.

My tar was a very soft one, but it differed from a perfect fluid in the same sense as other viscous substances do, though to a smaller degree than most of them. The experiment might have been made with hard asphalt or sealing wax if it had seemed worth while, but qualitatively the results must have been the same, while, had pressure enough been applied to produce deformation at the same rate, these substances must have given a larger angle of deflection from the vertical and a larger horizontal traction.

Direction of Upheaval.—In my experiments I found that if after a considerable deformation had been produced all the weights were removed excepting a very thin and light one, this would return to substantially the same position which it occupied at the beginning of the experiment, however often the experiment might be repeated. This was entirely expected, for just as it was shown that on a viscous earth the mass at B in figure 9 must be impelled by a force directed downwards and with an inclination towards A, so it can be proved that the force acting on the bottom of the pit dug at A must be upwards and away from B.

Geological Application.—The geological application of these inferences and experiments is obvious. That the earth tends to an isostatic condition, or to a condition of hydrostatic equilibrium, is shown by pendulum experiments and by many geological observations. It is also a manifest fact that erosive action removes masses of material from some limited areas and deposits them upon others. To restore isostacy these masses must sink in their new positions. If the earth's crust has a fluid substratum they will sink vertically, unless some force independent of erosion and gravity is brought to bear upon the transported material. But if the earth is a solid though viscous mass, the sedimented areas will not sink vertically and the denuded areas will not rise vertically.

In the following diagram (figure 12) let the dotted line represent in vertical cross-section a range of mountains and a valley in an isostatic state (so that the irregular surface is wholly due to difference in density). Let erosion remove a mass, *a*, from the range and deposit it in the valley at *b*, so that the outline becomes that shown by the full line. Then, provided the earth

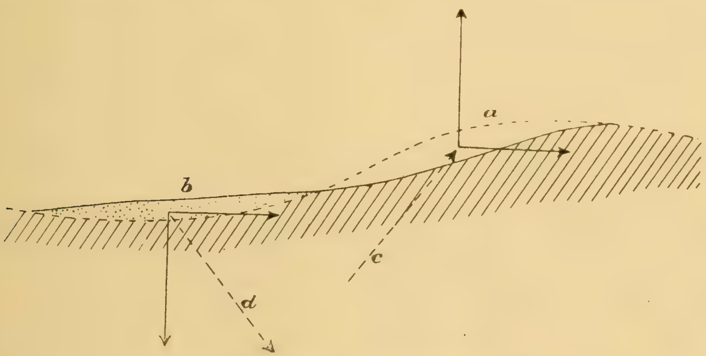

FIGURE 12—*Analysis of Upheaval and subsidence.*

is viscous, diagonal forces *c* and *d* will act on the two areas. These may be resolved into vertical and horizontal components, as shown in the diagram. The two horizontal components then coöperate to produce a compressive horizontal thrust on the range. The two vertical components, on the other hand, form a couple, tending to tilt the range towards the valley.*

If now there is a resistance to this tilting, as there surely would be on a solid globe, this resistance would also form a couple. Then the system of forces would be as shown in figure 13 on page 74.

Application to the Sierra.—This system of forces is precisely that which my analysis of the fissure system in the Sierra shows must have existed there. Figure 12 also represents such a configuration as the Sierra and the great valley of California must have had during the Pliocene. One point, however, requires a few words of explanation. The trend of the Sierra and of

*In any such deformation of the globe there will be certain strains falling entirely within the elastic limits of the rocks involved. The principles of viscous flow and isostacy are, of course, inapplicable to these strains, which are probably small. See Mr. G. K. Gilbert's "Lake Bonneville," U. S. Geol. Survey Monograph I, 1890.

the great valley is about northwest to southeast, and it would be natural to suppose that the right line connecting the center of inertia of the eroded area and the center of inertia of the sediments of the great valley would strike at right angles to this trend. The strike of the thrust, on the other hand, was determined at south-southwest to north-northeast.

At present the rain-fall is far smaller towards the southern end of the range than in its more northerly portion, and such, too, seems to have been

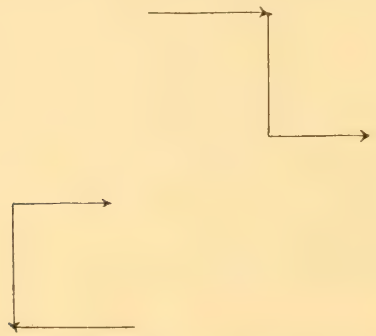

FIGURE 13—*Forces involved in upheaval and subsidence.*

the case during the period of glaciation, for the glaciers were much less extensive to the south than to the north. During the Tertiary the greater abundance of gravel to the northward is at least consistent with a similar distribution of precipitation. Hence erosion was probably greater towards the north. The deposits of the great valley, on the other hand, form an almost level plain, seemingly the bottom of a shallow Tertiary gulf.

It seems, then, that much of the material derived from the northern end of the range must have moved down the valley to the southeast. This transfer would evidently deflect the line of thrust towards the meridian.

Thus the theory that the earth is a solid, highly viscous mass is in all respects compatible with the observations, fully explaining every one of the six fissure systems, the faults observed, and the enormous resistance to tilting which the range has displayed.

WASHINGTON, D. C., *November*, 1890.

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THE PHOSPHATE DEPOSITS OF THE ISLAND OF NAVASSA.

BY EDWARD V. D'INVILLIERS.

CONTENTS.

The Physiography of the Island.

Geographic Position.—The island of Navassa is situated in latitude 18° 25′ north and longitude 75° 5′ west of Greenwich, in the Windward Passage channel, between the islands of Hayti on the east and Jamaica on the west, and about 1,300 miles from New York. Its discovery is generally credited to Captain E. K. Cooper, a Baltimore sea captain, who, at least, in 1857, placed it under the protection of the United States flag.

The extreme length of the island, between its northwestern and eastern points, is 2¼ miles (11,700 feet), and its greatest width is 1⅓ miles (7,250 feet). The island is shaped something like a pear, with the stem to the westward.

The small sketch map forming figure 1, drawn from surveys in 1803 by Captain R. Owen, of the English service, and printed in 1856 by the French Marine department, shows with sufficient accuracy the varying outline and indentations of the shore line. It is the only chart showing the soundings and the approximate location of the surrounding reef that could be obtained.

Configuration.—A reef surrounds the island at a distance of about 2,000 to 2,300 feet from the cliff, except on the western side, where it extends out for over 4,000 feet from the present shore line. The soundings, expressed in meters (1 meter = 3.397 feet), show the depth of water on this reef to vary from 22 meters along the western shore to about 36 meters along the edge of the reef, except at one point at the extreme western end of the island where a small local reef is covered in places by only 3 to 7 meters of water. Immediately outside the reef line the depth of water increases rapidly to 45 meters, or 153 feet, with a steep sea slope.

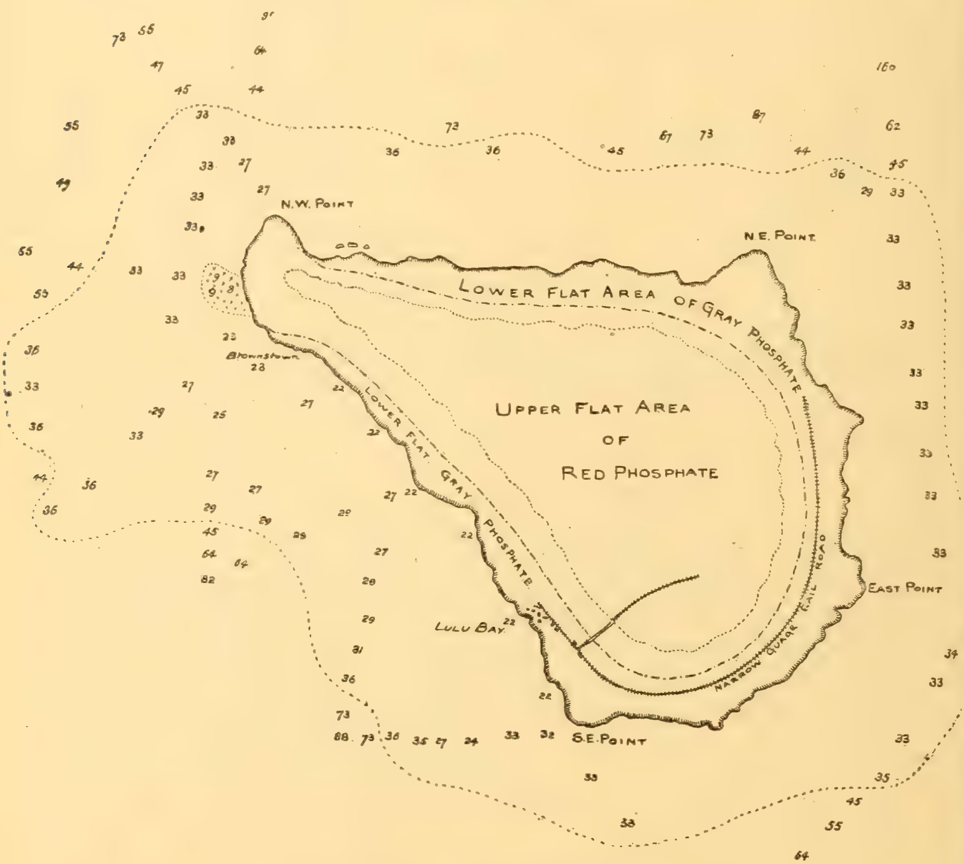

FIGURE 1—*Map of the Island of Navassa, West Indies.*
Scale, 1:40,000, or about 0.6 mi. = 1 inch; soundings expressed in meters; magnetic declination (in 1862), 4° 2o′ E.

The northern side of the island, while greatly indented, presents from the sea a comparatively straight face, 7,500 feet long, between the two prominent northwestern and northeastern points, the former being a rounded knob with steeply inclined flanks rising to 150 feet above the sea level and the latter a sheer vertical cliff 35 feet high to the first terrace.

The whole island seems to have a northwesterly slope. On both sides of the high knob just mentioned the cliff is only 6 to 8 feet high to the first terrace—so low, in fact, that during a calm sea it is entirely practicable to land there in a small row-boat. But from these points eastward the height of the cliff increases to 60 or 70 feet, and on top of this cliff is the lower terrace or flat carrying the gray phosphate, one of the two commercial grades of phosphate found on the island. This terrace, as the sketch map will plainly show, increases in width as it rises eastward, from a few yards near the western knob to fully 300 yards at the eastern end of the island.

From this lower terrace the island rises on a 30° slope to about 220 feet above sea level, forming two opposing walls on either side which, coälescing in the western knob, gradually separate eastward to encircle an oblong, oval area, slightly depressed between the walls. This is the upper flat or terrace, containing the red phosphate of the island.

The greatest elevation on the island is 255 feet above sea-level; but the average elevation of the upper terrace or flat is not over 230 feet.

Lulu Bay, the site of the present settlement and shipping wharf, is situated on the southern shore around a small opening in the cliff, 300 feet wide. The name is a misnomer, as there is no bay whatever, the sea beating continuously against a 60-foot cliff, and gradually undercutting it. The depth of water here is at least 10 fathoms, and the absence of good harborage, no less than the difficulties attending the transportation of the material from the diggings to the wharf, have in the past greatly retarded shipments.

Geology.—The entire island is of recent geological age, and is formed wholly of coralline limestone of several varieties. Superficially this rock, throughout the island, is characterized by a pock-marked, honey-comb structure, with sharp, uneven surfaces. Indeed, everything points to its coralline growth and its subsequent elevation, as opposed to the volcanic origin sometimes suggested. At least a dozen different varieties of coral rock were gathered during my brief stay on the island, besides a number of shells.

Externally the whole island presents a rough, uneven surface, often difficult and dangerous to walk over after removal of the phosphate. But the underlying rock is compact and close grained, and exhibits a partial stratification, well seen in the numerous caves and sink-holes which abound in the different parts of the island. In these caves, whose sides, being less exposed to weathering, present regular surfaces of white and blue limestone, the occurrence of stalactites hanging from the roof was frequently noticed, although the stalagmitic growth was largely concealed by a deposit of excellent gray phosphate, said to be very rich in phosphoric acid, but of which the supply is naturally somewhat limited. Several of these caves are from 60 to 70 feet deep. The limestone on the top and making the flanks of the central hill of the island is usually of a distinct color, in places a deep blue; while that making the lower flat is more commonly white in color. Both varieties of limestone, wherever exposed, give off a ringing, metallic sound when struck, and are quite brittle; but when burned both give a white powder. Holes and shafts, sunk on the upper flat, show the limestone, under good cover, to exist as a pure white stone, often amorphous carbonate of lime.

The topography of the upper terrace suggests a lagoon character, inclosed by a coralline limestone wall on all sides, the interior shut off by it from all further encroachments of the sea, which, as it slowly dried up, gradually filled with phosphate (guano) and became elevated enough to support a meager growth of cactus, stunted palms and a few small trees, while extracting from the stagnant sea water the various ingredients it carries in solution—potash, soda, iron salts, etc.

The irregular growth and spread of the coral limestone connecting the surrounding main reef wall is well displayed wherever the phosphatic material has been removed, showing a mass of pock-marked limestone, filled with roughly cylindrical holes and trenches.

In places the phosphate is so intimately mixed with the limestone as to give the latter a conglomeratic appearance, especially well seen near the border of the main surrounding reef, where attrition was greatest.

Subsequent elevation of the island has exposed the original sea slope of the reef until a later phosphate deposit took place at or near sea level, represented now by the lower terrace, which is from 150 to 900 feet wide; and as the greatest elevation of the island has been towards its southeastern side, it is there that we find the lower terrace the widest. Unlike the upper flat, this terrace could never have been an enclosed lagoon, but was continually exposed to the sea wash until it, too, was gradually lifted to its present position, 10 to 70 feet above the water. Erosion was therefore more complete here, and leaching of the phosphate by rains and winds was carried on with less interruption than upon the enclosed top of the island; therefore it is in the lower-flat (gray) phosphate that we find the least percentage of sesquioxide of iron and alumina, because here the sea water carrying them in solution, unlike that of the upper enclosed lagoon, escaped quickly and thus diminished the amount of their precipitation.

Climate and Vegetation.—Navassa, like other islands near the equator, is not exposed to continued rain storms and has no protracted rainy season. Moreover, the absence of all fresh water has still further favored the preservation of the phospate deposits, and accounts for the absence of soil and the stunted growth of timber, as well as for the presentation of the phosphate earth, without cover, in the condition most favorable for its economical extraction.

The yellow plum, india-rubber tree, iron-wood, cactus and century plants (the latter 15 to 20 feet high) and a profusion of scrub palms and a rank grass make up the principal growth; but nowhere do any of the trees grow to sufficient size to furnish merchantable timber, nor in sufficient abundance to at all present the appearance of tropical growth.

Character, Variety and Methods of Occurrence of the Phosphates.

Principal Varieties.—There are two principal varieties of phosphate mined and shipped from the island: 1. A *gray phosphate,* confined to the lower flat, from 30 to 300 yards wide and from 10 to 70 feet above sea level; 2. A *red phosphate,* occupying the oval flat on the top of the island, an area about two miles long and varying in width from a half mile near the center of the island to about 2,000 feet at the southeastern end and 500 feet at the northwestern end. The upper flat is further subdivided by barren strips of limestone, locally called "white rock reefs," into seven districts or "fields" and as many smaller distinct pockets, in addition to a great number of individual areas not sufficiently large or prolific to merit special distinction but which taken collectively will furnish a large amount of phosphate. The lower flat, on the contrary, occurs as one distinct deposit completely encircling the island except at its extreme northwestern point.

To the eye the only distinction between the two varieties is the difference in color; but the gray phosphate is the better grade, containing from 10 to 15 per cent. more of phosphate of lime and a comparatively low percentage of sesquioxide of iron and alumina, of which this gray variety may, however, contain anywhere from 5 to 15 per cent.

Perhaps 85 per cent. of both varieties occurs as soft earth, made up of rounded oölitic grains, forming, when dried, a coarse granular powder. The balance, or 15 per cent., occurs as hard rock, generally attached to limestone walls of the individual pockets, but occasionally found as undecomposed lumps within the body of the softer earthy phosphate. Under a lens these lumps show a dense mass of closely cemented oölitic grains, frequently so coarse and so loosely held together as to plainly show the granulated structure of the rock to the naked eye. In digging this rock variety, striking bars and dynamite must be used, and it is often hard to separate from the attached limestone; but the softer material yields readily to scrapers, picks and shovels.

Systemic Character.—In Bulletin 48 of the United States Geological Survey, "*The Nature and Origin of Deposits of Phosphate of Lime,*" by R. A. F.

Penrose, Jr. (1888), all phosphates are divided into two general classes, with the following subdivisions:

1. *Mineral phosphates*, embracing
   - Apatites,
   - Phosphorites;
2. *Rock phosphates*, embracing
   - Amorphous nodular phosphates,
   - Phosphatic limestone beds,
   - Guanos
     - Soluble guanos,
     - Leached guanos,
   - Bone beds.

"The former includes all deposits of phosphate of lime which, besides having other properties inherent in a true mineral, have a definite chemical composition or at least show a strong tendency toward such properties and composition. The latter includes the deposits which, having no definite chemical composition and lacking the homogeneous nature and other fixed characteristics of a true mineral, cannot be classed with mineral phosphates."

Such classification is necessarily somewhat arbitrary; but under its plan the Navassa phosphate would be placed in the second class, and under the subdivision of "*leached guano*"—*i. e.*, a deposit composed largely or entirely of animal excrement, the soluble constituents of which have been leached by the action of rain and sea water, and the remainder converted into a mass insoluble in water and varying in consistency from a loose powder to a hard, compact rock.

Many of the West Indies, according to the same authority, contain deposits of leached guano, among other islands mentioned being Sombrero, Turk, Aruba, Curaçoa, Orchilla, Arenas, Roncador, Swan, the Pedro and Morant keys, and some of the coral islands and reefs of Maracaibo gulf.

The character of the phosphate on these several islands varies greatly, and were it not for the large percentage of sesquioxide of iron and alumina that is frequently found these phosphates of the West Indies would be much more desirable than they are for the manufacture of fertilizers.

Method of Occurrence.—The method of occurrence of both varieties of Navassa phosphate is precisely similar. The material occurs in cavities and fissures in the surface of hard, gray, white and blue limestone, and while there is generally no connection between the irregular, cylindrical pockets and narrow, crooked fissures, they show throughout the island a tendency to rough parallelism, trending about north 20° west and south 20° east. The cavities are rarely over four or five yards wide on the surface, and are often found only sufficiently large to admit a man's body. Occasionally several individual pockets, divided by barren limestone at the surface, may come together ten or fifteen feet beneath the ground and create one large, circular opening. The holes and trenches, indeed, show every conceivable variation of form and outline, and though ordinarily very rough, holes shaped like inverted, truncated cones were seen sometimes with their sides smooth and even as if worn and ground by eddying waters.

The line of demarkation between phosphate and limestone is generally very sharp though always irregular, and there is no difficulty, with but ordinary attention, in thoroughly separating the rock.

The yield of phosphate from the individual cylindrical pockets varies usually from two to ten tons as the depth varies from five to twenty feet; but in many places, where the depth was increased to thirty feet by the coälescence of several small pockets, the yield has been very much greater, one such hole on the lower flat having contained nearly 300 tons, while another in the upper flat furnished upwards of 1,000 tons.

Experimental shafts were sunk at several points on the island to determine whether the phosphate occurred below the general line of the surface pockets. One such shaft, started on the top of the upper terrace 248 feet above sea-level, was carried down 251 feet, and when abandoned held from 12 to 36 inches of salt water at the bottom. It failed to show anything but limestone of a remarkably pure white color, much of it amorphous and not roughened like the surface rock. The smaller shafts were likewise non-productive. I therefore conclude that while phosphate may be found to extend below the general depth of the field at some few individual points, such cases will be exceptions to the rule, which limits the depth on either flat to about twenty feet, varying from that figure to only four or five feet.

Chemical Character of the Phosphates.

Composition.—No very complete records of the chemical character of the two varieties of phosphate found on the island seem to be available. The composition varies considerably; the gray perhaps averaging 65 to 70 per cent. bone phosphate, and the red 50 to 65 per cent.

A rather recently shipped sample of the gray variety showed, upon analysis, the following result, which may be said to fairly represent the character of the material which finds its way into commerce:

Analysis of Gray Navassa Phosphate.

	Per cent.
Water, at 100 C.	2.33
Organic matter and water of combination	7.63
Lime	34.22
Magnesia	.51
Sesquioxide of iron and alumina	15.77
Potash and soda	.86
Phosphoric acid	31.34
Sulphuric acid	.28
Chlorine	.15
Carbonic acid	1.84
Silica	4.53
Bone phosphate	68.46
Bone phosphate (dry basis)	70.09

This sample, which came from the "diggings" August 13, 1890, was analyzed by Dr. W. J. Gascoyne, chemist.

A sample of the red variety (dried) taken by myself from the drying house in July, 1890, gave the following results upon analysis in the laboratory of the University of Pennsylvania:

Analysis of Red Navassa Phosphate.

	Per cent.
Loss on ignition	14.223
Lime	23.090
Magnesia	(Trace)
Sesquioxide of iron	9.796
Alumina	18.425
Phosphoric acid	29.779
Sulphuric acid	1.160
Carbonic acid (by difference)	3.527
Bone phosphate	65.037

Numerous partial analyses of the red variety have shown moisture from 6.71 per cent. to 9.10 per cent., and bone phosphate from 49.69 per cent. to 55.84 per cent.; but such samples were not thoroughly dried.

Moisture.—In addition to the somewhat varying percentage of phosphoric acid, iron and alumina, another qualifying feature of the Navassa phosphate is its moisture. A shower of short duration soon converts it into a sticky mass, difficult to dig, handle and transport.

Experience has demonstrated the fact that the phosphate earth cannot be dried properly under cover, and hence the practice prevails of piling the newly dug material in long heaps about 10 feet high, when exposure to wind and sun brings about such a reduction in moisture as enables it to be conveyed to storage houses near the wharf, there to await shipment. Once put under cover dry, it can be kept dry. Of course the water of composition is chemically combined and cannot be decreased by such means; but owing to the great swelling which ensues while the material is moist it becomes absolutely necessary to thoroughly wind-dry it before storing or loading into vessels.

To determine the real effect of moisture more definitely I took three samples of the red phosphate from approximately the same locality, measured them into a box 1 cubic foot in capacity, and weighed with the following results:

No. 1. Freshly dug phosphate earth from near surface—weight, 63 pounds.

No. 2. Phosphate from edge of exposed drying pile—weight, 68 pounds.

No. 3. Phosphate from dried pile in storage-house—weight, 89 pounds.

Therefore a cubic yard of the same materials would show weights respectively as follows: 1,701 pounds, 1,836 pounds and 2,403 pounds, making a difference of 41½ per cent. between the freshly dug and thoroughly dried phosphate. A cubic foot of the red rock phosphate weighed about 79 pounds; the gray material weighs from 5 to 8 per cent. more.

Area and Tonnage of the Phosphate Deposits.

Careful planimeter measurements of the phosphate areas, based upon instrumental field work, show the island to have originally contained about 244 acres of gray phosphate, confined to the lower flat, while of the upper flat red phosphate there were originally nearly 300 acres.

Of the gray phosphate area perhaps one-half has been exhausted during the last thirty years of development, yielding about 2,000 tons an acre; 95 acres have been partially worked over and should still yield about 400 tons an acre, while 32 acres is virgin territory, from which the yield may be estimated at 1,500 tons an acre.

The red phosphate areas have scarcely been drawn from at all. An estimated area of about 40 acres already worked out is said to have furnished about 45,000 tons, and from this and correlative testimony these upper fields may be expected to yield an average of 1,000 to 1,200 tons per acre.

The principal deposits on the upper part of the island have been divided into seven large districts or "fields;" but the surveys demonstrate the existence of at least fifty-six additional separate areas, varying from a few square feet up to 165,000 square feet (or four acres) in area, the aggregate of whose yield in tons will be considerable.

Mining and Transportation Facilities.

The present methods of digging, transporting and shipping the phosphate material are extremely crude and expensive, and have no doubt been largely the result of plans originally adopted when the material dug occurred close to the present wharf. The company, however, contemplate a radical change in the manner of transporting the phosphate from the diggings to the wharf and vessels, though it is extremely doubtful whether the conditions under which the material exists will justify any change in the system of mining. From the wharf a narrow-gauge railroad track about $1\frac{3}{4}$ miles in length extends along the lower flat to the present diggings, being advanced as the phosphate is exhausted. Cars 12 feet long and 4 feet wide outside and $9' \ 1\frac{1}{2}'' \times 3' \ 9'' \times 1' \ 5''$ inside, holding about 50 cubic feet of phosphate, are shoved by hand from the diggings to the wharf, where the material is stored in covered houses.

The phosphate rock is readily extracted from a series of contiguous pockets, though at a considerable discomfort sometimes to the laborer, who frequently has an opening only large enough to squeeze his body into, affording scarcely room enough to scrape or dig out the material. Occasionally, when the phosphate is hard, striking bars from a foot to fifteen inches long are used to cut it loose from the surrounding limestone wall, while often it is necessary to resort to dynamite to effect the same purpose. When the phosphate is loose and earthy, which is the character of nearly 85 per cent. of the deposit, short iron scrapers or scoops are used, when the material is thrown into a cylindrical can and drawn to the surface; here it is filled into a box-tray holding about half a ton and placed conveniently to four or five holes; thence it is wheeled to the drying pile beside the railroad track. In rare cases the phosphate holes become large enough to admit several men at one time, when pick and shovel can be brought into service and the yield per man greatly increased; and this would seem to be more frequently the case on the upper (red phosphate) flat.

In partially dug fields it has been found possible to average about two-thirds of a ton per day per man, mostly rock phosphate; but in a new, untouched area the yield is about $1\frac{1}{2}$ tons per man. From the storage house the material is thrown into hoppers on the wharf 47 feet above sea-level, and from there it is drawn through long sheet-iron chutes into lighters, carrying about $3\frac{1}{2}$ to 4 tons, and thence conveyed to the ship.

The work so far done on the upper flat is carried on in very much the same manner, the material being conveyed in cars to the edge of the cliff and dumped there through a chute 194 feet long to cars on the lower track, and thence to the storage house. The two varieties of phosphate are stored in different compartments near the wharf and drawn from at will. Each lighter, of which there are at present seven, is manned by five men, and during good weather is capable of making two round trips an hour to a vessel moored from quarter to half a mile from the shore. As the average load carried cannot be over 4 tons, the loading capacity under the most favorable circumstances of wind and weather would be about 75 tons a day of 10 hours for each lighter in service. The sea current is generally so strong and the swell so great that this output is rarely maintained for two consecutive days, and the material when dry is constantly exposed to loss in its frequent handling, blowing away in clouds of dust. Still, with all the disadvantages under which the company labors, compelled as it is to transport men, food and materials of all kinds from the United States, and greatly handicapped by the lack of sufficient appliances for landing and utilizing the same, a considerable annual output is regularly maintained; and if the plans now in contemplation, looking toward a more rapid and economical movement of material from the pits to the vessels, are carried into effect, the output can be readily trebled and the cost very materially decreased.

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A LAST WORD WITH THE HURONIAN.

BY ALEXANDER WINCHELL, LL. D., F. G. S. A.

(*Read before the Society December* 30, 1890.)

CONTENTS.

Citations from the Founders Touching the Typical Area.

In entering on a fresh discussion of the Huronian system * it appears desirable to show, by documentary citations, what were the conceptions of the founders of the system.

Murray's earliest Description.—The term "Huronian" was based on the name of Lake Huron, along whose northern shores, and contiguous thereto, the rocks are located to which the name was first applied. The earliest description of these rocks was by Alexander Murray, in 1848.† He says:

"The older groups observed consist, firstly, of a metamorphic series, composed of granitic and syenitic rocks in the forms of gneiss, mica slate and hornblende slate, and, secondly, of a stratified series, composed of quartz rock or sandstones [‡], conglomerates, shales and limestones, with interposed beds of greenstone. * * * On a cluster of small islands * * * granite was found breaking through the quartz rock. The color of the rock was red. On one of the islands, quartz beds on opposite sides of the granite were observed to dip in opposite directions, north on the north side and south on the south side, at an angle of 70° or 80°; and in another of the islands the quartz rock and granite were seen in juxtaposition, the former reclining on the latter."

The chief importance of the last statement quoted consists in the evidence afforded that along the immediate shore the higher members only of the series rest in contact with the older gneiss, and do not constitute deposits immediately successive to it in a chronological sense.

Logan's Description.—In a report made the same year by Logan these rocks were compared with those previously seen by himself § on the south of

* In this memoir no attempt has been made to employ the nomenclature which stands approved by the International Geological Congress, because, as an American geologist, the writer feels that the question has not yet been settled by an adequate representation of the geologists of the civilized world.

† Report of Progess of the Geological Survey of Canada for 1847–'48, pp. 107–113.

‡ Afterward generally called quartzites.

§ Report of Progress for 1845–'46, p. 67.

the Mattawa and Ottawa; respecting which he had made the following remarks:

"The succession of rocks in ascending order, * * * after crossing sixty-three miles * * * occupied by the unbroken uniformity of the lower metamorphic or syenitic gneiss formation, is as follows:

"3. Fossiliferous limestones.

"2. Greenish sandstones (quartzites).

"1. Chloritic slates and conglomerates."

The fossiliferous limestones were referred to the Niagara, and the "chloritic slates and conglomerates" were subsequently embraced in the Huronian. This series of rocks Mr. Logan thought to "form a connecting link between lakes Huron and Superior to the vicinity of Shebawenahning, a distance of 120 miles."*

Rocks supposed to be of the same age had already been studied at various points along the Canadian shore of Lake Superior, as will be pointed out, and the opinion at the time entertained was that they represented the Cambrian. In a communication made to the British Association in 1851,† speaking of the geological position of these rocks, Logan said:

"And in this sequence those [rocks] of Lake Huron, if not those of Lake Superior, would appear to be contemporaneous with the *Cambrian series* of the British Isles.

In the next paragraph he says "the Lower Silurian on the lower St. Lawrence appears to rest upon gneissoid rocks without the intervention of the Cambrian;"‡ and in the next he uses the phrase "Cambrian formation of Lakes Huron and Superior" (p. 227), and the same again on the next page. It is evident, then, that in 1851 Sir William Logan considered the rocks on the north shore of Lake Huron as equivalent to the Cambrian of Sedgwick.

Murray on the Grouping and Details.—In his report for 1848–'49§ Mr. Murray gave further details of this region. He divided the rocks into a lower "Granitic or Metamorphic group" and a higher "Quartz Rock group." Of the latter group he says:

"The rocks of this group, where they came under our observation, like those examined the previous season further to the west, were found to be partly of aqueous and partly of igneous origin. The former consisted of sandstones, conglomerate slates and limestones; the latter, of beds of trap and trap dikes. The prevailing color of the sandstones was white, sometimes with a tinge of pale green; often the color was gray. The rock was always very silicious, and most frequently fine grained, in some cases of so close a texture as to assume the aspect of a compact, crystalline quartzite; but sometimes it was sufficiently coarse to constitute a fine conglomerate, of which the component grains and pebbles were by far the greater part of the quartz; but in the

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*Logan, Report on the North Shore of Lake Huron, p. 8.

†Rep. Brit. Assoc. Adv. Sci., 1851, Transactions of Sections, pp. 59–62; Amer. Jour. Sci., 2nd ser., vol. XIV, 1852, pp. 224–229. See also Bull. Soc. géolog. de France, 1849–'50, 2nd ser., vol. VII, pp. 207–209.

‡Amer. Jour. Sci., 2nd ser., vol. XIV, p. 226.

§Report Geolog. Surv. of Canada for 1848–'49, pp. 36–38.

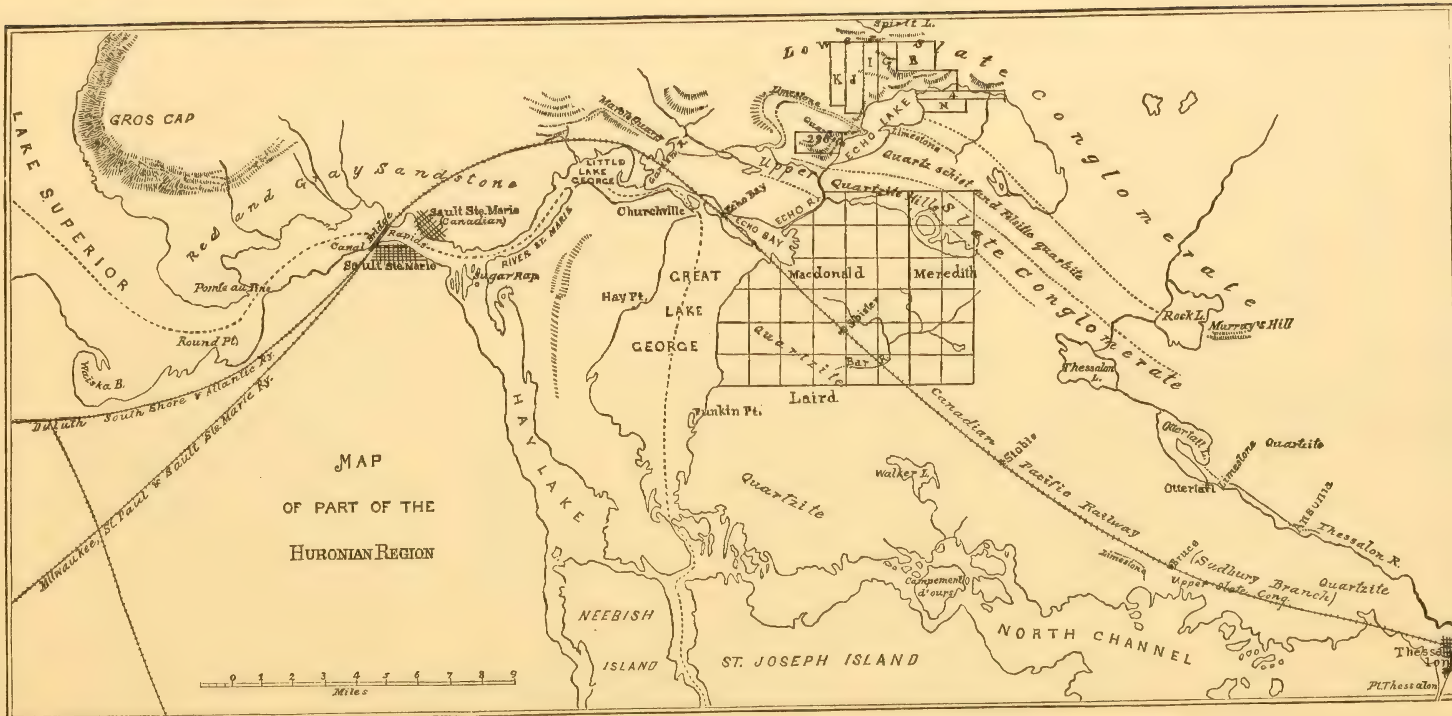
MAP
OF PART OF THE
HURONIAN REGION
LAKE SUPERIOR
GROS CAP
Red and Gray Sandstone
Pointe au Pins
Round Pt.
Waiska B.
Duluth South Shore & Atlantic Ry.
Milwaukee, St. Paul & Sault Ste. Marie Ry.
Canal
Bridge
Rapids
Sault Ste. Marie
Sault Ste. Marie (Canadian)
RIVER ST. MARIE
Sugar Rap.
LITTLE LAKE GEORGE
Churchville
Hay Pt.
GREAT LAKE GEORGE
HAY LAKE
NEEBISH ISLAND
ST. JOSEPH ISLAND
NORTH CHANNEL
Punkin Pt.
Quartzite
Walker L.
Campement d'ours
Lower Slate Conglomerate
Spirit L.
Limestone
ECHO LAKE
Upper Quartzite Hills
Echo Bay
ECHO BAY
ECHO R.
Quartz schist and Felsitic quartzite
Slate Conglomerate
Macdonald
Meredith
Laird
Bar R.
Quartzite
Canadian Pacific Railway
Rock L.
Murray's Hill
Thessalon L.
Otter Tail L.
Otter Tail
Limestone
Quartzite
Thessalon R.
(Sudbury Branch)
Bruce
Upper Slate Cong.
Thessalon
Pt. Thessalon
Miles
0 1 2 3 4 5 6 7 8 9

FIGURE 1.

beds of coarser quality pebbles of red or gray syenite occasionally occurred; small red jasper pebbles were observed in one or two places, imbedded in white quartz rock, but they were by no means numerous, and were confined to the upper portion of the formation. Some of the quartzose sandstone beds were of a deep orange red, but this seldom extended far. The slates were gray, green or blackish in color, and were usually more or less silicious, and frequently very micaceous. Some parts of the formation, being the more schistose portions, were almost exclusively composed of mica, generally of a gray color, but sometimes tinged with iron-brown, and the parallel layers into which the rock was divisible presented on their surfaces small, sharp corrugations. Some parts were marked by small shining specks of chlorite, and, in some places, the slates contained imperfect crystals of epidote, occasionally arranged along planes of the bedding, but more frequently along cracks or joints. In these epidotic slates the prevalent color of the rock was gray, and the epidote a dingy brownish green and sometimes disseminated, gave to smooth weathered surfaces the appearance of belonging to a slate conglomerate."

So much, touching the slates, evidently relates to the lower portion of the formation holding what was afterward called the "lower slate conglomerate." But the following clearly relates to the "upper slate conglomerate":

"The more purely argillaceous portions of the slate were generally black, or of a very dark brownish tinge, and, in these, a very symmetrical jointed structure, dividing the rock into rhombohedral forms of considerable regularity, was frequently recognized. The slates were very often observed to pass into a conglomerate holding pebbles of granite or syenite chiefly, varying in diameter from an eighth of an inch to a foot, and imbedded in a black argillaceous matrix. The limestones observed, though of minor importance as regards thickness, were of a marked character, and in most respects bore a strong resemblance to those found associated with the quartz rock formation at the western end of the north shore of Lake Huron. They consisted of calcareous beds of a dark-blue color interstratified with layers in which lime appears to be altogether absent, the composition of these being almost purely silicious or argillaceous. The outcropping edges presented alternations of thin, sharp ridges and grooves."

Mr. Murray, in review, makes enumeration of the following constituent members of the series (p. 39):

Pure massive beds of white, associated with thin beds of gray quartz rock and beds of greenstone, underlaid by less massive beds of greenish white, gray and red quartz rock, sometimes of a slaty structure, which, in all, amount to a thickness of about	4,000 feet.
Black argillaceous slates and conglomerates, with syenitic pebbles	800 "
Limestone band	500 "
Micaceous slates, interstratified in parts with gray quartz rock, all the lower visible portions near the granite consisting of chloritic and epidotic greenstone	5,140 "

Mr. Murray does not estimate the thickness of the lower member by itself, but he states that "the total thickness can scarcely be less than 10,000 feet." The formation thus described lies along the valley of Spanish river.

Murray and Logan on the Region South of the Ottawa.—In 1851 Director Logan and Assistant Murray examined different portions of the district between the Ottawa and the St. Lawrence. As this region may well be regarded as an extension of the geological district north of Lake Huron, some passages from this report may be cited.

Mr. Logan describes the Potsdam sandstone as reposing unconformably on the "Metamorphic or gneissoid group" (p. 6). This group, as thus understood, embraced the body of rocks extending from the Potsdam sandstone to the granites and gneisses. Of the character of this group in the seigniory of Rigaud, Mr. Murray, after speaking of the gneisses, says:*

"These beds are interstratified with others of a different character. One set is composed of small cleavable forms of black hornblende and grains of translucent, yellowish-white feldspar, weathering opaque-white, and crystals of brown mica [micaceous, quartzless syenite (hyposyenite)]; another consists of grayish-green, cleavable pyroxene, with individuals of greenish feldspar, weathering white, and largely disseminated grains of magnetic iron [gabbro], and a third consists of translucent albite, with black hornblende and magnetic iron ore disseminated [magnetitic diorite] alternating with micaceous layers. All these beds are intersected by transverse dikes, some of which are fine-grained, grayish-black trap, probably a greenstone, with disseminated grains of calc-spar, while others are porphyritic, having a fine-grained, blackish-green base, with individuals of greenish-white feldspar."

It is difficult to form a clear conception of a formation thus constituted. Though it rests, like the lowest strata along Thessalon and Spanish rivers, immediately above the gneisses, the description of it sounds extremely unlike the descriptions cited of the Thessalon and Spanish river strata.

Logan on Rocks North of Lake Huron.—Director Logan again, in 1852, returned to a notice of the rocks north of Lake Huron.† He says:

"On Lake Huron the Lower Silurian group rests unconformably upon a silicious series, with only one known band of limestone, 150 feet thick, with leaves of chert in abundance, but as yet without dicovered fossils. This series is supposed to be of the Cambrian epoch. It comprehends the copper-bearing rocks of that district, and with its igneous, interstratified masses has a thickness of at least 10,000 feet."

Introduction of the Name "Laurentian."—In 1854 the term "Laurentian" was introduced by Logan in the following words: ‡

"The name which has been given in previous reports to the rocks underlying the fossiliferous limestones in this part of Canada is "the Metamorphic series;" but inasmuch as this is applicable to any series of rocks in an altered condition and might occasion confusion, it has been considered expedient to apply to them for the future the more distinctive appellation of the *Laurentian series*, a name founded on that given by Mr. Garneau to the chain of hills which they compose."

This term, therefore, was at first employed for the entire series of rocks

* Report of Progress for 1851, p. 63.
† Quart. Journ. Geolog. Soc., vol. VIII, 1852, p. 200.
‡ Report of Progress, Geol. Surv. of Canada, 1852–'53, Quebec, 1854, p. 8.

older than the Potsdam sandstone, and was thus precisely equivalent to the Taconic proposed by Emmons ten years previously. It was employed in the same sense till 1855.

Murray employs the Terms "Laurentian" and "Huronian."—The Canadian report published in 1857 comprised the annual reports for 1853, 1854, 1855 and 1856. In Murray's reports for 1853 and 1854 he describes the country between Georgian bay and Ottawa river. In his report for 1855 he says:

"Among the bowlders on Lake Nipissing many were observed to be of a slate conglomerate, and they were frequently of very great size. In their aspect and general character these have a very strong resemblance to the slate conglomerates of the Huronian series,* from which, in all probability, they were derived" (p. 125).

In the report for 1855, speaking of the drift in the peninsula between Lakes Huron and Erie, he says:

"The pebbles and bowlders of metamorphic rocks which abound in the gravel and clay deposits, and are numerously scattered over the surface, are clearly derived from the Laurentian and Huronian formations on the north shore of Lake Huron" (p. 134).

In this passage Laurentian and Huronian are used in coördinate senses. As the former had been employed in a systemic sense, it is not likely to have been employed here in a geographic sense. In such case "Huronian" was not employed simply in a geographic sense. Murray was undoubtedly the first to employ the term "Huronian" in any sense; but as he has not expressed any intention to use it in a systemic sense, it would be straining a courtesy to base credit for such employment on the inference above indicated. It seems probable, nevertheless, that Murray was meditating such use of the term.

In his report for 1856, however, dated March 1, 1857, Murray, speaking of the "distribution of rock formations" between Lake Nipissing and Lake Huron, says:

"The rocks of the region explored during the season embrace two of the oldest recognized geologic formations, the *Laurentian* and *Huronian*. * * * The slates, conglomerates, limestones, quartzite and greenstone of the Huronian occupy the northern and western parts." "The immediate contact was nowhere distinctly seen" (pp. 168, 171).

It is thus placed beyond question that Murray was the first to use the term "Huronian" in a taxonomic sense. It follows from his introduction of this term that he was the first to employ the term "Laurentian" in a new and restricted sense. This was in 1855 and 1856, but his reports were not published till 1857.

Murray on the Constitution of the Huronian.—In the report last mentioned Mr. Murray gives a tentative statement (pp. 172, 173) of the constitution of

*This term appears to be employed here only in a geographical sense. Mr. Murray does not intimate that he intends it as the name of a geological system. Moreover, the rocks referred to were at this time embraced in a series known as "Laurentian."

the upper series or system in the neighborhood of Wahnapitæ lake—east and west. From this, inverting his arrangement, we make the following abstract:

6. Quartzite, white and very pale sea-green, close-grained, with beds of quartz conglomerate interposed, and layers of talco-quartzose slate. * * * The pebbles of the conglomerate are chiefly small, white, opaque, rounded masses of quartz, occasionally mixed with rounded masses of red and green jasper.
5. Slates, green, silicious, chloritic, with tolerably strong bands of quartzite.
4. Slate conglomerate, resembling the slate conglomerate No. 2.
3. Limestone, the strata always appearing much disturbed. It is in general associated with greenstone. Prevailing color when found in mass, a pale whitish gray, sometimes passing into dark blue. The band is frequently brecciated and often displays rough, jagged edges, which appear to belong to layers of hornstone. Portions of the band are indurated calcareous shale.
2. Slate conglomerate, the matrix always greenish in color, sometimes with a regular slaty structure, at others resembling a fine-grained greenstone trap. It holds pebbles of white and red syenite in great profusion, with occasional masses of green, brown and red jasper, rounded in form. Toward the bottom green slates with very regular laminæ, cleaving with the bedding and usually cut by parallel joints.
1. Slates, fine-grained, green, silicious, with thin bands of green quartzite interstratified. Also, fine-grained slates, sometimes of a green tinge and often bluish or black, weathering very black. Occasionally some layers assume a reddish color. Copper and iron pyrites frequently present.

The total thickness is supposed to be about ten thousand feet.

In the descriptions Mr. Murray speaks of the lower slates as standing nearly vertical, and having a "rough, jagged and wrinkled surface, breaking into elongated splinters when struck with the hammer" (p. 173). This is on Sturgeon river, not far east of Lake Wahnapitæ and near the gneiss. Nearer to Lake Wahnapitæ a conglomerate occurs, which "appears for the most part to be nearly horizontal" (p. 174). This was overlain in a high hill by a greenish-colored quartzite, having a dip of ten to twelve degrees. Further southwest, about Lake Metagamashing, "the rock is a very fine-grained, finely laminated green slate, portions of which contain rounded pebbles of syenite" (p. 174). The dip is 10° to 12°, and from this to horizontal. "They are divided by two sets of parallel joints, cutting the strata into rhomboidal-shaped blocks." The rock is "cleavable to an unusual extent." From this region, along Whitefish river to Lake Huron, the dips are changeful and inconstant, the entire country being "in a state of great disturbance" (p. 181). Mr. Murray becomes impressed with the conviction, however, that there are two slate conglomerates with a limestone between them (p. 186); and, though the upper, with the superincumbent white and greenish quartzites, is sometimes seen with a high dip, and the lower occasionally with a dip as low as 60° to 80°, the latter is generally vertical or nearly so, while the former varies between horizontality and a dip of 45°.

In his hypothetical section, however (p. 187), the higher and lower members of the assemblage are treated as conformable with each other.

Before proceeding to quote the language accompanying Sir William Logan's formal announcement of the adoption of the terms "Laurentian" and "Huronian," in the sense now understood, it will help to a comprehension of his positions to state, in appropriate citations, what had been learned about rocks, assumed to be of Huronian age, about the shores of Lake Superior.

Citations from the Founders touching the Vicinity of Lake Superior.

Logan's first Report.—In his report of progress for 1846–'47, Director Logan described the rocks on the north shore of Lake Superior as consisting of the following divisions:

5. Sandstones, limestones, indurated marls and conglomerates, interstratified with trap.
4. Bluish slates and shales, interstratified with trap.

Unconformity.

3. Chloritic and partially talcose and conglomeratic slates.
2. Gneiss.
1. Granite and syenite.

The following is a portion of Director Logan's remarks on these rocks:

"The gneiss is succeeded by [3] slates of a general exterior dark green color, often dark gray in fresh fractures, which at the base appear occasionally to be interstratified with beds of a feldspathic quality of the reddish color belonging to the subjacent granite and gneiss. * * * Some of the beds have the quality of a greenstone; others that of a mica slate, and a few present the character of quartz rocks. Rising in the series, these become interstratified with [3] beds of a slaty character, holding a sufficient number of pebbles of various kinds to constitute conglomerates. The pebbles seem to be of various qualities, but apparently all derived from hypogene rocks. * * * The formations which succeed [4] rest unconformably upon those already mentioned. The base of the lower one where seen [in Thunder bay] in contact with the subjacent green slates [3] presents conglomerate beds, probably of no great thickness, composed of quartz pebbles chiefly, with a few of red jasper, and some of slate in a green arenaceous matrix, consisting of the same materials in a finer condition (pp. 8–17). * * * The chloritic slates at the summit of the older rocks, on which the volcanic formations rest unconformably, bear a strong resemblance to those met with in the upper part of Lake Temiscaming, on the Ottawa, and it appears probable they will be found identical" (p. 34).*

Murray's Account of the same Region.—Mr. Murray, in the report for the same year (1846–'47), has an independent account of the formations in the

*See also Logan, Report for 1848, p. 29.

same region. In the basin of Kamanistiquia river, which empties into Thunder bay, he finds granite, syenite, gneiss, micaceous and chloritic schists. These are overlain by blackish, argillaceous slates, with associated trap—Logan's nos. 4 and 5. Of the lower series, he says:

"Where they make their appearance at the lower end of the portage the character of the rock is a red, or, in some instances, a whitish, massive syenite, which passes gradually into a gray, gneissoid syenite, dipping at a high angle north-northwest. Resting conformably on the gneiss, there occurs a series of dark greenish-blue, or greenish-black, altered slates, the one rock passing almost imperceptibly into the other. * * * Towards the bottom, near the junction with the syenitic portion, the slates are of a dark bluish and occasionally of a brownish color. They appear to be highly altered."

Of the upper, unconformable series of black argillaceous shales he writes:

"The base of this formation * * * was observed on the Kamanistiquia river, near the Grand falls. Its immediate junction with the rock on which it reposes was concealed from view."

Points established.—The points established by these extracts from the reports of Logan and Murray for 1846–'47 are the following:

1. The existence of two slate conglomerates with associated strata.
2. The existence of an unconformity between them.
3. The dark or black color of the upper series of slates and slate conglomerates.
4. The greenish or bluish color of the lower series.
5. The graduation of the lower series downward into gneissic rocks.
6. The resemblance of the upper series to strata observed north of Lake Huron.

Logan's Identification of Huron and Superior Rocks.—Some account of Mr. Murray's report on the region north and northeast of Lake Huron has already been given. Director Logan himself subsequently published* comments, comparisons and inferences based on Murray's report, from which the following extracts are taken:

"The series of rocks occupying this country form the connecting link between Lakes Huron and Superior to the vicinity of Shebawenahning, a distance of 120 miles, with a breadth in some places of 10 and in others exceeding 20 miles, [and] it appears to me must be taken as belonging to one formation. On the west it seems to repose on the granite which was represented in my report on Lake Superior as running to the east of Gros Cap, north of Sault Ste. Marie. On the east the same supporting granite was observed by Mr. Murray north of La Cloche, between three and four miles in a straight line up the Rivière au Sable, * * * and again about an equal distance up another and parallel tributary, * * * in both cases about ten miles from the coast. * * * In respect to the geological age of the formation, the evidence afforded by the facts collected last year by Mr. Murray * * * is clear, sat-

* Report on the North Shore of Lake Huron, December 29, 1848.

isfactory and indisputably conclusive. * * * Successive formations of the lowest fossiliferous group of North America were each, in one place or the other, found in exposures divested of all vegetation, resting in unconformable repose in a nearly horizontal position upon the tilted beds and undulating surface of the quartz rock and its accompanying strata, filling up valleys, overtopping mountains, and concealing every vestige of dikes and copper veins. * * * The chief difference in the copper-bearing rocks of lakes Huron and Superior seems to lie in the great amount of amygdaloidal trap present among the latter and of white quartz or sandstone among the former. But on the Canadian side of Lake Superior there are some considerable areas in which important masses of interstratified greenstone exist without amygdaloid, while white sandstones are present in others, as on the south side of Thunder bay, though not in the same state of vitrification as those of Huron. But notwithstanding these differences, there are such strong points of resemblance in the interstratification of igneous rocks and the general mineralized condition of the whole as to render their positive or proximate equivalence highly probable, if not almost certain; and the conclusive evidence given of the age of the Huron would thus appear to settle that of the Lake Superior rocks, in the position given them by Dr. Houghton, the late state geologist of Michigan, as beneath the lowest known fossiliferous deposits."

Remarks on the Identification.—On the foregoing extract the following observations should be made:

1. The whole mass of strata from the gneiss up to the Potsdam sandstone is conceived as a unit and generalized from as a unit; while in that interval lie two systems unconformable with each other, as already pointed out by Director Logan himself.

2. This assemblage is distinctly next inferior to the Potsdam sandstone.

3. The identification of the copper-bearing rocks of the south shore of Lake Superior with those of Lake Huron is erroneous, because:

(*a*) The Superior cupriferous rocks have little analogy with those of Lake Huron, the fragmental strata of Superior being porous sandstones and loose conglomerates of felsitic pebbles, while those of Huron are clean vitreous or vitreo-granular quartzites, with firmly imbedded quartzose and jaspery pebbles; also the volcanic beds of the Superior series are interbedded amygdaloids and hold native copper, while those of Huron are crystalline or altered diabases, and the copper consists of sulphides in veins of quartz.

(*b*) The real analogue of the cupriferous series of the south shore of Lake Superior, as now recognized, is separated from the system which rests on the gneiss by a series of "blackish argillaceous slates and slate conglomerates," designated (4) and (5) in Logan's report of 1846–'47, and which are the real analogue of the cuprif-erous rocks of Lake Huron.

(*c*) The sandstones of Thunder bay, instead of being in the position of the white quartzite of Lake Huron, are in a higher horizon—either the Kewenawan or the Potsdam sandstone.

4. Logan's opinion of the Cambrian age of the cupriferous rocks of Lake Huron, made by the identifications, held the Cupriferous series of the south

shore of Lake Superior also Cambrian, and the parallelism was maintained by him.*

5. The opinion attributed to Dr. Houghton is correct, since Houghton always held the "mixed traps and sandstone" as older than the "red sandstone," whatever views he may have held temporarily as to the age of the sandstone.†

Proposal of the Name "Huronian."

First Use of the Name.—It has been shown that Alexander Murray first employed the term Huronian, though apparently in a geographical sense, in 1853 and 1854 (*ante*, p. 91).

In 1855 he employed the terms "Laurentian" and "Huronian" as coördinate, and apparently, therefore, in a taxonomic sense. Such use of the terms in 1856 is unquestionable. But Murray's reports were not published till 1857.

Hunt's Use of the Name.—It belonged to Dr. T. S. Hunt to publish, in 1855, the first formal proposal for the use of the term "Huronian." In "A Sketch of the Geology of Canada," speaking of the rocks on the north shore of Lake Huron, then recently studied by Mr. Murray, he says:

"As these rocks underlie those of the Silurian system, and have not as yet afforded any fossils, they may probably be referred to the Cambrian system (Lower Cambrian of Sedgwick). * * * This Huronian formation is known for a distance of about 150 leagues upon Lakes Huron and Superior." ‡

It can hardly be said that Hunt here employed the term in anything more than a geographic sense, since, taxonomically, he says the rocks are Lower Cambrian. It is not known whether he was then aware of Murray's use of the term in the same sense in his unpublished reports.

Logan's Proposal of "Laurentian" and "Huronian."—It remained for Sir William Logan, in 1857, to make a proposal of unequivocal intent. In a paper read before the American Association, in August,§ "On the Division of the Azoic Rocks of Canada into Huronian and Laurentian," he speaks of them confidently as "a series of very ancient sedimentary deposits in an altered condition." He refers to his suggestion of 1845 to separate the purely gneissoid portion from the portion consisting of interstratified gneisses and limestones, but says the evidence does not permit him to decide certainly which of these divisions of the Laurentian is most ancient. He next refers to what was published in the report of 1845 relative to the rocks of Lake Temiscaming:

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* Bull. Soc. géolog. de France, 1849–'50, 2d ser., VII, pp. 207–209. Report Brit. Assoc. Adv. Sci., 1851, Transactions of Sections, pp. 59–62. Amer. Jour. Sci., 2d ser., vol. XIV, 1852, pp. 224–229.

† See a different interpretation of Houghton by Wadsworth in Bull. Mus. Compar. Zool., 1880 (Geol. series, I), p. 83.

‡ Canada at the Universal Exposition of 1855, pp. 427, 428 [Esquisse géologique, 1855, pp. 28–33].

§ Proc. Amer. Assoc. Adv. Sci., 1857, pp. 44–47.

"Consisting of silicious slates and slate conglomerates, overlain by pale green, or slightly greenish-white sandstone, with quartzose conglomerates. The slate conglomerates are described as holding pebbles and bowlders (sometimes a foot in diameter) derived from the subjacent gneiss, the bowlders displaying red feldspar, translucent quartz, green hornblende and black mica, arranged in parallel layers which present directions according with the attitude in which the bowlders were accidentally inclosed. From this it is evident that the slate conglomerate was not deposited until the subjacent formations had been converted into gneiss, and very probably greatly disturbed; for while the dip of the gneiss, up to the immediate vicinity of the slate conglomerate, was usually at high angles, that of the latter did not exceed nine degrees, and the sandstone above it was nearly horizontal."

We interrupt this quotation for the purpose of remarking that such juxtaposition of unconformable dips is evidence that Director Logan is here speaking of the "upper slate conglomerate," for it is notorious that the "lower slate conglomerate" passes, through the interposition of pure slates, with perfect conformity, to the crystalline schists, and thence to the gneissic rocks.* This is further evinced by the low dip ascribed to it, because, while this is common with the "upper slate conglomerate" and the overlying quartzites, it is almost never the case that the "lower slate conglomerate" has a dip so low as 60° or 70°; and when thus low the occurrence is in the immediate vicinity of a local disturbance. The mean attitude of the lower slate conglomerate is vertical. It is evident, therefore, if slates of low dip lie upon usually vertical or high-dipping gneisses, they belong to the upper portion of the series here called Huronian; while the strata of the lower portion are wanting—a state of things actually observed by the writer and previously described by the Canadian geologists—along the north shore of Lake Huron. Sir William Logan therefore deliberately embraced in one system an extensive body of strata, generally of very low dip, and an equally extensive body of strata, generally of very high dip, equally contrasted also, in lithological characters.

The communication continues:

"In the report transmitted to the Canadian government, in 1848, on the north shore of Lake Huron, similar rocks are described as constituting the group which is rendered of such economic importance from its association with copper lodes. This group consists of the same silicious slates and slate conglomerates, holding pebbles of syenite instead of gneiss, similar sandstones [quartzites?] sometimes showing ripple-marks, some of the sandstones [quartzites?] pale red-green, and similar quartzose conglomerates in which blood-red jasper pebbles become largely mingled with those of white quartz and in great mountain masses predominate over them. But the series is here much intersected and interstratified with greenstone trap, which was not observed on Lake Temiscaming. These rocks are traced along the north shore of Lake Huron, from the vicinity of the Sault Ste. Marie, for 120 miles east."

Sir William Logan indicates the further extension of this group toward

*See the author's memoir, Bull. Geol. Soc. Amer., Vol. I, 1890, pp. 357–394, and all recent writers on the structural relation of the semi-crystalline schists to the crystalline schists and gneisses.

the northeast, through the region of Maskinonge and Sturgeon rivers (tributaries of Lake Nipissing), as far as Lake Temiscaming. He continues:

"The group on Lake Huron we have computed to be about 10,000 feet thick, and from its volume, its distinct lithological character, its clearly marked date posterior to the gneiss, its economic importance as a copper-bearing formation, it appears to me to require a distinct appellation and a separate color on the map. Indeed, the investigation of Canadian geology could not conveniently be carried on without it. We have, in consequence, given to the series the title of Huronian.

"A distinct name being given to this portion of the Azoic rock renders it necessary to apply one to the remaining portion. The only local one that would be appropriate in Canada is that derived from the Laurentide range of mountains, which are composed of it from Lake Huron to Labrador. We have, therefore, designated it as the Laurentian series."*

Mature Definition of "Huronian."—With a view to attaining as exact a comprehension as possible of the conception of the Huronian system entertained by Sir William Logan and his eminent collaborators, it may be best to make a few citations from the "Geology of Canada," published in 1863, and embodying more matured views than those contained in the annual reports. In this work Sir William Logan makes statements from which the following extracts are drawn (p. 90):

"On Lake Temiscaming the Laurentian orthoclase is followed by a slate conglomerate. The finer parts of the rock are dark gray, weathering to dark green. They are of a uniform grain, and, being at the same time argillaceous and silicious, they present the characters of a hard, compact slate. Some parts, not so fine in texture, are a hard, dark-gray sandstone, weathering to a dingy olive-green. In both cases the rock frequently exhibits the character of a compact conglomerate, holding pebbles and bowlders, sometimes a foot in diameter, of the subjacent gneiss, from which they appear to be principally derived."

Some other conditions of the formation are described as finer textured, penciled in transverse fracture by fine-colored lines; another as a "very close-grained, compact, dark-gray mica slate. When cleavage exists, the planes cut the pebbles in common with the matrix." It is never fit for roofing-slates. To this slate conglomerate succeeds a quartzite apparently 400 to 500 feet thick.

The Huronian system was most specially studied along that part of the northern shore of Lake Huron which lies between the Missisagui and Ste. Marie rivers. A general section of the Huronian, generalized from observations in this portion of Canada, is given on pages 55–57, and an abstract of this is here appended:

	Feet.
13. White quartzite, imperfectly examined	400
12. Yellowish chert and impure limestone, similar to 10	200
11. Quartzite, white, frequently of vitreous aspect	1,500

*See also the Canadian Journal, vol. II, 1857, pp. 439–442; Canadian Naturalist and Geologist, vol. II, 1857, pp. 255–258.

		Feet.
10.	Yellowish chert in thin and very regular beds, interstratified with layers of green, buff and gray silicious limestone and green and pale-drab silicious slate	400
9.	Quartzite, white, very frequently of a vitreous aspect; large portions so massive as to render observation of dip and strike impossible	2,970
8.	Red jasper conglomerates, varying, however, from a fine-grained quartzite to a conglomerate with pebbles of colored jaspers, flint and quartz, and ranging in size from that of duck-shot to grape and canister	2,150
7.	Quartzite, red, generally fine granular, sometimes conglomeratic	2,300
6.	Slate conglomerate of the same general character as No. 4, but the pebbles are not so large. It is interstratified with beds of reddish and gray quartzite [silicious schist?] and layers of fine-grained, greenish-black, light olive-green silicious slate, some of which yield hones of a very fine description. Considerable masses of greenstone are interstratified in various parts of the deposit	3,000
5.	Limestone, usually of a compact texture, but sometimes partially granular. The colors are green, drab and dark gray, the latter two prevailing. Occasional beds are dull white, with waxy luster in fresh fractures; these weather to a yellowish-brown on the exterior and appear to be dolomitic. The whole band is in general thin-bedded, and a diversity of characters in the layers, probably arising from the presence of more or less silicious matter, causes the surface of the weathered blocks to present a set of bold but minute ribs of various thicknesses, which, when the beds are much affected, as they often are, by diminutive undulations, contortions and dislocations, exhibit on a small scale a beautiful representation of almost all the accidents that occur in stratification, affording very excellent ready-made geological models	300
4.	Slate conglomerate, composed of pebbles of gneiss and syenite, held in an argillo-arenaceous cement of a gray or more frequently of a greenish color, the latter arising apparently from the presence of chlorite. The pebbles, which are of reddish and gray colors, vary greatly in size, being sometimes no larger than swan-shot and at others bowlders rather than pebbles, measuring upwards of a foot in diameter. The proportions of these also vary much; they sometimes constitute nearly the whole mass of the rock, leaving but few interstices for the matrix; and sometimes, on the contrary, they are so sparingly disseminated that intervals of a foot or several feet intervene between them, and each may be still several inches in diameter. With the pebbles of gneiss and syenite are occasionally associated some of different colored jaspers and others of quartz. The matrix appears to pass, on the one hand, into a gray quartzite by an increased proportion of the arenaceous grains, and, on the other, into a thin-bedded, dark greenish, fine-grained slate, which is sometimes very chloritic. A third form assumed by the matrix is one in which it is scarcely distinguishable from a fine-grained greenstone. In this state the stratification is often marked by slight differences of color in the direction of which it is occasionally cleavable; the bands, in other instances, are finely soldered together, but in both cases joints usually prevail, dividing the rock into rhomboidal forms which are sometimes very perfect. Very heavy masses of greenstone are gen-	

	Feet.
erally interstratified in the rock, which do not seem confined to any one stratigraphical place	1,280
3. Quartzite, white, the color sometimes passing into gray, principally fine-grained, but great masses become vitreous quartzite; sometimes, also, coarse-grained and passing to the character of a conglomerate, from the presence of pebbles chiefly of white quartz; the massive beds frequently separated by layers of fine-grained, greenish-gray silicious slate; greenstones intercalated throughout	1,000
2. Slates, greenish, red-weathering, chloritic and epidotic; trap-like beds interstratified	? 2,000
1. Quartzite, gray, thin-bedded in parts	? 500
	18,000

The foregoing is a careful and excellent description of the various members of the series of rocks north of Lake Huron, which were embraced in the original Huronian. From personal examination in various portions of the region, the writer can testify to its general accuracy. It is a fair picture of the Huronian as we actually see it. It is a product of long-continued patient industry and physical endurance never surpassed, in a vast and wild expanse of the continental surface, and prosecuted with skill and judgment equal to the best standards of similar work in any country. To suggest an interpretation required by a much wider range of observations is not to destroy the fabric of Canadian results, but to assist in its completion.

Two Systems united under the Name "Huronian."

STRUCTURAL DISCORDANCES IN THE LAKE HURON DIVISION.

We shall first discuss this branch of the question from the evidence of the documents supplying the original facts. We shall then consider the bearing of facts of later development, especially such as have come under our personal observation.

Evidence from the Documents.—Were no records in existence touching the Lake Huron district except such as existed when the term "Huronian" was proposed, it would be easy to overlook the evidence that the original Huronian was not homogeneous. Without critital examination of Canadian geological literature, the inherent evidence of the confounding of two systems might remain unnoticed. The language employed by Messrs. Logan and Murray implies that no suspicion existed in their minds that the series which they were describing extended over a great geological break; and in such a state of mind they neglected to dwell upon those facts which in the light of more recent studies must be regarded as intimations, if not proofs, of the duplex character of their system. Nor are the field proofs of its duplex character conspicuous. They are even disguised by the similarity of the two characterizing "slate conglomerates." We have ourselves been over the whole breadth of the system, in its typical region, without at first discovering any necessity for new interpretations. It was the study of contemporaneous formations in northeastern Minnesota and north of Lake Superior which first clearly revealed to us the fact that the so-called "Huronian" has there been rent into two systems. It was this revelation in northwestern geology which prompted us to a review of the recorded facts in Lake Huron geology, and to new explorations in certain critical districts between the Lake Huron and Lake Superior districts.

Premising that the present inquiry must necessarily be based on evidences drawn from structural and lithological data, we present, first, the fact of the *stratigraphic unconformity between the upper and lower divisions of the original Huronian*, as described by its authors. We have already directed attention to the fact that in the region around Lake Wahnapitæ, northeast of Lake Huron, the average dip of the members nearer the gneiss is much higher than of the members remoter from the gneiss. As a rule the older members there, as elsewhere, stand nearly vertical, while as a rule the newer members very seldom have an inclination greater than 45°. But the region is one of numerous abrupt and local disturbances. It hence becomes quite true that in single instances the lower members, or what seem to be the lower members, approach a horizontal position, while the higher members, or what seem to be the higher members, are locally thrown into steep attitudes. In studying the details of other regions, we find a similar contrast between the dips of lower and higher members of the system. We do not consider this method of reasoning conclusive; but it seems to show that if the later disturbances which affected in common all the strata embraced in the nominal Huronian have left the older strata more highly tilted than the newer, the result depended on the fact that they were originally more highly tilted—that is, that the older and newer members of the system were in a state of discordance before the disturbances occurred to which we here refer.

Again, we have already cited Sir William Logan's statements in reference to the structural relation of certain Huronian members and the underlying gneiss along the north shore, and near the shore, of Lake Huron. Here, he says, the slate conglomerate has as low a dip as nine degrees, while the sandstone [granular quartzite] above it is nearly horizontal and the underlying gneiss is nearly vertical. That this flat-lying slate conglomerate is the "upper" is proved by the fact of a quartzite overlying it, for no quartzite is described as overlying the "lower" slate conglomerate (see the general section already cited from Logan). It is also proved by the facts of its discordance with the underlying gneiss; for in every instance in which the lower slate conglomerate has been traced to the proximity of the gneiss, these two formations seemed to be conformable in position, though generally the actual juxtaposition was concealed by a bed of intercalated greenstone or by low ground. Now the disturbances which affected the Huronian must have affected similarly the underlying gneiss. If, therefore, the "upper slate conglomerate" is discordant with the gneiss, it must have been discordant before the common disturbance; and if the "lower slate conglomerate" is conformable with the gneiss, it must have been so before the disturbance. The "upper slate conglomerate" therefore, as a final inference, must have been unconformable with the "lower slate conglomerate." We base this conclusion on the language of the founders, and not, at present, on any evidence from personal observation.

The facts here stated throw light on the mooted question of the conformity or unconformity between the Huronian and the subjacent gneiss. Every reader of Huronian literature has been puzzled by the numerous contradictions of writers. These, when not the result of carelessness of statement, are caused by the discordance of the upper and lower Huronian between themselves. The lower Huronian is conformable with the gneiss; the upper Huronian unconformable. Wherever the upper Huronian extends beyond the limits of the lower Huronian it rests unconformably on the gneiss. This happens along the north shore of Lake Huron, where the upper slate conglomerate rests on the gneiss. Farther south and west (on Ste. Marie river) the upper slate conglomerate is itself wanting, and the white quartzite rests immediately on the gneiss. On some of the islands in the North channel (of Lake Huron) the quartzite, in turn, is wanting, and the Paleozoic limestones rest on the gneiss.

It appears that the Canadian writers, whatever they may have understood about an "upper" and "lower" slate conglomerate, whenever they met a slate conglomerate were in the habit of speaking of it as *the* slate conglomerate. If they noted discordances between the two they naturally attributed them to unequal local disturbances. It is not to be believed that they would have failed to note the discordance and to inquire into its meaning if their observations had extended into regions where each was found reposing persistently in an attitude of discordance with the other. This theoretical union of the two was all the easier in those parts of the territory where the two were separated only by 150 feet of limestone.

Evidence from Personal Observation.—To these inferences from the older Canadian reports may be added the results of our own observations.* Everywhere along the coast between the Sault Ste. Marie and Blind river, wherever the Huronian quartzites or schists are exposed to view, we find them, as Logan states, with a low dip. The same is true along the Sault road from Thessalon to the rear of the Bruce and Wellington mines. The same is true along the valley of Thessalon river, by the turnpike, on both sides of

*Some notes of a trip to this region by the writer and Professor N. H. Winchell may be found in 16th Report of the Geol. Survey of Minnesota, 1887, pp. 13–40, 145–179.

the river, as far as Ottertail. The same is true north from Ottertail across the quartzite ridges. The slate conglomerate met in this direction, two miles south of Murray's Corners, has a dip of 40° toward south 30° west. This is certainly the upper slate conglomerate, since it immediately underlies the lower, or red, quartzite. Logan's map also locates the upper slate conglomerate near here, though its southern border is laid down a mile and a half further north. Two miles north of this is Murray's hill, about 170 feet high, and formed of a slate conglomerate of a somewhat different character, and having a dip southward of 78°. Here is a discordance in dip and strike with the first slate conglomerate; and though this is embraced by Logan in the coloration of the *upper* slate conglomerate, we feel confident that it is the *lower*—an opinion apparently sustained by the discordances noted. Between the first occurrence and the second is space for a normal thickness of 5,745 feet, basing the calculation on a dip of 40° in a direction making an angle of 30° with the meridian. This normal thickness is sufficient for the upper slate conglomerate and the underlying limestone, or felsitic quartzite and limestone, known to be present in some other places. Thus the top of the upper slate conglomerate makes an angle of 38° with the top of the lower slate conglomerate two miles distant, and the two strikes are at an angle of about 30° with each other.

It may be permitted to mention here also an observation made* near the Vermilion river, where crossed by the Sudbury branch of the Canadian Pacific railway. Here is a very dark compact, slaty rock, quite arenaceous, with shining particles, looking micaceous or graphitic, and having a dip of 45° in a direction a little east of south. This rests on a different schist, having a different dip. Opportunity did not permit complete observations here, but it was noted that the two formations have strikes making an angle of about 40° with each other. This occurrence and others of the kind were noted by different members of the party. Though nothing could be concluded from observations so incomplete, they tend to confirm the position here maintained, that an older system of rocks, with steep dips, is partially covered, in the region north of Lake Huron, by a newer formation, with dips less inclined to the plane of the horizon.

Evidence from Independent Observation.—An independent version of these observations has just come into our hands. Professor N. H. Winchell, one of the Huronian excursionists, says: †

"At the crossing of the Vermilion river is a repetition of the falls, ridges and rapids seen at Thompson, Minnesota, the whole being manifestly of the same age, and supposed to belong to the Animike or true Huronian. The dip of the slates is 45° toward

* During the "Huronian Excursion" from Toronto, generously arranged by Dr. Selwyn, of the Canadian Geological Survey, for the benefit of the geological section of the American Association, September 4-5, 1889.

† In Eighteenth Annual Report, Minn. Geol. Survey (p. 54), from advance sheets of which the citations are made.

the south. Dr. Bell stated that the train, before arriving at Vermilion river, had passed over these slates for about five miles, viz., through a very flat and good agricultural tract, indicating a profound change in the underlying rock, inasmuch as, up to the place of entering on these slates, the country had been very rough, with frequent exposures of the rock. The slate is black (or purplish black when dry), generally fine-grained, yet with some evident grains of quartz. * * * From the Vermilion river, traveling still southwest, we passed on to a lower series of strata, the dip being to the southeast. This is a slate conglomerate, and causes an immense ridge, 150 feet high, more or less."

Speaking of an apparent unconformity at Wahnapitæ, which we were not allowed sufficient time to examine, he says:

"Subsequently Dr. A. C. Lawson reëxamined this point in order to get a better idea of the relations of the formations, and, according to verbal description from him, there appears to be an unconformity of stratigraphy at Wahnapitæ similar to that at Penokee Gap, Wisconsin. At the immediate contact the lower rock is the fine micaceous gneiss or mica schist, probably belonging to the series seen at North bay (Lake Nipissing), and the upper rock is quartzite and gray argillite interbedded" (p. 52).

Other evidences of two unconformable systems were found at the Stobie mines (pp. 52, 53). In conclusion, he says:

"It appears, therefore, that both northwest from Sudbury and eastward from Algoma there are two formations" (p. 57).

LITHOLOGICAL DISCORDANCES IN THE LAKE HURON DIVISION.

We have next to direct attention briefly to the lithological contrasts noted between the two divisions of the original Huronian. We will confine the comparison to the two slate conglomerates.

Murray's and Logan's Descriptions.—We have already quoted passages from Mr. Murray's report of 1848 (see *ante*, pp. 86, 93). From these it appears that Murray did not distinctly note the aspects of the slate conglomerate as chronologically successive, but the lithological distinctions were very clearly and fully drawn. One is "more argillaceous," "generally black," with "a very symmetrical jointed structure, dividing the rock into rhombohedral forms," often "passing into a conglomerate" with pebbles "imbedded in a black argillaceous matrix." The other is "gray or green," "usually more or less silicious, and frequently very micaceous," sometimes "almost exclusively composed of mica." "Some parts were marked by small, shining specks of chlorite," and in some epidote was present. "In these epidotic slates the prevalent color of the rock was gray." In his summary of results, however, he puts the "black argillaceous shales and conglomerates" above the separating limestone, and the micaceous and chloritic slates below; so this, finally, is evidence that Murray did not fail to notice not only the contrasts of the slates, but also their order of sequence.

On other occasions both Murray and Logan describe one of the slate conglomerates by saying it resembles the other; but this must be understood only of the general features (see *ante*, p. 92 and p. 94). In his description of the country around Lake Wahnapitæ, Murray speaks of the lower as standing nearly vertical, and having a "rough, jagged and wrinkled surface, breaking into elongated splinters when struck with the hammer" (*ante*, p. 92). About Lake Metagamashing the slate is "green, fine-grained and finely laminated," with "rounded pebbles of syenite," and a dip of 10° to 12°. It is "divided by two sets of parallel joints, cutting the strata into rhombohedral-shaped blocks." Sir William Logan, in his general table of the constitution of the Huronian system, already cited from the "Geology of Canada," does not give a full description of the upper slate conglomerate, and there is reason to think, as has been stated, that in certain regions, at least, he included a portion of the lower with the upper formation. Nevertheless, he states that the upper has "pebbles not so large," and is "interstratified with beds of quartzite" and "silicious slate" suitable for hones—characters never attributed to the lower slate conglomerate by either Murray or Logan.

Personal Observations.—Referring again to the writer's observations on the upper slate conglomerate at the outcrop two miles south of Murray's hill, we find the following record published:

"Metamorphic slates, mostly compact, with slatiness moderately well developed, but to a large extent a well-characterized slaty argillite, silicious in places, and inclosing bands of silicious schist." *

It is impossible to possess any information respecting the Animike series without recognizing that formation here.

Of the formation at Murray's hill it is said:

"It contains pebbles of red granulite of all sizes, up to two feet in diameter."

It recalls somewhat the peripheral portions of the Ogishke conglomerate.

This formation is said to be "similar" to the other; that is, they are both slate conglomerates.

The writer's brother made independently the following observations on these two exposures. Of the first he says:

"This ridge, which is a characteristic bluff of characteristic Animike slates, dips S. 30° W. (magnetic). * * * It is minutely granular, almost aphanitic. It is thin-bedded, but hardly slaty, evidently of sedimentary origin. * * * It breaks with a flinty, subconchoidal surface of fracture."

Of the Murray's hill formation he says:

"The rock is but scantily slaty in the direction of the sedimentation. Close jointage sometimes produces an appearance of slatiness. Neither has it any slaty cleavage.

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* Seventeenth Ann. Rep. Minn. Geol. Survey, 1887, pp. 158, 159.

"The general weathered aspect is slightly greenish, but the color within is dark green to gray. * * * This rock appears like the Ogishke conglomerate of Minnesota."*

These observations were made under the impression, on the part of both observers, that the two slate conglomerates were properly included in one system. That prepossession removed all motive for seeking distinctions, and all the more because the work was at the time casual and hurried.

Further personal observations will be presented in separate paragraphs relating to Echo lake.

Irving's Observations.—Professor Irving, who, as is well known, had devoted great attention to the older rocks of the northwest, was firmly persuaded of the equivalence of the typical Huronian with the Animike of Lake Superior. "The whole aspect of the Huronian," he says, "as thus described by Logan [in the 'Geology of Canada' as quoted *ante*, p. 98], is strongly suggestive of the Animike group of the north shore [of Lake Superior]. To me it appears more than probable that the original Huronian of Lake Huron and the Animike slates of Thunder bay and thence southwestward to the Mississippi river are one and the same formation."† This opinion was several times recorded at later dates.‡

There is reason to suppose that this identification by Irving was based upon a study of the upper Huronian and not those lower slate conglomerates which occupy much of the surface fifteen to twenty miles remote from the shore of Lake Huron, and which, from their prominence, were always present to the minds of the Canadian geologists when defining the Huronian. Professor Irving, in making reference to his personal study of the original Huronian, says:

"The coast line from the Sault Ste. Marie eastward to Serpent River bay was examined in some detail, during the summer of 1883, by myself and Assistant Geologists Van Hise and Merriam, with Logan's map in hand; while the country back from the coast was traversed sufficiently to enable us to see those members of the series which do not reach the coast line."§

It is not stated how many miles back from the coast the explorations extended. The lower slate conglomerate, as here understood, is 23 miles by wagon road from Thessalon. The low outcrops three to five miles back from the coast, between Thessalon and Bruce, though some of them are mapped by Logan as lower slate conglomerate, have, to our apprehension, the lithological characters of the upper slate conglomerate. Hence we state that Irving, in identifying the Huronian in general with the Animike, may really

* Professor N. H. Winchell: Sixteenth Ann. Rep. Minn. Geol. Survey, 1886, pp. 30, 31.
† Third Ann. Rep. U. S. Geol. Surv., 1883, pp. 164, 165.
‡ Copper-bearing Rocks of Lake Superior, 1883, p. 390; Fifth Ann. Rep. U. S. Geol. Surv. 1885, pp. 203, 204, etc.; Seventh Ann. Rep. U. S. Geol. Surv., 1888, especially map plate XLI, facing p. 418; Amer. Journ. Sci., 3d ser., vol. XXXIV, 1887, pp. 263, 368.
§ Fifth Ann. Rep. U. S. Geol. Surv., 1885, pp. 187, 188.

have had his mind on the upper Huronian. This supposition is strengthened by Irving's definition of the Huronian. He says:

"The series of rocks here displayed may be briefly characterized as a great succession of quartzose layers, including a subordinate quantity of graywackes [argillites and slate conglomerates as here designated], a much smaller proportion of limestone and chert, and numerous greenstones of eruptive origin, the latter occurring both in dike and bedded form."

Not a phrase of this is applicable to what we have understood by the lower slate conglomerate, though the definitions of Murray and Logan invariably embraced them, and hence Irving's opinion that describers had insisted too much on the chloritic and epidotic constituents.* Hence, finally, room for the conviction exists that Irving, when he identified the Animike and the Huronian, had in mind only the upper Huronian. In such identification we shall show that he was correct.

DISCORDANCES IN THE LAKE SUPERIOR DIVISION.

Logan's Views.—In the vicinity of Thunder bay, on the north shore of Lake Superior, the two systems of rocks which had been so easily confounded on the shore of Lake Huron present such unconformity as to render it impossible to unite them. The upper slate conglomerate presents a gentle inclination, and rests on the upturned edges of the lower slate conglomerate. Nevertheless, both were for a time described as different portions of the Huronian, just as they had been, and still are, confounded in the "original Huronian" (see *ante*, pp. 93, 97, 101). In both regions the system was conceived as reaching from the Potsdam sandstone downward to the gneisses, and that one system was Huronian. "The series of rocks occupying this country," says Sir William Logan, "form the connecting link between Lakes Huron and Superior to the vicinity of Shebawenahning, a distance of 120 miles, * * * [and] it appears to me, must be taken as belonging to one formation. On the west it seems to repose on the granite; * * * on the east the same supporting granite was observed by Mr. Murray. * * * The evidence afforded by the facts collected by Mr. Murray * * * is conclusive * * * that successive formations of the lowest fossiliferous group of North America" rest nearly horizontal on these uptilted beds. Thus "one formation" is included between the gneiss and the Potsdam sandstone.

At a later date Sir William Logan separated the rocks above the unconformity from those below, and restricted the term "Huronian" to those below, as first suggested by Murray in 1861. As the Huronian of Lake Huron was the seat of the Bruce and Wellington mines, he designated these rocks the "lower copper-bearing series," identifying with them the cuprif-

* See note, ibid., p. 188.

erous [Keweenawan] series of the south shore of Lake Superior. As the rocks above the break contained native copper, he designated them the "upper copper-bearing series."* This series was also manifestly divisible into two parts—the lower consisting of "bluish slates or shales, interstratified with sandstones and beds of columnar trap, and the upper of a succession of sandstones, limestones, indurated marls and conglomerates, also interstratified with trap, which is often amygdaloidal" (p. 67). We may speculate as to the motives which led to this arrangement. In the Huron region had been seen, indeed, the upper and lower types of slate conglomerate; but if their discordant structural relations had not been noted they could easily have been regarded as members of one system. At Doré river, on the east shore of Lake Superior, was a slate conglomerate, reproducing perfectly characters seen north of Lake Huron, and therefore unhesitatingly pronounced Huronian, and conceived as holding a geographical connection (*ante*, p. 94) with the system north of Lake Huron, not yet suspected of being duplex. At Thunder bay, north of Lake Superior, was a slate conglomerate of identical character (*ante*, p. 93); and having recognized that as Huronian, the upper slate conglomerate there was of necessity excluded, for there the discordance of stratification was glaring. Thus, since 1861, the "Huronian" of the east, north and south shores of Lake Superior has been understood as meaning the series of schists immediately succeeding the gneisses.

Views of Hunt and Lawson.—In 1873 Dr. Hunt† applied the term "Animike" to the lower group of the "upper copper-bearing series"—later equated with the Taconic—and the term "Keweenaw" (later "Keweenian") to the upper group of that series; while in 1866 Dr. Lawson applied the term "Keewatin" to the so-called "Huronian" or "lower copper-bearing series" of the north shore of Lake Superior.‡

Summary of Logan's Conception.—Sir William Logan's conception, therefore, of the taxonomic arrangement and equivalences of the Canadian rocks about the Great Lakes, may be set forth in the table which follows:

On Lake Superior.		*On Lake Huron.*
Potsdam sandstone.		Potsdam sandstone.
Unconformity.		*Unconformity.*
Upper Copper-bearing series	Upper group.	
	Lower group.	
Unconformity.		
Huronian, or Lower Copper-bearing series.		Huronian.
Gneiss.		Gneiss.

* Geology of Canada, 1863, chapter V.
† Trans. Amer. Inst. Mining Eng., vol. I, p. 339.
‡ Geological Survey of Canada, New ser., vol. I, Report for 1885, CC, pp. 10-15.

Views of the Author.—On the contrary, the succession and synchronism contended for in the present paper are set forth as follows:

On Lake Superior.	*On Lake Huron.*
Potsdam sandstone.	Potsdam sandstone.
Unconformity.	*Unconformity.*
Keweenian* (Upper group, Upper Copper-bearing series).	(Keweenian not known.)
Animike or Huronian (Lower group, Upper Copper-bearing series).	Huronian, upper.
Unconformity.	*Unconformity.*
Kewatian † (Lower Copper-bearing series).	Pseudo-Huronian.
Gneiss.	Gneiss.

UNION OF TWO SYSTEMS IN MINNESOTA AND THE NORTHWEST.

Views of Logan and others.—It is well known that the Animike slates continue southwestward as far as Pigeon river.‡ From Pigeon point westward they have been traced by Irving and N. H. Winchell as far as Grand Portage on the international boundary; and by the geologists of the Minnesota and National surveys as far as Gunflint lake, on the boundary.§ Between the vicinity of Thunder bay and Gunflint lake the older and vertically standing schists are entirely concealed, so far as the writer is informed, except at one locality near North Fowl lake.|| On the north side of Gunflint lake the vertical Kewatian schists emerge from beneath the Animike in a discordant outcrop which has been frequently described by the writer. The Animike has been traced in unbroken continuity still further westward to the vicinity of Ogishke-muncie lake, and, with interruptions, as far west as Duluth. Throughout this whole extent no one has ever suggested that the formation is not the same as occurs on Thunder bay, where Irving identified it with the Huronian of Lake Huron—meaning, as we understand him, the *upper* Huronian of Lake Huron, with which meaning we are entirely in accord. But from the vicinity of Ogishke-muncie lake, the vertical Kewatian system of rocks has been many times traced, without interruption, to Vermilion lake, where it embraces conformably the great iron-ore

* This group is thought by Irving unconformable with the Animike ("Copper-bearing Rocks of Lake Superior," 1883, pp. 157, 385, 405, 416–7). Hunt thinks the assumed upper beds (Nipigon group) distinct and unconformable (Min. Physiology and Physiography, 1886, p. 578; Azoic Rocks, 1878, pp. 240, 241), but Irving finds them beneath the Animike (ib., p. 157).

† A homophonous adaptation of "Keewatin" of Lawson.

‡ Logan, Geology of Canada, 1863, p. 77; Bell, Report Geol. Surv. of Canada for 1866–9, p. 322.

§ See the writer's memoir in Bull. Geol. Soc. Amer., vol. I, 1890, pp. 385–90.

|| Sixteenth Annual Report Minnesota Survey, 1887, pp. 284, 338.

deposits. In its various exposures it reveals all the characters of the vertical pseudo-Huronian schists north of Lake Superior which stand under the Animike. The evidence of this is spread on the pages of the Minnesota annual reports. These are the system of vertical strata which graduate conformably into crystalline schists and gneisses—just as Logan, Bell, and Macfarlane describe the vertical schists north of Lake Superior. Besides standing proximate to the crystalline beds, they are lithologically the same from Thunder bay to Vermilion lake—greenish, gnarled, silicious slates, often conglomeratic, but less so westward, passing to argillites, either characteristic, graywackenitic, or silicious; often, also, conglomeratic, as seen characteristically about Ogishke-muncie lake, and felsitic and poroditic schists giving evidence, greater or less, of intense metamorphic, perhaps eruptive, action, alternating frequently with beds of decayed diabases and intersected by well preserved diorites and diabases. If the identification of the Vermilion iron series of schists with those of Thunder bay is established, there can be no more uncertainty in tracing the identification to the east shore of Lake Superior, and thence, as we shall show, into the typical Huronian region.

Views of Irving.—But the late Professor Irving presents obstacles to such identification. He claims, as we do, that the Animike is the characteristic Huronian of Lake Superior; but he claims also that the vertical iron-bearing series of Vermilion lake is Huronian.* The iron-bearing schists are vertical and the Animike varies little from horizontal. The iron-bearing schists maintain their verticality as far east as Knife and Ogishke-muncie lakes. They are vertical at their exposure north of Gunflint lake. Schists lithologically identical are vertical at Thunder bay and on the east shore of Lake Superior. The theorem which Professor Irving attempted to demonstrate was the continuity of the vertical and the horizontal slates. He begins by attempting to invalidate, in part, the statements of Dr. Bell respecting the so-called Huronian north of Lake Superior:

"An examination of Bell's various reports upon the region north of Lake Superior seems to make it evident that in separating the Huronian from the gneisses of the region his only criterion has been the schistose or non-schistose character of the rocks. All rocks of strongly schistose character seem to have been regarded at once as Huronian. At times there seems to have been some difficulty, as, for instance, when mica schists have been found to grade directly into gneisses. That some of the rocks included within Bell's schistose belts are lithologically like the original Huronian there seems to be no doubt; but, on the other hand, there is reason to believe that schistose rocks do not occur as dependencies of the older gneisses. My own experience, indeed, leads me to believe that mica-schists, hornblende-schists and chlorite schists do occur in such relations [†]. I regard it, then, as a question still entirely open to investigation

*Archean Formations of the Northwestern States, Fifth Ann. Rep. U. S. Geol. Surv., 1883, pp. 206–208. Compare, also, Third Ann. Rep. Wis. Geol. Surv., 1880, p. 171; and Monog. V., U. S. Geol. Surv., 1883, pp. 399, 417.

† But the two former have seldom been included in the Lake Superior Huronian.

whether more than a small proportion of these folded schists be referred to the Huronian, although in the present state of our knowledge it seems probable enough that a large part of them should be so referred."

Before proceeding with this quotation one cannot help remarking that the diminution of the volume of vertical schists hardly facilitates the demonstration of their structural and petrographic continuity with horizontal schists not only contiguous, but actually overlying. But Irving proceeds:

"Accepting for the time some of them as Huronian, we are immediately confronted with a structural problem of a good deal of difficulty, *i. e.*, the relation of these folded schists to the unfolded Animike series. Generally, as the Animike series is traced towards its western border, it is found to lie against a belt of granite and gneiss. This is so along the shore of Thunder bay, and thence westward to Gunflint lake [*], and is true again at the Nesabi range and Pokegama falls district in Minnesota. North of the belt of granite again come the belts of folded schists [†]. The appearance thus presented is at first sight one of general unconformity between the flat-lying Animike and an older series, including the gneisses and folded schists. But a closer study of the folded schists indicates, as has already been shown by Bell, Chester, [N. H.] Winchell and myself, much lithological similarity between portions of them and the Animike series, so that a different structural hypothesis at once presents itself to the mind. This is the one that I have elsewhere illustrated and explained. The hypothesis is, briefly, that the Animike rocks were once continuous with the folded schists to the north of them, and that they were now separated merely because of the erosion of the crowns of the folds between them, the close folding of the folded schists being supposed, on this view, to have been produced concomitantly with the broad, simple bend which forms the trough of Lake Superior. On this hypothesis the folded schists of the north shore are compared with the unfolded Penokee of the south shore, and the folded schists of the national boundary with the folded schists of the Marquette and Menominee regions. All are supposed to represent a great sheet of Huronian deposits continuously spread upon a floor of far older gneisses and schists which have since been brought to view by folding and denudation." ‡

Objections to Irving's Hypothesis.—The nature of this hypothesis involves no action mechanically impossible; but we must test its validity by its adaptation to the particular case rather than by its abstract possibility. We deny, therefore, that any evidence exists that it represents the actual mechanism which wrought out the Archæan geology of the northwest.

1. The structural relations now existing between the Animike and the "folded schists" are evidence excluding the hypothesis. Professor Irving claims the flat-lying Animike of Thunder bay as Huronian, and he claims as Huronian the vertical schists on which this Animike rests. Now, we hold it as impossible to conceive of a method of common folding and denudation which would result in such a mode of superposition. Such super-

* North of Gunflint lake, however, the vertical ("folded") schists intervene between the Animike and the granite.

† See an exposition of the distribution of the schists in the author's memoir in Bull. Geol. Soc. Amer., vol. I, 1890, pp. 360–367.

‡ Fifth Ann. Rep. U. S. Geol. Surv., 1883, pp. 206, 207.

position of the Animike is now known in a dozen instances, but it is only justice to say that they were probably unknown to Irving.*

It is claimed, however, that the superposition north of Gunflint lake was known to Irving, but that he held the vertical schists here to belong to the crystalline series. That he was wrong in this assumption appears from the facts (*a*) that they have been traced again and again by the geologists of the Minnesota survey, with unimportant interruptions, through East and West Seagull lakes, Frog-rock lake, Kekequabic, Knife, Sucker, Basswood, Fall, Long and Burntside lakes, to Vermilion lake and beyond. (*b*) While these vertical schists on Gunflint lake are more crystalline than in many other districts, especially about Knife lake and the Vermilion iron mines, they are no more crystalline than the formation is on the eastern borders of Vermilion lake, about Dike and Zeta lakes, on the long eastern arms of Knife lake, along the southern shore of Sucker lake, and in many other regions.

2. The Animike is flat-lying, and the iron schists of Vermilion lake are vertical; yet Irving maintained that the iron schists are Animike. This made it necessary to assume, gratuitously, that the iron schists are in shallow folds, resting in a basin of older vertical schists. The impossibility of this explanation is apparent (*a*) from the assumption which it makes of vertical (iron) schists of later age, standing edgewise on the edges of schists of an older age.† Here we encounter again the impossibility of conceiving how, after the lower schists had been made vertical, the upper schists of later age could have been placed vertically upon them. If it is pretended that the upper schists are *less* vertical than the lower (as Irving's figures represent), we contradict the facts of observation; for they are *vertical*, and the lower cannot be more so. The explanation is impossible also (*b*) because we find the iron schists passing conformably in both directions across the strike, by the well-known gradations, into those very crystalline schists which the hypothesis supposes to be under them.

3. The inapplicability of Irving's hypothesis appears from the fact that the Animike, for six hundred miles east and west, is a formation comparatively earthy or non-crystalline, while the folded schists over the same distance are generally semi-crystalline.

4. Its inapplicability is shown by all the evidence which precedes; that the material of the folded schists was laid down and the sheets tilted and folded and denuded before the now flat-lying Animike was deposited.

Professor Irving's assemblage of thirteen detached formations which, by anybody, had ever been pronounced "Huronian," and his promulgation of them to the world, under authority of the United States Geological Survey,

* Cf. A. Winchell, Some Results of Archæan Studies, Bull. Geol. Soc. Amer., vol. I, 1890, pp. [illegible]6–390, and the references there made, which need not be repeated here.

†See his figure, Amer. Journ. Sci., 3d ser., vol. XXXIV, 1887, p. 259; also Seventh Ann. Rep. U. S. Geol. Surv., 1885–'86, printed 1888, pp. 421, 434.

as "the Huronian group," tested and proved, is an act of hasty generalization as difficult to reconcile with his acknowledged sagacity and learning as his hypothesis is difficult to reconcile with the facts. Yet it is apparent that in his successive publications he made progress toward true conceptions; and had it not been for early prepossessions, derived from the geology of Wisconsin, he must have obtained the simple clew which would have led to a solution of all the difficulties which beset him.

We think it may be concluded that the exceptional and apparently untenable views inculcated by Professor Irving should not prevent us from accepting the abundant evidence which we have of the existence of two systems of strata between the Potsdam sandstone and the fundamental gneiss.

The evidence of two systems could be traced much further. It could be pointed out in the Penokee and Gogebic regions, and in the Marquette and Menominee districts. In respect to the Marquette district, this was vaguely discerned by Irving, as it had previously been by Brooks, Röminger and Hunt; but Irving, of course, in identifying the Vermilion with the Gogebic and Penokee and part of the Marquette series, was misled by his antecedent assumption that it was a folded condition of the Animike.

Views of Lawson.—Much more clearly has the existence of two systems and the non-Huronian character of the older one been discerned by Dr. A. C. Lawson, whose field of work for several years was in the district of Lake of the Woods and Rainy lake, contiguous to Minnesota, and whose geological sagacity is most creditably reflected in his two reports.* After completing his field-work on the Lake of the Woods, he felt it incumbent on him to propose a new name for the assemblage of older folded schists, which had by his predecessors been denominated "Huronian." From his introductory remarks we make the following quotations:

"The schistose belt of the Lake of the Woods appears to me to differ from the typical Huronian of Sir W. Logan, both lithologically and in other respects. The typical Huronian of Logan is, from his description of it, essentially a quartzite series, in which the quartzites are true indurated sandstones [†]. The schistose belt of the Lake of the Woods is not so characterized. Quartzites form an extremely small proportion of the rocks of the Lake of the Woods, and they are only local developments in formations of mica schist and felsite schist. Bedded limestones are characteristic of Logan's typical series. On the Lake of the Woods there are, so far as I have been able to determine, no bedded limestones, the nearest approach to them being small segregated bands of dolomite of the character of veinstones. These two differences alone are sufficient to throw doubt on the equivalence of the two series, if lithological character is to be regarded as an aid to geological classification. There are, however, other differences. The basal conglomerate of Logan's Huronian [‡] on Lake Temis-

*Geology of Lake of the Woods, Canad. Geol. Rep. for 1886, Document CC; and Geol. of Rainy Lake, Canad. Geol. Rep. for 1888, Document F.

† This is Irving's generalization, as already shown.

‡ In point of fact the "basal conglomerate" in general was sometimes the upper and sometimes the lower slate conglomerate, and was always separated from the gneiss by an unknown interval or by a bed of greenstone schist. On Lake Temiscaming it was the lower slate conglomerate (see *ante*, p. 102).

caming is described as 'holding pebbles and bowlders sometimes a foot in diameter,' etc. * * * The rocks on the Lake of the Woods which are in the following pages referred to as 'agglomerate schists' are not basal conglomerates. They are not at the base of the series included in the schistose belt, nor are they apparently composed of water-worn fragments derived from the rocks upon which they rest.*

"The green slate rock conglomerates at the mouth of Doré river, Lake Superior, described by Sir William Logan [†], supposed by him to be the equivalent of the rocks of his main Huronian area, appear to resemble the agglomerate schists of the Lake of the Woods. This Doré river area of 'green slate rocks' is, however, geographically distant, and appears to differ from the series in the typical Huronian region [‡]. The rocks are described as standing in a nearly vertical attitude, while those of the latter are comparatively flat. Neither are they associated with beds of quartzites or limestones to a material extent. These differences, with the geographical separation, may, I believe, warrant us in considering the possibility of Logan having embraced under one designation two distinct series."

Personal Observations in the Echo Lake Region.

The Region studied and Murray's Views concerning it.—These observations, recently made, connect the "original Huronian region" north of Lake Huron with the areas assumed to be Huronian about Goulais bay and the mouth of Doré river on the eastern shore of Lake Superior. They tend to reconcile the conflict of opinion between Sir William Logan and his collaborator Murray and those who have maintained that the assumed Huronian of Lake Superior is wholly distinct from the "original Huronian;" and they do this by showing that the original Huronian was two-fold, while most of those who have reëxamined the original area have seen only the upper portion of the two-fold system. So we shall convict neither party of avoidable mistakes.

Our late studies extended from the Sault Ste. Marie to Great Lake George and several miles into the interior east of that lake. They extended inland north of the Ste. Marie for five or six miles and along the valley of Echo river to the lake of that name. North of the foot of the lake a traverse of a mile was made through a very broken country. The shores of the lake were studied and the examinations were extended two or three miles up Echo river beyond the head of the lake. But the most suggestive studies were made across the rough country stretching to the north of the head of the lake.

This whole country is laid down on Logan's map as Huronian, except a strip bordering Ste. Marie river. A graphic description of "Echo lake" and the surrounding country is given by Mr. Murray in the Report for

* The "agglomerates" described by Lawson are in the same stratigraphical position as the lower "slate conglomerate" described by Logan, and, according to the contention of this memoir, some of them are the equivalents of this slate conglomerate.

† Cited, *ante*, p. 108.

‡ See *postea*, on the geology about Echo lake.

1857,* and this is followed by a sketch of the "Character and distribution of the rocks;" the whole occupying six pages. The map represents the lower portion of the lake as bordered on both sides by the upper slate conglomerate and the northern two-thirds of the lake as in the lower slate conglomerate. Between them is a limestone band which crosses the lake, indenting conspicuously the east and west shores. The remainder of the country recently visited is mapped as underlain by the quartzites holding position at the top of the Huronian. Beyond the information contained in the Report for 1857, nothing has come to our knowledge touching the region here considered.

The region to the east of the head of Great Lake George, for an observed distance of eight or ten miles, is occupied by different members of the great quartzite formation. This is mainly the white quartzite division. But the red quartzite was occasionally seen. The pebbly character was very generally dispersed. The white quartzite is so massive that many observations and expedients are requisite for ascertaining the dip and strike. The only clews are the outcroppings of gigantic steps and the infrequent tendency of the pebbles to distribution in courses. The general dip, as thus ascertained, is about ten or fifteen degrees in a westerly direction. The quartzite is intersected by many vertical joints and a few veins. Some of these are small, recticulating, and filled with shining hematite, sometimes quite specular. Others are broader, reaching a width of twelve to sixty feet, and filled with a heavy, light gray, kaolinic substance, in which were innumerable particles of hematite not discernible by the naked eye. By an interesting change these are seen to grow, in certain portions of the vein, until a general red color is acquired and the vein is a "soft hematite," sometimes limonitic. In a more advanced stage the hematite is hard and even brilliant. But it is not known to be aggregated in workable quantity. The gray gangue is found, on analysis, to be largely silicious, with much kaolin and iron. Its specific gravity is 2.69. The quartzite is also intersected by vertical dikes of diorite, and in some cases these are accompanied by small veins of specular hematite.†

In approaching the foot of Echo lake by the deep and sluggish channel of Echo river we pass from the higher members of the Huronian to the lower. No outcrops, however, are seen along the immediate banks of the stream, though from the foot of the lake its shores are occupied by an unbroken series of outcrops. A section across the strata in this vicinity is given by Murray as follows:

* Geological Survey of Canada, Report of Progress for 1857. The reader may consult this map, figure 1, *ante*, p. 88.

† These veins have been more particularly described in the American Geologist, 1890, vol. IV, pp. 360–370.

9. Greenstone	700 ft.
8. Whitish or whitish gray quartzite passing into quartzose conglomerate with blood-red jasper pebbles	1,000
7. Dark-blue and blackish fine-grained slates with dark-gray quartzite	500
6. Slate conglomerate	800
5. Limestone	250
4. Slate conglomerate	1,000
3. Greenish, silicious slates, unstratified, with pale greenish quartzite	1,200
2. Greenstone	400
1. Green, altered slates of a chloritic character	1,000

Mr. Murray recognizes the two slate conglomerates as separated by the limestome, but his language would lead us to suppose them not separated by any considerable amount of other strata; and he may have overlooked or underestimated such intervening strata under the impression, which he brought from Thessalon valley, that the two slate conglomerates were one formation. He says:

"Both above and below the limestone the rock is a slate conglomerate, the base of which is usually of a greenish color, frequently having the aspect of an igneous rock; but it contains numerous rounded pebbles of various kinds, the chief part of which are syenite, quartz, gneiss and jasper. In some cases the conglomerate is very coarse, the pebbles or bowlders, as they may be called, forming the greater part of the mass. In other cases the rock is a fine compact slate, inclosing rounded masses of various sizes and characters, which are scattered through the slate at wide distances from one another."

"The rocks beneath the lower slate conglomerate are greenish silicious slate and pale-green quartzite. * * * These are underlaid by greenstone, and below the greenstone is a highly altered green chloritic slate, which is exposed in nearly vertical strata, forming high precipices at the extreme head of the lake.*

The limestone between the two conglomerates is set down, meantime, as having an "average inclination of about 25°" (p. 21).

Mr. Murray speaks of tracing the two conglomerates on their strike southeastward for a distance of about six miles, and says it is probable that the intervening limestone "holds the same course until it strikes the Thessalon and Ottertail lakes, on the Thessalon river, where it is already known to be exposed." But he nowhere gives a description of either slate conglomerate by itself.

The Succession on Echo Lake.—Now, let us consider carefully the stratigraphical succession seen along the shores of Echo lake. The upper slate conglomerate lies beneath the low ground which extends for about three miles to the foot of the lake. It is here succeeded (underlain) by a quartzite of a different character from the quartzites above the conglomerate, being, in its lower part, greenish or blackish and slaty. It passes thus from a

* Geology of Canada, 1863, pp. 22, 23.

massive fine-grained and vitreous quartzite above to a compactly silicious slate below. It holds ramifying veins of hematite, from which, in one place, two or three tons have been mined. This member of the system is indicated by the figure 2 in the accompanying diagram, though the examination of it was made at least half a mile back (north) from the lake. About three-quarters of a mile north of the approach of this quartzite to the shore occurs another in a low outcrop, having a dip of about 20°. This is dark bluish gray, very fine-grained, approaching vitreous (number 3 on the diagram). Half a mile beyond is the long, low projecting point of limestone. The external aspect of this outcrop is dark and indescribably rough. The forma-

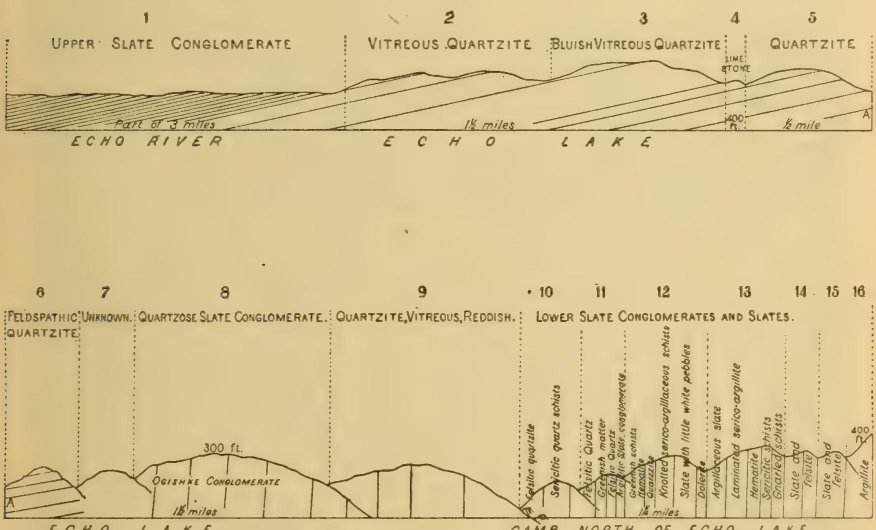

FIGURE 2.—*Section along Echo River and Lake and northward, showing Unconformity of Huronian and Kewatian.*

The numbers 1–16 designate regions described in the text.

tion is intersected by harder laminæ, which resist weathering, and project in thin plates one, two or three inches above the general surface. Being conformable with the bedding, they project at an angle of about 20° with the horizon, but they are grotesquely crumpled in consequence of the plicated condition of the formation. An attempt was made to photograph this surface (see cut, figure 3). The limestone weathers umber brown; but fresh surfaces are bluish gray and exceedingly fine grained, sometimes marked by delicate bands of harder texture and different color, but not generally brought out except by weathering. The point on the opposite side of the lake is similarly characterized. Toward the west the limestone rises in a high bluff-faced hill, which pursues a devious course as far as Garden river, one mile north of which it becomes the site of a marble quarry, yielding a delicate and beautiful product. Toward the southeast it has been traced for nearly six miles; but its continuity with limestones seen in the valley of the Thessalon is a question which will be taken up after completing a description of the section exposed along Echo lake and northward.

The breadth of the limestone outcrop is about 400 feet, if we take the mean of the points on opposite sides of the lake. Immediately north a hill

FIGURE 3.—*View of rough Surface of Echo Lake Limestone.*

(number 5) rises on the western shore about 100 feet, and the rock exposures present every appearance of a quartzose character; but the hill was not ascended. In close contiguity is another (number 6), which examination showed to be essentially quartzitic and finely granular, with minute disseminated individuals appearing like reddish orthoclase, but which in thin section prove under the microscope to be, in part, specks of iron peroxide. This formation is very thick-bedded, and dips about 20° toward south 40° west. Thus it appears that though the limestone is between two slate conglomerates it is separated from the upper by 2,700 feet, and from the lower by 900 feet. In other words, the slate conglomerates are here at least 3,700 feet apart.

Beyond this for the space of one-third to one-half a mile the high hills (number 7) were not examined, but still north for the distance of one and a half miles the talus (numbers 8 and 9) is composed of fragments of dark, hard, greenish slates and argillites, among which are many enormous blocks of a conglomerate closely similar to the vertical conglomerates on the shore of Thunder bay, Lake Superior, with the fractures passing through the pebbles. The hill (number 9), however, is essentially a reddish, vitreous quartzite. Neglecting the results of observations made in traveling about two miles up the river entering at the head of the lake, we pursue a traverse nearly north through the wilderness. Ascending the first hill (number 10), the lower surface is covered with angular fragments of reddish and felsitic quartzite, succeeded by sericitic quartzose schist and many large masses of slate conglomerate, of which the slate is dark greenish, considerably warped and twisted, and the pebbles partially rounded, reddish, mostly of feldspar, with some of quartz. Some of the pebbles are smoothly rounded. Near the top of this hill (number 10), which is about 125 feet high, the slate conglomerate is in place, apparently standing about vertical. It is knobbed and rough, and strikes about east and west.

Climbing the next hill (number 11) and still maintaining a general northerly direction, many sharp, angular fragments of felsitic quartzite are encountered, and some greenish argillitic matrix of slate conglomerate. Toward the summit are beds of felsitic quartzite, standing vertical, and striking north 70° west and north 60° west. There are also many rounded bowlders of red jaspery quartzite, with black flint and glassy quartz. With these are fragments of hard, bluish, non-fissile, argillitic slate, with laminæ of felsite, and also fragments of petrosilex.

On the summit of the third hill (number 12), about 400 feet above the lake, is seen vertical, knotted, serico-argillitic schist, woven into meshes by half-inch thick quartz veins. In this vicinity occur outcrops of hematite, ochreous on surface and joints, but solid, and consisting of compacted lamellæ, remote from surfaces. The country rock here is quartz, and the iron occupies little nests in it. The formation, however, seems to be originally a greenish schist, which has been cut by quartz veins in such number and magnitude as to have mostly replaced the schist in some places, though in others considerable areas of the schist remain. Down west from the summit of this hill, 50 feet, is another occurrence, with the gnarled greenish slate more abundant. The formation dips about 85° southwesterly. A hundred and fifty feet beyond, the slate is comparatively free from quartz, but contains courses of granulite pebbles. The slate formation shows an even surface, with lines of bedding very distinct, and running north 55° west. Here and there the pebbles appear at the surface, exactly as in Minnesota. In this place the slate is argillitic and not gnarled.

Going one-eighth of a mile east, we arrive at a huge mass of diorite with bright black hornblende and red feldspar. This is just west of the highest peak (number 13).

Immediately east of this the slate appears again. Nearer the summit the slate is laminated, sericitic argillite standing about vertical. Still nearer the summit is a considerable iron location, partly exploited. In the pit the rocks lie in such confusion that no system of structure can be discovered. On the slope above the pit are remnants of laminated sericitic schist squeezed in between masses of quartz in most irregular fashion. The trench dug here is east and west, but this does not appear to be the strike of the formation. There is neither distinct vein nor stratum. From a central tract, along which the iron is most concentrated, it diffuses itself through the quartz-charged formation, so that the breadth of space showing good indications of iron is about eight feet.

Close by this the sericitic argillite, standing vertical, strikes N. 75° E. On the north side of this pinnacle, overlooking Fairy lake, the gnarled Kewatian schists outcrop in frequent ledges.

Passing on to the northeast, a cliff (number 14) is reached, in which slate and felsite are so mixed that the attitude of the formation could not be readily determined. In the hill (number 15) separated from the last by a ravine is an outcrop petrographically similar, and with strike and dip equally uncertain.

Continuing northward across another ravine, we find (in hill number 16) regular blue-black argillite, the exact counterpart of that about the western end of Knife lake in Minnesota. The strike appears to be N. 50° W., but after climbing over an enormous talus of huge sharp-edged fragments and seeking the mass of the formation, we found bedding lines, cleavage and joints in such a state of obscurity that we reached no certain conclusion. We incline, however, to regard the cleavage coincident with the bedding. The sight of these smooth-faced slabs afforded relief to the eye so long accustomed to the harsh surfaces, twisted fibers and knotted structures of the green schists associated with the lower slate conglomerate. The day was too far spent to pursue the traverse further. We may fairly conjecture, however, what would be probably the further succession of strata to the passage into crystalline schists and gneisses.

These ancient schists have been traced westward from Echo lake half way to Goulais bay, on the east shore of Lake Superior. We know that similar schists exist in the rear of Gros Cap, and probably connect with those at Goulais and Bachewahnung bays. We feel great confidence in conceiving a continuity between them and the schists of Echo lake. We know that the same schists and schist conglomerates reappear at the mouth of Doré river, and we are not disposed to differ from Sir William Logan in following the same formation as far as Thunder bay.

In the opposite or southeastern direction from Echo lake the lower slate conglomerate mass trends toward the similar mass seen on the north side of the valley of Thessalon river, especially in Murray's hill, on the east of Rock lake. This vicinity is appropriated, on Logan's map, to the *upper* slate conglomerate; but, as we have shown, the upper slate conglomerate terminates three miles south and is followed by felsites and felsitic quartzites, and this is, therefore, the *lower* slate conglomerate. Logan has located a "supposed outcrop of limestone" to the north of this, and has connected it with the Echo lake limestone toward the west, and extended it as far as Wahbiquekobing lake on the east; and then, by the manipulation of supposed faults in the valley of the Thessalon, has caused the limestone to reäppear nearer the coast and pass into the observed position of a limestone back of the Bruce mines. The Bruce limestone should then be identifiable with the Echo lake limestone—a question which we shall presently examine. In the intervening distance between these two branches of the limestone belt designated "3*e*," Sir William locates the similar branches of a calcareous formation designated "3*k*, Yellow chert and limestone." This is represented as coming between two quartzites, as "3*e*" is put down between two slate conglomerates. The whole geologic structure is worked out with consummate ingenuity on the assumption of faults in such places as would be necessary to produce the results depicted on the map. That a synclinal exists along the Thessalon valley it is easy to admit after an examination of the complementary dips. That the assumption of faults would afford easy explanations of phenomena as identified and understood by Logan will not be disputed. But to us who have studied a considerable part of the field, the numerous Logan faults appear a heavy tax on credulity and introduce what appears an artificial complexity in the geology of the region. It is admitted, however, that one or more faults probably exist—possibly all those laid down on the map.

Now, it was the opinion of Mr. Murray that the Echo lake limestone trends more to the southeast than Logan has represented, and makes connection with the limestone of Ottertail lake and Thessalon river, and, by means of a flexure, with the Bruce limestone also. Our petrographic examinations show that Murray was probably correct.

Microscopic Characters of Echo Lake Rocks.—Thin sections of the limestone from the western side of Echo lake (XXVI, 11 and 12) * show it to consist of very fine rounded grains of calcite, mostly quite refractive and showing extinctions on rotation. The grains are closely compacted, with very little interstitial matter. The dark linear bands are composed of matter of decomposition; apparently an argillaceous residuum after the solution of the calcareous matter of some portion of the original material. The rock contains occasional minute grains of quartz. This limestone is evidently fragmental, formed of grains of an older crystalline mass; at least of crystal fragments

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* Our examples of these limestones are registered as follows, the numbers in parentheses referring to thin sections: Ansonia, 409 (IX, 6), 410 (IX, 7), 449 (XII, 11), 450 (XII, 12), 452 (XII, 14; Ottertail, 438 (XII, 6), 439 (XII, 7); Bruce, 388 (VII. 6); Echo lake, west side, 1092 (XXVI, 11), 1093 (XXVI, 12), 1095 (XXVI, 13), 1107 (XXVI, 16); Echo lake, east side, 1096 (XXVI, —); Garden river, 1108 (XXVI, 14).

which have been rolled on the shore of a gentle sea, with frequent intervals of calm, accompanied by aluminous deposition. Limestone from the east side of Echo lake (XXVI, 13) presents almost exactly the same appearances, with a slightly larger volume of decomposition products giving denser lines of argillaceous deposition. An occasional rufous tinge is due undoubtedly to the presence of iron peroxide.

We have on other occasions examined outcrops of limestones at Ansonia, in the valley of the Thessalon,* and near Ottertail, on Ottertail lake, and brief notices of them are here introduced for comparison. The external characters of the Ansonia limestone (IX, 6, 7), especially pinkish samples, are exceedingly like those of the Echo lake limestone;* but there is a greater amount of flocculent matter, and the calcitic individuals are sometimes large enough to show cleavage cracks. Occasionally they are large enough to give the rock a sparry character (XII, 14). There appear, also, numerous bright green grains, apparently chloritic, and disseminated black opaque specks which appear to be anthracitic. The thin section (IV, 6) is composed of rounded grains, but with a greater frequency of silicious particles. The specimen, however, is not so exclusively fragmental, for there are areas of identical crystalline orientation across which calcitic cleavage may be traced. But these may be only larger fragments of the original material. Some of these sections (IX, 7; XII, 11) show the argillaceous banding seen at Echo lake so perfectly that one cannot doubt the identity of the formation. Many examples (XII, 12) from Ansonia have a semi-brecciated structure, with not a little angular quartz; but this condition is evidently due to the action of the dike there present. Other portions of the same specimen pass to the fine condition of the Echo lake limestone.

The limestone called "lithographic," from near Ottertail (XII, 6), is greenish, excessively fine-grained, weathering buff, with numerous refractive specks disseminated, and also stick-like objects, resembling ground wood-fibers, lying in all directions. In thinnest section the rock structure is fine as that of a precipitate. One condition of the Ottertail limestone, 439 (XII, 7), is a little brecciated, as at Ansonia. The color is dun as at Echo lake, but near the weathered surface it is dull pink. The lines of sedimentation are distinct and delicate. Disseminated through certain portions of the rock are angular and rounded grains of quartz, as also the wavy and fiber-like objects before mentioned.

The comparison of specimens from Echo lake with others from the Thessalon valley makes it quite clear that we are dealing with one and the same formation.

On the other hand, the Bruce limestone, 388 (VIII, 6), is composed of calcitic grains ten times as coarse, without any trace of quartz, and with the interstices filled with decomposition products. Its bedding is much less com-

* Sixteenth Ann. Rep. Geol. Surv. Minn., 1887, pp. 155, 23-50, and pp. 158, 28.

pact and approaches a shaly character. But while so strikingly distinct from the Echo lake limestone, we are finally impressed with the suspicion that the Bruce limestone is the same formation, but deposited nearer the shore, or, at least, in less quiet waters.*

Conclusion.

Two Systems of Rocks in the Huronian Region.—Now, since the position of the Echo lake limestone is between the upper and lower slate conglomerates, the Ansonia and Ottertail limestone must hold a similar position—that is, it must be in the position of Logan's "*e*, Limestone;" and hence Logan's "*k*, Yellow chert and limestone" is the same thing, and has no separate existence, as indicated by him. In a table, however, which we have published,* we placed the Ottertail limestone above the upper slate conglomerate, thus, though on independent evidence, agreeing with Sir William Logan; but it is probable we both have been in error. If, then, things are so, the geographical position of the Ottertail limestone remains to be explained, as both slate conglomerates lie on the same side of it; and we may need to invoke a fault to bring it up from a position 9,500 feet below. We may still be in ignorance of a limestone actually seen between the two slate conglomerates as occurring in the Thessalon region. But this ignorance is not fatal, for it may result either from insufficient observation or from a local absence of the intervening limestone.

But the adjustment of the complicated geology of the Thessalon valley is not necessary to the establishment of our main contention. We have shown that in the original Huronian region there are two systems of strata, petrographically dissimilar and structurally unconformable, the characteristic part of one being the upper slate conglomerate, and of the other the lower slate conglomerate. We have shown that the same two systems exist on Thunder bay and in northeastern Minnesota, as also, apparently, in the Marquette, Gogebic and Penokee regions. We have identified the upper system on Thunder bay and in Minnesota with the upper system north of Lake Huron. We have identified the lower system on Thunder bay and in Minnesota with the lower system north of Lake Huron. We have shown that if any doubt could exist respecting the distinctness of the two systems north of Lake Huron, none can be entertained (as none has been entertained for many years) respecting their distinctness on Thunder bay and in Minnesota.

But both these systems were included in the Huronian, and are still included in it on the north shore of Lake Huron. Both were also included at first in the Huronian of Thunder bay, but since 1848 the upper has been excluded, and the name Huronian has been applied only to the lower; while,

*Sixteenth Ann. Rep. Minn., pp. 569, 570.

by a singular, but sagacious, contrariety, Irving applied the term Huronian only to the upper.

The Name "Huronian" must be restricted to the upper System.—Clearly, the interests of geology and of truth demand an adjustment of these conflicting conditions in terminology. If Sir William Logan unwittingly extended the term Huronian over two systems now known to be distinct, that usage cannot be continued. Either the name must be restricted to the upper system or it must be restricted to the lower system or it must be relegated to synonymy. We think it may may be appropriately attached to the upper system. The early Canadian geologists sought a term which would cover, first and chiefly, the great quartzites which were found to follow the Silurian strata in downward succession. Underneath were seen so-called chloritic schists and a slate conglomerate, In the region first studied these were seen to rest on crystalline rocks and appeared to fill completely the gap between the Silurian and the gneisses. These strata were all conformable and evidently constituted a system. If it had not been previously named, the Canadian geologists conferred a service on science in giving it a designation.

Soon, however, older schists than these were described, but since their structural discordance with these was not striking in the original region, as known thirty years ago, and since their conglomeratic and slaty characters were similar to those in some strata of the system first named, it was natural, or at least it was venial, to include these latter with the former. If, now, we have learned that they are geologically incongruous with the higher, it appears obviously necessary to drop them off, however prolonged the period in which they have been associated together.

This is the view which we have maintained for several years. We have insisted that the so-called Huronian of Lake Superior is an older system than the Huronian of Lake Huron. But we were not aware, it must be confessed, until our recent studies, that the same older system was actually present north of Lake Huron.

If, then, we restrict the term Huronian to the upper system it remains attached to the best-known and characteristic portion of the old complex Huronian. There will remain the older system, not distinctively named until Dr. Lawson in 1886 bestowed upon it the name "Kewatin." In volume, in petrographic and stratigraphic characters, it is a system. It should therefore receive a name of systemic form. Such name is *Kewatian*, homophonous with Huronian, Silurian and the remaining systemic names.

Whether the term Huronian must not yield to the priority of Taconic or Cambrian we will not discuss. Whether Kewatian can take precedence over Azoic, Taconic and Cambrian, remains to be decided. It is the misfortune of all these names, except Kewatian, that they were originally intended to cover a complex of strata which has been proved to constitute two distinct systems.

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THE NICKEL AND COPPER DEPOSITS OF SUDBURY DISTRICT, CANADA.

BY ROBERT BELL, B. A. SC., M. D., LL. D., ASSISTANT DIRECTOR OF THE GEOLOGICAL SURVEY OF CANADA.

With an Appendix on

THE SILICIFIED GLASS-BRECCIA OF VERMILION RIVER, SUDBURY DISTRICT.

BY GEORGE H. WILLIAMS.

(*Read before the Society December* 31, 1890.)

CONTENTS.

INTRODUCTION.

The town of Sudbury, a creation of the Canadian Pacific railway, is situated in the backwoods of Ontario, thirty-six miles north of the mouth of French river, on Lake Huron. Parts of the surrounding country are tolerably level, but in a general way this region may be said to be hilly. Some sections are very broken and rugged, while in others rocky ridges alternate with swamps or alluvial intervals. Occasional tracts of land are fit for cultivation, but, as a rule, where the surface does not consist of rock or swamp it is much encumbered with bowlders. At one time the district supported large quantities of white-pine timber, but forest fires at different periods have destroyed the greater part of it and inferior kinds of wood are now growing up in its place. Rock maple, red oak, black birch and other hard woods form considerable groves in some sections. The general elevation of this tract is probably between 800 and 1,000 feet above the sea.

The construction of the Canadian Pacific railway in 1882 led to the discovery of nickel and copper, besides various other metals, in this part of the province, and now the Sudbury district promises to become of great importance as a mining region. It may be remarked in passing that Sudbury is not the name of a political division but is merely a convenient designation, in connection with mining, for the territory lying partly in the district of Nipissing and partly in that of Algoma.

The Geology of the District.

As a preliminary to the proper understanding of any account of the nickel and copper deposits of the Sudbury district, some remarks on the geology of the region will be necessary. The district is situated in the course of the best known and perhaps the longest Huronian belt in Canada. Beginning in the west, the general northerly boundary of this great belt commences at the promontory of Namainse* on the east side of Lake Superior and runs approximately parallel to the shore of that lake, the St. Mary's river and the north shore of Lake Huron as far as Spanish river, leaving a border of Huronian rocks of varying width between the water and the Laurentian nucleus to the north. Near Spanish river the dividing line between the two systems turns inland and runs northeasterly nearly to Lake Wahnapitæ, whence it trends northward and northwestward till it gains a point lying northeast of Michipicoten on Lake Superior, thus almost surrounding a large elliptical area of Laurentian rocks.

The boundary between the Huronian trough and the Laurentian system along its southeastern side leaves the shore of Lake Huron at Shibaonaning ("Killarney") and runs in a tolerably direct line to the foot of Lake Temiscaming at the great bend of Montreal river, and thence it continues in a somewhat zigzaging course nearly to the southern end of Lake Mistassini, 335 miles due north of Montreal, or a total distance of 600 miles from the commencement of the belt on Lake Superior in a general course, or 700 miles, following the axis of the trough. Lake Wahnapitæ lies at the upper extremity of the contracted portion of the Huronian belt after it has turned northeastward from Lake Huron, but beyond it these rocks spread out widely to the northward.

Within the general limits of the Huronian region just sketched, we find a good many inliers of gneiss and red quartz-syenite, some of which correspond with Laurentian types of these rocks, and it is uncertain whether they are

* Meaning, little sturgeon; often improperly spelled Mamainse.

protrusions of the older rocks from beneath or whether some of them may not be portions of the Huronian itself which have undergone further metamorphism. Among these inliers the following may be mentioned: A large one between Goulais bay and St. Mary's river; a long narrow one occupying the shore of Lake Huron between Thessalon and Mississagui rivers; a small one in the township of McGiverin; three on Lake Wahnapitæ; one at Paul's lake on Sturgeon river; one to the east and one to the north of Lake Temagami; one on Lake Temiscaming; two on the main Montreal river, and several on its upper branches.

In the middle of that portion of the belt in which Sudbury is situated there is, besides the inliers mentioned, a long tongue of gneiss and red quartz-syenite, which begins beyond the northeast corner of the township of Garson and runs southwestward into Denison, a distance of thirty miles, and is joined to the main body of these rocks to the westward by dark gray, rather fine-grained, imperfect quartz-syenite and gneiss, which may be seen all around Wia-shai-gaming (or "Fairbank") lake.

The gneiss and the quartz-syenite of these isolated areas in the Sudbury district replace or pass into each other in such a way that it would be very difficult to represent them separately on a geological map. A singular feature about them is that both kinds are in many places broken up into separate masses like large and small bowlders, the interspaces being filled by a breccia with a dioritic paste, of which the fragments consist of the country rock or of a finer or preëxisting breccia of the same composition. This takes place over such considerable tracts as to suggest the idea that these rocks may be underlain at no great depth by diorite which was in a soft condition after the gneiss and syenite had been consolidated.

The narrowing of the Huronian belt, which happens in the Sudbury district, is due to the extension into it, from the westward, of a large area consisting mainly of red quartz-syenite. This rock is of a medium texture and has a very uniform character over several thousand square miles, except that in some parts it gives place to red syenite without quartz and in others to ordinary gneiss. The relation of this great syenite area to the vast Laurentian country to the northwest has not been carefully determined, but it appears to merge into the prevailing gneiss in that direction and is certainly connected directly with that terrane.

At some places within the syenitic area, as for example about two miles west of Cartier, a massive fine-grained rock, like some varieties of graywacke, may be seen passing into thoroughly crystalline quartz-syenite. The fine-grained imperfect gneiss and quartz-syenite around Fairbank lake may represent one of the earlier stages of the coarser and more crystalline varieties of these rocks. An ordinary looking variety of gneiss is being formed out of a slaty kind of graywacke in the township of Hyman.

In the district under consideration the main line of the Canadian Pacific railway crosses, almost at right angles, the narrowest part of the Huronian belt proper, which has here a width of only about twenty-four miles. The strike is therefore northeast and southwest, and in this pinched portion of the trough the rocks on the opposite sides dip at high angles toward the center. Sudbury Junction is situated southeast of the center of the trough, and from it the Sault Ste. Marie branch of the railway runs upon the general strike of the Huronion rocks throughout almost its entire length. At thirty-three miles northwest of Sudbury Junction, or near Geneva lake, the main line enters upon an outlying basin of stratified Huronian rocks measuring eight miles in width on the railway by seventeen in length from northeast to southwest, and having a long point running westward into the township of Craig. This, for convenience, may be called the Geneva lake outlier. At the southern extremity of Onaping lake, a few miles to the north of this outlier, there is a smaller one, measuring only three miles in width by four in length.

The various members of the Huronian system in the Sudbury district are of much interest in connection with questions relating to metamorphism and the origin of crystalline rocks, and also as illustrations of the general character of the system in this part of Canada. They consist principally of graywackes and quartzites, various forms of diorites, quartz-diorites and hornblende schists, mica schists, diabases, argillaceous sandstones, black and drab clay slates, together with volcanic breccias, in addition to the gneiss and quartz-syenite already referred to.

The rocks which occur in greatest quantity in the stratified Huronian belt between lakes Huron and Wahnapitæ, and which constitute the lowest members of the series, are quartzose graywackes and quartzites, with occasionally a little felsite. Thick bands of quartzites, mostly very light in color and standing at high angles, form the conspicuous range of La Cloche mountains overlooking Lake Huron and the long narrow points projecting into that lake between Spanish river and Killarney. The fact that this great local development of quartzites happens to occur at the most accessible part of our principal Huronian belt has given rise to the erroneous notion that the Huronian rocks of Canada in general consist mostly of these rocks. The quartzites of the region about La Cloche appear to belong to three or four belts which double around in a synclinal form, and are thus repeated within comparatively narrow limits. Quartzite constitutes the principal rock all around Lake Panache and along the lower parts of Vermilion and Spanish rivers, but further to the northeastward, or in the contracted part of the belt of the Sudbury district, the corresponding rocks, with a greatly diminished volume, are much mixed with felspathic and argillaceous matter, constituting massive graywackes; while still further on, or in the country east of Lake Wahnapitæ, they have passed almost entirely into pure argillites, which are there very extensively developed. To the north of Lake Wahnapitæ the quartzites reäppear in great force. On the opposite or northwestern side of the Sudbury trough this series is represented by a thick band of gray quartzite, which appears to be always characterized by scattered pebbles of white quartz, but it is insignificant in volume compared with the quartzites and graywackes along the southeastern side of the trough.

In the graywacke and quartzite area of the region under consideration the crystalline diorites occur as numerous intruded masses, varying from half a mile to ten miles in length. They are of various forms, but their greatest diameters are approximately parallel with the strike. The rock is generally of a dark or sea-geen color and moderately finely crystalline. Three or four of these masses occur around Lake Panache and nine or ten to the northeast, between this lake and the Canadian Pacific railway line, and seven more beyond that part of the railway between Sudbury and Wahnapitæ river. About a dozen small diorite areas have been found in the quartzite and argillite region around Lake Wahnapitæ. Besides these massive diorites, bands of obscurely stratified varieties of the same rocks, of quartz-diorite and of dioritic and hornblendic schists are sometimes associated with the quartzites and graywackes in the townships of McKim and Denison, in the Geneva lake outlier, along Spanish river and around Lake Wahnapitæ. A beautiful and very coarsely crystalline hornblende rock occurs near the Dominion, the Stobie, and the McConnell mines and in a few other localities.

Bands of compact brown-weathering dolomite, generally whitish and dove-colored, occur locally in the graywacke and quartzite series. They are found in considerable volume on different parts of Lake Panache, and they occur also near Lake Huron in the township of Rutherford, on La Cloche lake, on Wahnapitæ river, on Geneva lake, and near Cartier station. Similar dolomite is occasionally found as patches in the finer-grained syenite or altered graywacke.

Two long and remarkable intrusions of diorite of a gray color and having a coarser texture than those already described are found cutting the gneiss and quartz-syenite areas of this region. They are each about a mile wide in the middle. Both run northeast and southwest, or parallel to the general strike of the stratified portions of the Huronian rocks nearest to them, and diminish to narrow points at the extremities. The first of these commences at Whitson lake, in the township of Blezard, and runs southwestward into Denison, a distance of twenty-four miles, while the second has been traced from the northeastern part of Levack for about eighteen miles southwestward. Most of the heavier deposits of nickeliferous ore, so far discovered, are associated with these two diorite belts, and they will be again referred to in this connection. A smaller dioritic intrusion, apparently of the same class as those two and running parallel with them, is found in the northeastern part of the township of Morgan.

The next member of the series, in ascending order, is the most remarkable of all. It consists of a thick belt of nearly black volcanic breccia, which has been traced from Vermilion lake northeastward in the valley of Vermilion river to beyond the latitude of Wahnapitæ lake. It is a compact silicious rock, with conchoidal fracture and consists of angular fragments, mostly small, closely crowded together and flecked with irregular angular white spots. These Dr. G. H. Williams finds to consist of fragments of pumice, which, while retaining their structure, are completely replaced by silica. This band appears to be several thousand feet thick and, as it has resisted denudation well, forms an elevated, rough and broken country along its whole extent.

The highest rocks of the series in this district, or those which occupy the center of the trough, are made up of evenly bedded drab and gray argillaceous sandstones or graywackes, interstratified with shaly or slaty belts, and overlain at the summit by black slates. As these rocks dip at comparatively low angles, they occupy a greater geographical width than the other members in proportion to their thickness, which, however, must be very considerable.

Along the lower part of Spanish river, above and below the great bend, the Huronian belt has a wider spread than near Sudbury Junction and here we find a considerable development of rocks associated with the quartzites which are not met with to the northeastward in the district under consideration. Among these are, soft bluish-gray satiny sericitic schist, sometimes ligniform, accompanied by nearly black hornblendic schist; coarse and fine-grained glossy green and greenish-gray schist; silver-gray fine-grained mica-schist, studded with crystals of staurolite; hard green schist; dark-gray clay-slate; fine-grained greenish-gray silicious felsite; and slaty graywacke, passing into gneiss.

The stratified Huronian rocks and also the gneiss and quartz-syenite of Sudbury district are traversed by dikes of gray, coarsely crystalline diabase, which are often large and can be traced for considerable distances. Their commonest course is about west-northwest. They all have the same physical characters and appear to be of identical composition. The sound, fresh rock is extremely tough, but the exposed surfaces disintegrate easily under the weather into brown crumbling débris, especially along the joint-planes and at their angles. The outer portions of the masses thus separated scale off concentrically, so that they become rounded and bowlder-like. These dikes, as we shall show further on, apparently play an important part in the economic geology of the district.

The Ores and their Associations.

Referring now to the nickel and copper ores for which this district is becoming famous, it may be remarked, in the first place, that there is much uniformity both as to the characters of the ores themselves and the conditions under which they occur. Yet these deposits are not confined to the undoubted Huronian rocks, but are equally abundant within the gneiss and quartz-syenite areas. They may be said to be connected with a certain geographical area rather than with a single geological horizon. In other words, it would seem as if, within certain limits, the ores might have had their origin beneath all the rocks found at the surface. The ore consists in all cases of a mixture of chalcopyrite and nickeliferous pyrrhotite. The area over which this ore has been found up to the present time extends from the Wallace mine, on Lake Huron, in the vicinity of La Cloche, northeastward to the north side of Lake Wahnapitæ, a distance of about seventy miles, and from the southeastern boundary of the Huronian belt, in the Sudbury district, northwestward to the limits of the Geneva lake outlier, a distance of about fifty miles.

It is rather singular, first, that pyrrhotite should exist so commonly within this region as compared with any other in the country, and, secondly, that no matter in what kind of rock we find it to occur, it should generally be nickeliferous to an economic extent. Although, as a rule, pyrrhotite, wherever found, contains traces of nickel, it has only been detected in commercial quantities in a few places in other parts of the world.* The investigations of the writer in the Sudbury district have shown that the combined nickel and copper ore is found on or near certain lines of contact between diorite, on the one hand, and gneiss or quartz-syenite most frequently on the other, but only at certain points on these lines. As no circumstance is without a cause, we may look for some reason which determines the concentration of the ore at one place more than another, and the writer believes he has found the reason in this case to consist in the intersection of the ore-bearing belts near these occurrences either by one of the diabase dikes above described or else from the pinching in or perhaps from a transverse disturbance of the belt.

The ore seems to have been derived in all cases from the diorite, but for some reason the proximity of the gneiss or quartz-syenite appears to be also favorable for the production of the large deposits. If the diorite flowed out originally upon the nearly horizontal surface of the other rock, the constituents of the ore which it contained may have sought the

* Assays have recently been made of samples of pyrrhotite from near Shreiber and Jackfish bay, Lake Superior, and from the counties of Peterboro', Hastings, and Lanark, in Ontario, none of which yielded more than traces of nickel.

lower portion of the mass; or if it were injected between the preëxisting rocks, these materials may have been impelled to the sides.

In some cases the belts of diorite are much broken up and disturbed longitudinally, and along these horizons they are mixed with large and small fragments of other rocks showing lines of volcanic movement during their formation. Examples of coarsely brecciated diorite of this kind may be seen near the Dominion mine, the Stobie mine, and thence southwestward to beyond the Canadian Pacific railway, at the Copper Cliff, the Crean or McConnell and the Vermilion mines, in Denison, at Ross' location north of Morgan township, in the northeastern part of Levack and near the western end of Bannerman lake. This condition of the diorite seems favorable for the production of the ore, probably on account of the physical disturbance which it indicates. The lines of northeast and southwest disturbance, along which successive occurrences of the ore are found, cannot always be traced continuously on the ground, but as the evidences of such disturbances make their appearance from place to place upon these lines, and as geological breaks are apt to be very persistent, we may infer that they are continuous.

The first of the two long, narrow intrusions of gray crystalline diorite which have been referred to, in its course from Whitson lake to the township of Denison, cuts off a narrow slice all along the southeastern border of the tongue of gneiss and quartz-syenite which lies in the middle of that part of the Huronian belt. The ore deposits of the Waddell, Dominion, Russell, Little Stobie, Murray, McConnell (in Snider), Lockerby and McIntyre properties, of lot 10, range I, of Snider, of the Crean or McConnell mine, and of the "mineral range" of Denison appear to be all situated along the southeastern side of this diorite intrusion, or in its course, when it becomes narrow; while those of the Stobie and Frood mines and the other occurrences for two miles southwest of the former, of the Copper Cliff and others in the vicinity, of the Evans, of lot 12, range III, of Graham, and of the Vermilion mine lie along the southeastern side of the separated slice of the gneiss and quartz-syenite range just referred to, and mostly within the diorite belt which skirts it on that side.

The north wall of the Copper Cliff mine is formed of felsite, quartzite, and a coarse red mixture of feldspar and quartz, besides diorite like that of the south wall; but the ore itself is invariably associated, here as elsewhere, with the diorite. The Evans mine is situated further from the contact of the gneiss than any of the others. The top of the ridge on which it occurs consists mostly of graywacke, but the ore is accompanied by diorite which in parts passes into a kind of soapstone or serpentine. A break in the continuity of the gneiss and quartz-syenite ridge runs northwestward across it from the Copper Cliff to the McConnell mine, and all along this break there are evidences of the existence of the ore, accompanied by crystalline and schistose diorites and a brecciated condition of the gneiss and quartz-syenite. The Evans mine appears to be connected with a continuation of this break.

A number of more or less promising occurrences of the mixed ore have been found in the two southern ranges of Denison, in Louise, Lorne, Nairn, Baldwin, Drury and Hyman, and further north in Neelon and McKim. All

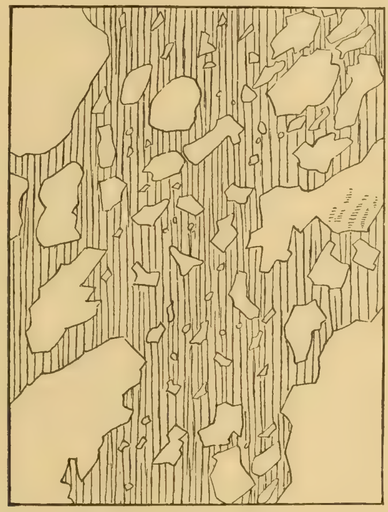

Figure 1—*Section of brecciated Ore from Murray Mine.*

these are associated with diorite. In some instances they have been found to be connected with lines of fracture, and this may prove to be so in all cases. The discoveries of the ore which have been made to the west of Lake Wahnapitæ are also in diorite in the vicinity of quartz-syenite.

Mode of Occurrence of the Ores.

The various occurrences of the mixed nickeliferous pyrrhotite and chalcopyrite, as far as they have yet been opened up, all resemble each other so closely that a description of one will apply to all. They are associated primarily with the diorite masses which conform more or less nearly with the general strike of the other rocks of the country. The older lines of fracture or disturbance are also approximately parallel with the strike, but their planes may incline at different angles from the local dip. The ore-bodies take the form of stock-works, following the direction of these ancient faults. The bodies are made up of a mixture of the country rock and the sulphides in the shape of a confused mass of coarse and fine fragments of the former, while the ore itself constitutes the matrix or filling between them. The fragments are of every size, from mere grains to that of nuts and small and large bowlders and even great horses. Sometimes the smaller pieces are packed so closely together as to admit of the addition of little ore, while at other

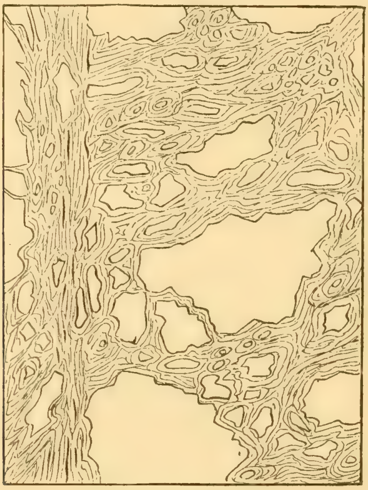

FIGURE 2—*Section of decomposed Ore from Murray Mine.*

times the interspaces are wide and allow the introduction of large quantities of solid ore. The chalcopyrite generally occurs in the midst of the pyrrhotite as distinct masses of irregular form (sometimes quite large), or as streaks,

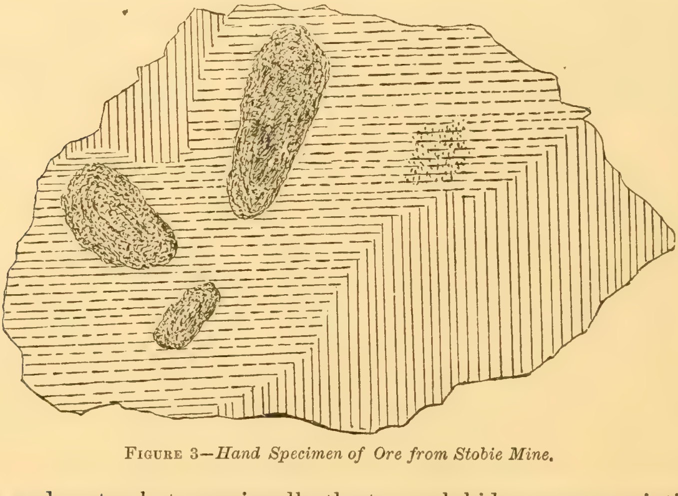

FIGURE 3—*Hand Specimen of Ore from Stobie Mine.*

patches and spots; but occasionally the two sulphides are more intimately mingled. In a part where the pyrrhotite prevails, an included fragment of the country rock may be coated with chalcopyrite, or the latter may lie as a bunch between the rocky fragments, and *vice versa* as to the other sulphide. There is no uniformity in their mode of occurrence with regard to one another, and they appear to have been introduced among the fragments of broken country rock simultaneously and under the same conditions. The dioritic wall-rocks on either side and also the included bowlders and even the smaller fragments are often thickly impregnated with disseminated grains, spots and patches of all sizes, both of pyrrhotite and chalcopyrite. These spots of ore have usually rounded outlines in cross-section and approach spherical and ovate forms. The two sulphides may occur side by side in the same isolated kernels or amygdules; but just as frequently the latter consist of one or the other alone, although in such cases the same rock-section may contain as many of the one kind as the other and all indiscriminately mingled together.

Figure 1 represents a fresh section of the brecciated ore, two feet high and a foot and a half wide, as exposed at the northeastern end of the drift from No. 4 shaft, Murray mine, in October, 1890, the shaded part being mostly chalcopyrite (with some pyrrhotite) and the rest fragments of diorite. The shaded spots in one of the latter on the right side are included patches of the ore. Figure 2 represents a section four feet high and three feet wide of the decomposed ore on the southwestern side of the railway cutting through the mass at the Murray mine. The shaded portion is the gossan with some undecayed pyrrhotite and chalcopyrite, the rest being fragments of diorite. Figure 3 represents a hand specimen of the ore from the Stobie mine. It was traced directly from nature and reduced to one-half the linear dimensions. The portion shaded horizontally shows pyrrhotite, the vertical shading chalcopyrite and the dotted areas rounded fragments of the silicious country rock.

Numerous analyses of the ores have shown that the nickel is confined to the pyrrhotite, in which it is present in the proportion of about 1 to 5 per cent.; but it has not been determined whether it replaces a corresponding proportion of iron uniformly throughout the mass or exists in the form of disseminated grains of polydymite. This mineral occurs as crystals, plainly visible in some of the ores from the Worthington mine, in the township of Drury.

The Genesis of the Ores.

The ore bodies of the Sudbury district do not appear to have been accumulated like ordinary metalliferous veins from mineral matter in aqueous solution, but to have resulted from igneous fusion. The fact that they are always associated with diorite, which has been left in its present positions in a molten state, points in this direction. As the diorite and the sulphides fuse at about the same temperature, they would naturally accompany each other when in the fluid condition. The bodies of molten diorite, being large, would remain fluid for a sufficient time to allow the diffused sulphuretted metals to gather themselves together at certain centers by their mutual attractions and by concretionary action. In the case of great irrupted masses of diorite, the bodies of ore which had formed near enough to the solid walls cooled and lodged with a mixture of the broken wall-rocks where we now find them, while larger quantities, remaining fluid, probably sank slowly back through the liquid diorite to unknown depths. The causes which, at a subsequent time, favored the production of transverse dikes probably aided in determining the deposition of the ore near certain lines rather than elsewhere.

If we suppose that the molten sulphides abstracted themselves, by the laws of mutual attraction, from the general mass of the fluid rock and got together in considerable quantities in an intimately mingled form, the two kinds would tend by the same laws to separate themselves from one another, like going to like, just as salts of different kinds will separate into their respective crystals from an aqueous solution, because there is analogous action between mixtures liquefied by heat and by solution in a supersaturated menstruum. A study of the relations of the pyrrhotite and chalcopyrite to each other in these mixed ores and of the ores of the parent rock shows that this view is in accordance with the facts, and that it is probably a satisfactory explanation of the phenomena. No theory of aqueous deposition appears to account for the facts in connection with these ore bodies; still we do occasionally observe limited local modifications of the ore which may have been due to the solvent action of water with subsequent precipitation of mineral matters long after the consolidation of the mass. This is more particularly the case with regard to the chalcopyrite. Crystals of quartz and of the felspars and rarely of apatite are found embedded in the ore.

Extent and Associations of the Ores.

Other metals, including gold, platinum, tin, lead, silver, zinc and iron, have been found in the Sudbury district, and probably some of them may prove to exist there in paying quantities. The presence of a considerable proportion of nickel in the ore of the Wallace mine, on the shore of Lake Huron and in the strike of the Sudbury deposits, was ascertained by Dr. Hunt more than forty years ago; yet the presence of this metal in the latter does not seem to have been suspected for a considerable time after they had been worked for copper alone. The Huronian is notably a copper-bearing system. West of Sudbury, in the great belt we have already traced, this metal occurs around Batchawana bay, north of Sault Ste. Marie, at Little Lake George and Echo lake, at Huron Copper bay, in Wellington and Bruce mines, on Thessalon and Mississagui rivers, and elsewhere. To the northeastward it has been found on both sides of Lake Wahnapitæ, on Temagami and Lady Evelyn lakes, along Montreal and Blanche rivers, on the watershed east of the canoe route between lakes Temiscaming and Abbittibi, and finally near the southern extremity of Lake Mistassini. The search for this metal along the Huronian belt, which has been described above as running for more than 600 miles, is only in its infancy, and the copper-mining industry may some day be very extensively carried on in various parts of this, as yet, almost unknown section of Canada.

THE SILICIFIED GLASS-BRECCIA OF VERMILION RIVER, SUDBURY DISTRICT.

BY GEORGE H. WILLIAMS.

(*Read before the Society December* 31, 1890, *as an Appendix to the communication on the Nickel and Copper Ores of Sudbury District, Canada, by Dr. Robert Bell.*)

Among a considerable series of rocks from the Sudbury district which I have recently had the pleasure of microscopically examining for Dr. Robert Bell, of the Canadian Geological Survey, there was one of such unusual petrographical character that it well merits a special description. Moreover, this rock is not merely a petrographical anomaly, but it also occupies so large an area as to become geologically of great importance as a member of the Sudbury series.

The specimens of this rock examined by me in Dr. Bell's collection bear the label "Lowest fall of Onaping river, Sudbury," and turn out to be nothing less than a breccia composed of sharply angular fragments of volcanic glass and pumice, which, in spite of almost complete silicification, still preserve every detail of their original form and microlitic flow-structure with a distinctness not to be exceeded by the most recent productions of this kind.

Such porous glassy rocks are well known to be more subject than any others to either alteration or complete removal, so that the preservation of this glass-breccia from Huronian times without loss of its original characteristics must be regarded as very exceptional. The production of a mass like this on so large a scale in any geological time is also a matter worthy of notice, for Dr. Bell has traced it as a wide band for over forty miles without then reaching its northern limit.

The following memoranda on the occurrence and distribution of this ancient glass-breccia have been furnished by Dr. Bell and may best be given in his own words:

"This remarkable rock lies along the northwestern side of the Huronian trough, having the red quartz-syenite, which may be Laurentian, on its northwestern flank and being bounded on the southeast by what is here the highest member of the series, which consists of thick-bedded dark bluish-gray argillaceous sandstone, full of clear grains of quartz and interstratified with shaly beds of the same color, all overlain by black slates. Towards its southwestern termination the breccia itself passes into a black slaty mass holding many pebbles, mostly of syenite.

"The belt runs from the township of Trill northeastward along the northwestern side of Vermilion river to a point opposite Wahnapitæ lake, where it cuts across the river and continues on northeastward; but its limit in that direction has not been accurately ascertained beyond forty miles from the township of Trill. In this township it forms a sharp elbow apparently getting around an anticlinal axis and runs off to the eastward on the southern side of Vermilion lake; but here, as above stated, it passes into a slaty conglomerate holding pebbles of syenite. In this form it is traceable about ten miles more.

"A good section of the typical form of the breccia may be seen in the cuttings near Onaping, where the Canadian Pacific railway intersects it, twenty-three miles northwest of Sudbury Junction. It has an average breadth of fully a mile, and as it dips at angles of 45° and upwards it must have a thickness of over 4,000 feet. Owing to its hardness and toughness it has resisted denudation better than the sandstones and argillites, and it rises a few hundred feet above the latter in the form of a range of rugged hills overlooking the comparatively level country on the southeast. Along its northwestern side it is separated, in places at least, from the quartz-syenite by a massive band of ash-gray quartzite containing usually an abundance of white quartz pebbles scattered through it.

"It was supposed that from its compact nature this breccia might be used in ornamental construction; but, while it gives a good, smooth surface, it has not been found susceptible of fine polish."

In a hand specimen this rock presents a nearly black felsitic matrix, in which are embedded sharply angular or slightly rounded fragments, varying from 1½ cm. in diameter downwards to ultra-microscopic dimensions. These fragments are lighter in color than the matrix, but differ considerably among themselves in their tint, structure and composition. The majority resemble chalcedony in appearance, others are greenish, while some of the largest fragments are now replaced by a single calcite individual. Occasional small grains of clear vitreous quartz may also be detected, while specks of magnetic pyrites (pyrrhotite) are everywhere abundant. Many of the angular fragments show distinctly under the lens a flow or vesicular structure, which is still more apparent in a thin section of the rock when seen under the microscope.

FIGURE 4.—*Section of silicified Glass-Breccia.*

The appearance of this rock when viewed with a low magnifying power (× 20 diameters) is shown in the accompanying figure 4, for which I am indebted to the skill of Mr. Charles R. Keyes, Fellow in Geology at the Johns Hopkins University.

The fragments, even down to those of the smallest dimensions, have the angular form characteristic of glass sherds produced by explosive eruptions. The larger fragment in the lower part of the figure is finely vesicular, while the one above is more coarsely so. The flow structure is as perfectly marked by sinuous lines of globulites and microlites, which terminate abruptly against the broken edge of the glass particle, as in the most recent vitrophyre. Minute spots of opaque pyrrhotite are scattered through the section. The groundmass is of a dark color, owing to the massing in it of minute black globulites, to whose nature the highest magnifying power gives no clue.

Unfortunately, no analysis of this interesting rock has as yet been made. Between crossed Nicols it is seen to be made up largely of chalcedonic quartz, which has changed the easily destructible glass into a sort of jasper. Chlorite is also abundant, frequently arranged as a border of radiating scales around the edges of the fragments, so as to coat them green in the hand specimen. The larger grains are always a fine mosaic of interlocking quartz, but some of the smaller ones are composed of a unit individual of clear vitreous quartz. The only other minerals which could be identified in the section are calcite and a few grains of a glassy, striated feldspar. The presence of this latter mineral is very noteworthy, as we should expect it to have disappeared during the vicissitudes through which this rock has passed.

After a careful study of this rock I find it possible only to interpret it as a remarkable instance of a very ancient volcanic glass-breccia, preserved through the lucky accident of silicification. Nor did this process go on, as is usual, through dentrification and loss of structure, but rather like the gradual replacement of many silicified woods, whose every minute detail of structure is preserved. The rarity of such rocks in the earth's oldest formations is readily intelligible, but for this very reason the exceptional preservation of a rock like this is all the more welcome proof that explosive volcanic activity took place at the surface, then as now, and on a scale, if possible, even greater than that with which we are familiar.

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THE OVERTHRUST FAULTS OF THE SOUTHERN APPALACHIANS.

(*Read before the Society December* 29, 1890.)

BY C. WILLARD HAYES.

CONTENTS.

INTRODUCTION.

Through the work of the Rogers brothers in Pennsylvania and Virginia and of Safford in Tennessee, the characteristic forms of Appalachian structure have long been familiar to geologists. The *unsymmetrical fold* has been recognized as the normal structural form through Pennsylvania, Maryland, and a portion of Virginia. In east Tennessee, the *reversed fault,* transverse to the steeper limb of the anticlinal, becomes common. Recent study in the southern Appalachians has shown a modification of these well-recognized types, namely, broad *overthrust faults* which, as developed in northwestern Georgia, are comparable in magnitude with those of the Scottish highlands and the Rocky Mountains as described by Geikie* and McConnell.†

Stratigraphy of the Region.

The strata of the region shown in the accompanying map (plate 2) embrace representatives of all the larger groups of the Paleozoic from the Cambrian to the Carboniferous, inclusive. The formations appearing in the stratigraphic column, figure 1, represent a purely lithologic classification, and no attempt is made to correlate them with coördinate subdivisions in other regions.

Considered with reference to their structural relations, the rocks of the region fall into several groups of strata having varying degrees of rigidity. The ability of a given thickness of rock to transmit a lateral thrust without folding—that is, the rigidity—depends chiefly on the absence of bedding planes. The composition of the rock itself is an important but subordinate factor.

The upper portion of the column—including the Coal Measure sandstone, the Bangor limestone and the Oxmoor sandstone—forms a group of strata with many bedding planes on which motion may take place with comparative ease. Individual beds of sandstone or limestone are frequently quite massive, but these are separated at short intervals by beds of fissile shale. Hence this complex mass of strata possesses a rigidity below the maximum.

The next division consists of the uniformly thin-bedded Floyd shales. Here the number of planes on which motion may take place is the greatest possible, and consequently the rigidity of the mass is at a minimum.

The division below the Floyd shales embraces the Fort Payne chert, the Chattanooga black shale, the Rockwood formation and the upper part of the Chickamauga limestone. As in the case of the first mentioned division, bedding planes are abundant, yet the separate beds are composed chiefly of sandstone and limestone; and the mass of strata therefore possesses an intermediate rigidity.

The next division of the column embraces the lower part of the Chickamauga limestone and the Knox dolomite. In the latter, true bedding planes are almost wholly wanting. The formation consists of from 3,500 to 4,500 feet of massive, cherty, dolomitic limestone. Together with the lower por-

* "The Crystalline Rocks of the Scottish Highlands;" A. Geikie, Nature, vol. XXXI, 1884, p. 29. Also "Report on the Recent Work of the Geological Survey in the Northwest Highlands of Scotland;" A. Geikie, Quart. Jour. Geol. Soc., vol. XLIV, 1888, p. 378.

† "Report on the Geological Structure of a Portion of the Rocky Mountains;" R. G. McConnell, Geol. Surv. Canada, Annual Report for 1886, part D.

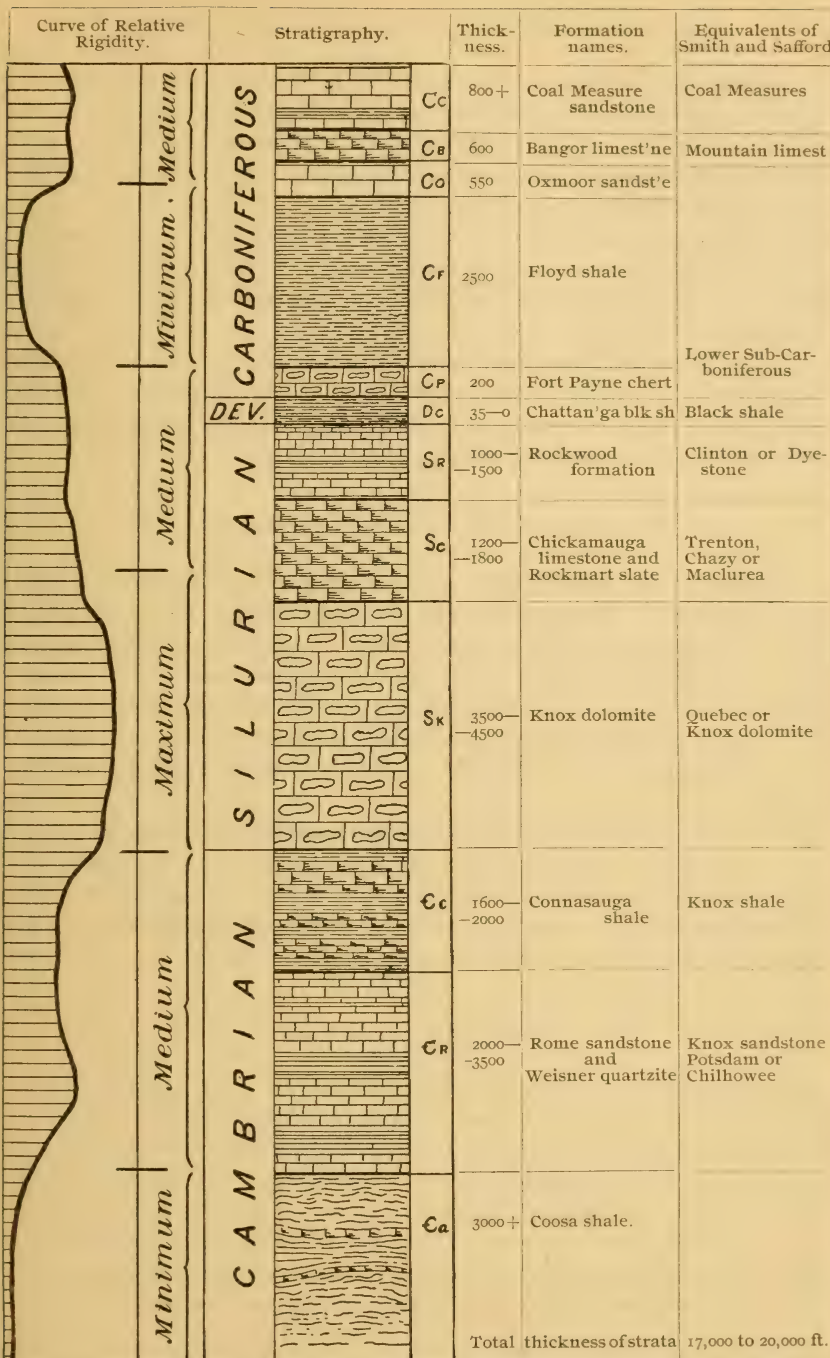


FIGURE 1.—*Valley Rocks of Northwestern Georgia.*

tion of the Chickamauga limestone, which is only less massive than the dolomite itself, there are approximately 5,000 feet of strata with indistinct bedding and entirely without beds of shale. The dominating influence which this mass of maximum rigidity has exerted on the structural forms resulting from lateral compression will be pointed out later.

The Connasauga, which is composed of alternating beds of limestone and calcareous shale, together with the Rome sandstone, form a group of strata with intermediate rigidity which lies below the Knox dolomite and is similar to the group above that formation.

Finally, below the Rome sandstone are the Coosa shales, having an unknown but very great thickness and a minimum rigidity. Some considerable beds of limestone occur in these shales, but they form too small a proportion of the mass to add appreciably to its rigidity.

General Structure of the Region.

In following the great Appalachian valley to the southwest, a marked change in structure is observed at the Tennessee-Georgia line. In place of the narrow, faulted synclinals which prevail throughout east Tennessee, a single broad, gently undulating synclinal occupies the whole of the eastern portion of the valley, while in the western part the structure resembles that of Virginia. The strata are rather closely compressed into unsymmetrical folds with occasional faults of slight displacement on the steeper side of the anticlinals.

The broad synclinal above mentioned as occupying the eastern portion of the valley extends from the metamorphic rocks on the east to the Oostanaula and Coosa rivers on the west. On either side is a thrust fault; that on the west may conveniently be called the Rome fault and that on the east the Cartersville fault. These will now be described in detail.

Rome Thrust Fault.

Characteristics north of Dalton.—The Rome fault is the southern prolongation of one of the main lines of Appalachian displacement. Willis and Keith * have traced it to the northwest entirely across Tennessee and into Virginia, where it has been described by Stevenson under the name of the "Saltville fault." † Thus its length from Dalton, Georgia, to its northern extremity in Virginia is at least 275 miles. Throughout this distance it differs from a dozen or more faults of the same region only in its greater persistence and perhaps by a somewhat greater average vertical displacement.

* Unpublished Atlas Sheets, Appalachian Division of Geology, U. S. Geological Survey; by Bailey Willis and Arthur Keith.

† Notes on the Geological Structure of Tazewell, Russell, Wise, Smythe and Washington counties of Virginia; John J. Stevenson, Proc. Am. Phil. Soc., vol. XXII, Philadelphia, 1884.

The hade of these east Tennessee faults is probably between 30° and 45°, always to the upthrow and with few exceptions dipping to the southeast. While they doubtless originated in the fracturing of the steep sides of unsymmetrical folds, all trace of the adjacent anticlinal and synclinal is usually lost and the strata appear as a series of overlapping monoclinals. Just south of Dalton there is a union of two faults of the east Tennessee type, resulting in a single displacement which from this point southward presents an essentially new type of structure.

Dalton-Coosaville Division.—Southwestward to Coosaville the vertical displacement is sufficient to bring Cambrian in contact with Carboniferous rocks. The contact is marked by no topographic feature and the discrimination of the two shale formations is at first difficult. Careful search, however, always reveals the presence of Cambrian fossils in the Coosa, while the presence of more or less carbonaceous matter serves to distinguish the Floyd shales. Occasional beds of highly fossiliferous limestone in the latter remove all doubt as to their Carboniferous age. The line of contact between the Coosa and Floyd shales is extremely irregular. It was traced with considerable care, some 110 points being accurately located. The dips of the Floyd shales were found to be uniformly under the Coosa, so that the long arms of Coosa which extend westward from the main body of that formation undoubtedly rest upon the Floyd, and a consideration of the relation which they sustain to the structure of the sub-terrane explains their peculiar distribution. The strata immediately west of the fault-line are thrown into a number of gentle folds. The axes are irregular in direction and pitch, but in general those north of Armuchee creek trend northwest and southeast, while those to the south trend northeast and southwest.

Among the anticlinals belonging to the northern group are: Chatoogata mountain (*A*, map, plate 2), Sugar valley (*B*), East Horn mountain (*C*), West Horn mountain (*D*) and Johns mountain (*E*), the axes of which all pitch to the southeast. In the southern group are Lavender mountain (*G*), Beech creek (*H*) and Horseleg mountain (*J*) anticlinals, with axes pitching to the northeast. As will be seen from the map, each resulting synclinal bears an arm of Coosa shales in its lowest parts. The disposition of the rocks over this considerable area suggests almost perfect stratigraphic conformity between middle Cambrian and middle Carboniferous, *the Cambrian being on top.* An examination of the sections will serve to indicate somewhat more in detail the evidence on which is based the conclusion that the Cambrian overlies the Carboniferous.

Going westward from Resaca (see the Resaca section, figure 1, plate 3), one crosses successively the Connasauga shales; a ridge formed of the purple Rome sandstone, dipping eastward; a narrow strip of Coosa shales; and then comes upon the Floyd shales and Fort Payne chert. The Carboniferous rocks are highly fossiliferous and there can be no mistaking their age. They form an oval area about three-fourths of a mile wide and two miles long. The strata are disposed in a gentle anticlinal, or rather a quaquaversal, elongated in a north and south direction, apparently a continuation southward of the Chatoogata mountain axis. This area of Carboniferous rocks is entirely surrounded by Cambrian, the younger strata dipping under the older with apparent conformity. West of this Carboniferous island there is a broad expanse of highly contorted Coosa shale extending to Sugar valley, where Carboniferous rocks are again found dipping eastward under the Cambrian. The Carboniferous rocks come up in an anticlinal forming Sugar valley ridge, on the west of which they again dip under an arm of Coosa shales which terminates a short distance to the north, but is continuous around the south end of the anticlinal with the great body of shales to the east.

On a section northwestward from Rome (the Rome section, figure 2, plate 3), a very similar succession is met with. A short distance west of the city the Floyd shales are found dipping southeastward under the Coosa. Passing the Horseleg mountain anticlinal they dip to the northwest under a narrow arm of Coosa, which occupies the synclinal between the Horseleg mountain and Beech creek anticlinals. Beyond the latter they dip under a second and broader arm of Coosa, which lies in the synclinal between the Beech creek and Lavender mountain anticlinals.

The present relation of these rocks is manifestly the result of a fault by which the older rocks were thrust from the east over upon the younger on a plane which coincides approximately with the bedding, and which has been subsequently thrown into a series of gentle folds. The greater part of the overthrust rocks have been removed by erosion, and both Cambrian and Carboniferous shales are at the base-level of Coosa river. Their line of contact is therefore the intersection of an undulating thrust plane with a horizontal base-level plane. Wherever the folding subsequent to the thrust has brought the thrust plane below the present base-level, there the overthrust rocks have been preserved, while those resting at higher levels have been entirely removed. The distance through which the older strata have been moved westward upon the horizontal thrust plane is, in the Sugar valley section, about four and one-half miles, and west of Rome at least four miles; and there is reason to suppose that in the latter section the thrust was two or three miles greater.

Coosaville-Round Mountain Division.—Between Coosaville and Round mountain the course of the fault is about east and west. The evidence of considerable folding, faulting and erosion prior to the overthrust is more marked in this division than at any other point. North of the east-and-west fault line are two synclinals forming Gaylor's ridge (*K*, map, plate 2).

and Dirt Seller mountain (*L*). Their axes trend N. 45° E. and pitch to the southwest. Both of these synclinals are terminated by transverse faults across their southern ends. The formation of the synclinals and the faults by which they are terminated evidently preceded the overthrust, since they have only slightly affected the regularity of the thrust plane. Thus the fault which shears off the eastern side of the Dirt Seller mountain synclinal and at Gaylesville brings the Connasauga shales in contact with Carboniferous rocks passes under the thrust plane without apparent disturbance of the latter. The Coosa shales rest upon all the formations from the upper Cambrian, Connasauga, up to the Floyd shales. A short distance west of Coosaville a small area of Coosa shales rests upon the upper beds of the Knox dolomite, being wholly detached from the main body of Coosa toward the south. This is the only point in this division where the evidence of a broad overthrust is apparent, and it is probable that the inclination of the fault plane is somewhat greater than it is further northward.

Round Mountain-Gadsden Division.—From Round mountain to Gadsden the intersection of the thrust plane with the present land surface follows approximately parallel to the eastern edge of Lookout mountain. This parallelism would indicate a comparatively steep hade for the fault, but that it is in reality even here a broad thrust is shown by the presence, five miles east of Gadsden, of an isolated area of Knox dolomite which has been exposed by the erosion of the overlying Coosa shales. This relation of the dolomite to the overthrust shales is exactly the same as that between Carboniferous and Cambrian shales occurring west of Resaca, as already described.

The continuation of the Rome fault southward beyond Gadsden has not been studied in detail. It is apparently replaced by several faults with the steep hade of the east Tennessee type, which shear off the eastern sides of the Cahaba and Coosa coal fields as shown by Squire and McCalley.*

Cartersville Thrust Fault.

Position of the Fault.—The Cartersville fault passes entirely across the area represented in the map (plate 2) in a direction strikingly parallel with that of the Rome fault already described. Its northern extremity is probably a few miles beyond the edge of the map, though with regard to its exact termination there is still some question.

In consequence of the induration of the rocks east of the fault, its position is clearly indicated by the topography. The metamorphic rocks form a nearly continuous line of bluffs from one to three hundred feet higher than adjacent portions of the valley. These bluffs are the western escarpment of

*"Map of the Cahaba Coal Field and Adjacent Regions;" Joseph Squire and Henry McCalley, Report Geol. Sur. Ala., 1890 (in press).

extensive ancient base-levels through which the streams flow in deeply eroded channels.

Stratigraphic Variations west of Fault.—The rocks west of the fault are the unaltered Paleozoic sediments shown in the stratigraphic column already referred to. There is a gradual change in the character of the sediments in passing toward the southeast. In general, limestones give place to shales and sandstones in this direction, indicating an approach to a shore line. Thus the blue Chickamauga limestones forming the middle division of the Silurian west of Coosa river are almost entirely replaced by the Rockmart slates on the eastern side of the valley, and considerable beds of sandstone are developed in the Knox dolomite. These rocks have suffered metamorphism only in a very slight degree. Some calcareous shales have been converted into roofing slates, but in general the valley rocks extend unchanged up to the fault line.

Rockmart-Esom Hill Division.—The region which shows most conclusively the presence of a fault is that between Rockmart and Esom Hill. The fault line is here nearly east and west in direction parallel with the division of the Rome fault between Coosaville and Round mountain. The two faults are also remarkably alike in the relation which the thrust-planes bear to the structure of the underlying strata. It was stated that the Rome thrust-plane passes across the southward-pitching synclinals apparently undisturbed by the folds and faults which have affected the rocks below. In like manner the undulating synclinal already described passes directly under the Cartersville thrust-plane and all formations from Cambrian up to Carboniferous come in contact with the overthrust metamorphic rocks.

Metamorphism east of Fault.—East of the fault metamorphism has affected all the rocks, though in widely varying degree. On Hiwassee and Ocoee rivers there is an almost perfect gradation from the unchanged valley rocks through indurated shales and quartzites, in which cleavage is only slightly developed, to black roofing slates, in which the bedding is almost wholly obliterated, and so to "curly slates" and phyllites, in which the original stratification is indicated only by the interbedded conglomerates. These in turn pass into highly crystalline mica and garnet schists. Further southward, at Holly creek, the transition is much more abrupt, the valley rocks being directly in contact with the "curly slates" and phyllites. East of Adairsville, on Pinhook creek, the garnet schists are less than a mile east of the fault line, and this is their nearest approach to the valley rocks. South of Cartersville the belt of semi-metamorphic rocks increases in width, and at Esom Hill, on the Georgia-Alabama line, the degree of metamorphism on opposite sides of the fault is slight. Although the rocks immediately east of the fault thus show a wide variation in degree of metamorphism, yet they appear to belong to essentially the same horizon. This great series of slates and conglomerates—the Ocoee group of Safford—shows a progressive regional metamorphism. In the Hiwassee section most of the intervening lithologic varieties are present between the unaltered shales and the crystalline schists, while on the Pinhook section these intervening rocks have been removed.

Inference as to Amount of horizontal Thrust.—If the progress of metamorphism toward the east was regular along this whole line from Hiwassee river to Esom Hill, we may infer from the width of the strip of semi-metamorphic rocks something as to the amount of thrust which has taken place. The width of this belt on the Ocoee is about twelve miles, while at Pinhook creek it is less than one mile. Hence the thrust at the latter point must be, on the assumption of uniform metamorphism, not less than eleven miles.

Phenomena at the Thrust Plane.—The inclination of the thrust plane is frequently so low as 5° and is rarely more than 25°. In all of the many sections examined, the rocks on opposite sides of the fault are apparently conformable, and while in the few localities in which the exact contact was observed the strata immediately at the fault show considerable distortion, this extends only a few feet on either side; so that in most sections there is no indication of faulting except the abrupt transition from unchanged to metamorphic rocks.

Probable Age of the Ocoee Group.—As to the age of the Ocoee group there has been little, if any, evidence discovered in the area represented in the accompanying map. The rocks have as yet yielded no fossils, and they are separated by a fault of unknown displacement from rocks whose age can be determined by paleontologic evidence. The work of Willis and Keith in east Tennessee, however, has firmly established the position of a corresponding group in the Big Butt range and east of Chilhowee mountain as belonging to the upper Silurian, and the rocks are continuous from one region to the other.

Hypothesis of Erosion prior to Thrust.—Assuming the age of the semi-metamorphic series to be Silurian, it will be observed that the Cartersville fault does not ordinarily place older rocks upon younger, but leaves formations in their proper relative position while one or more intervening members are wanting. Thus, at Holly creek, the Silurian Ocoee slates rest upon Cambrian shales, and the intervening Knox dolomite is wanting. The relation of the formations is represented in the generalized section (figure 4, plate 3). The hypothesis which most readily explains this relation is that of extensive erosion prior to the thrust. The probable condition preceding the faulting may be represented by the ideal section 1 (figure 4, plate 3), in which the plane of subsequent thrust is represented by the heavy broken line *T T*. It will be observed in section 2 (figure 4, plate 3) that if the strata were removed down to the line *A B* the same superposition of older strata upon younger would be produced as by the Rome fault—that is, Cambrian shales would be found resting upon middle Silurian.

Features common to the Rome and Cartersville Thrust Faults.

The characteristics which the two faults under discussion hold in common are (1) low inclination of the thrust plane; (2) great horizontal displacement; (3) constant relation of the thrust plane to the overlying beds, the faulting in both cases having taken place in thinly laminated rocks of low rigidity overlain by more rigid beds; and (4) absence of any uniform relation between the thrust plane and the underlying strata, the thrust plane in both cases being in contact with all formations from the Cambrian up to Carboniferous.

Similar Faults in other Parts of the Appalachian Province.

While the Appalachian overthrust faults probably reach their highest development in the region above described, a few have been discovered in other parts of the same province. Three small overthrusts having essentially the same characteristics as the Rome fault have been mapped by Keith* a few miles northeast of Knoxville, Tennessee. The largest of these has a horizontal displacement of about two miles and extends for about eight miles along the strike, being simply a modification for that distance of one of the ordinary east Tennessee faults.

In the Taconic region of New York a fault, probably in most respects similar to those of the southern Appalachians, has been figured by Walcott.† Of this he says: "The section of Bald mountain proves that the strata of the 'Upper Taconic' are pushed over on to the Chazy terrane." A photograph of the locality shows the exact position of the thrust plane, dipping at a low angle toward the east.

Theoretical Considerations.

From purely theoretical considerations, certain conditions would appear to be necessary, or at least highly favorable, for the production of broad thrusts such as have been described. The most important is the relation of *rigidity of strata* to *superincumbent load.*

The curve at the left of the stratigraphic column shown in figure 1 (page 143) expresses the relative rigidity of the strata, the vertical coördinate being

*Maynardville Atlas Sheet, Appalachian Division, U. S. Geological Survey; Geology by Arthur Keith (unpublished).

†"The Taconic System of Emmons and the use of the name Taconic in Geologic Nomenclature;" Charles D. Walcott, Am. Journ. Sci., 3d ser., vol. XXXV, 1888, p. 317.

proportional to the depth and the horizontal to rigidity, which is certainly a function of the number of bedding planes and may be assumed to vary inversely as the number. The maximum rigidity is in the middle portion of the column, and on either side are divisions with minimum rigidity. In the upper portion there is an increase to medium rigidity.

From considerations given in the description of the faults it seems probable that the strata were subjected to a certain amount of folding, and probably erosion also, prior to the thrust. With these facts in view, the ideal section forming figure 3, plate 3, may be regarded as representing the attitude of the strata when the faulting began. It will be seen that if horizontal compression were applied, the line of weakness, and hence the line of least resistance, which a fracture would certainly follow, is that marked by the broken line $P P'$.

But the most obvious result which would be expected from the application of further compression to the mass of strata represented in figure 3 is simply a continuation of the folding. The reason that such was not the result produced must be sought in the relation between rigidity and load. The layer *B* has a high degree of rigidity, while the load under which it rests is comparatively small—not enough, certainly, to render it in any degree plastic. Hence the formation of an incipient fold, as at *L*, would be accompanied by considerable fracturing of the strata on the steep side; and so a point would be reached early in the process beyond which folding could not proceed, since the slipping upon bedding planes necessitated by the fold would offer greater resistance than fracture across the beds. Further compression would necessarily be taken up by a fault shearing across the weakened rigid bed.

That such is the correct explanation is clearly shown by Willis,* both experimentally and from a consideration of the stratigraphic relations in faulted and folded areas in the Appalachian region.

Lateral compression is readily taken up in a mass of fissile shales by close folding, and hence the fracture would not penetrate to a great depth in the lower mass of minimum rigidity. It is on this account probably that, even with the great displacement which these faults show, the rocks underlying the Cambrian are never brought to the surface; and there is no evidence that the fracture originated much below the lowest beds now exposed.

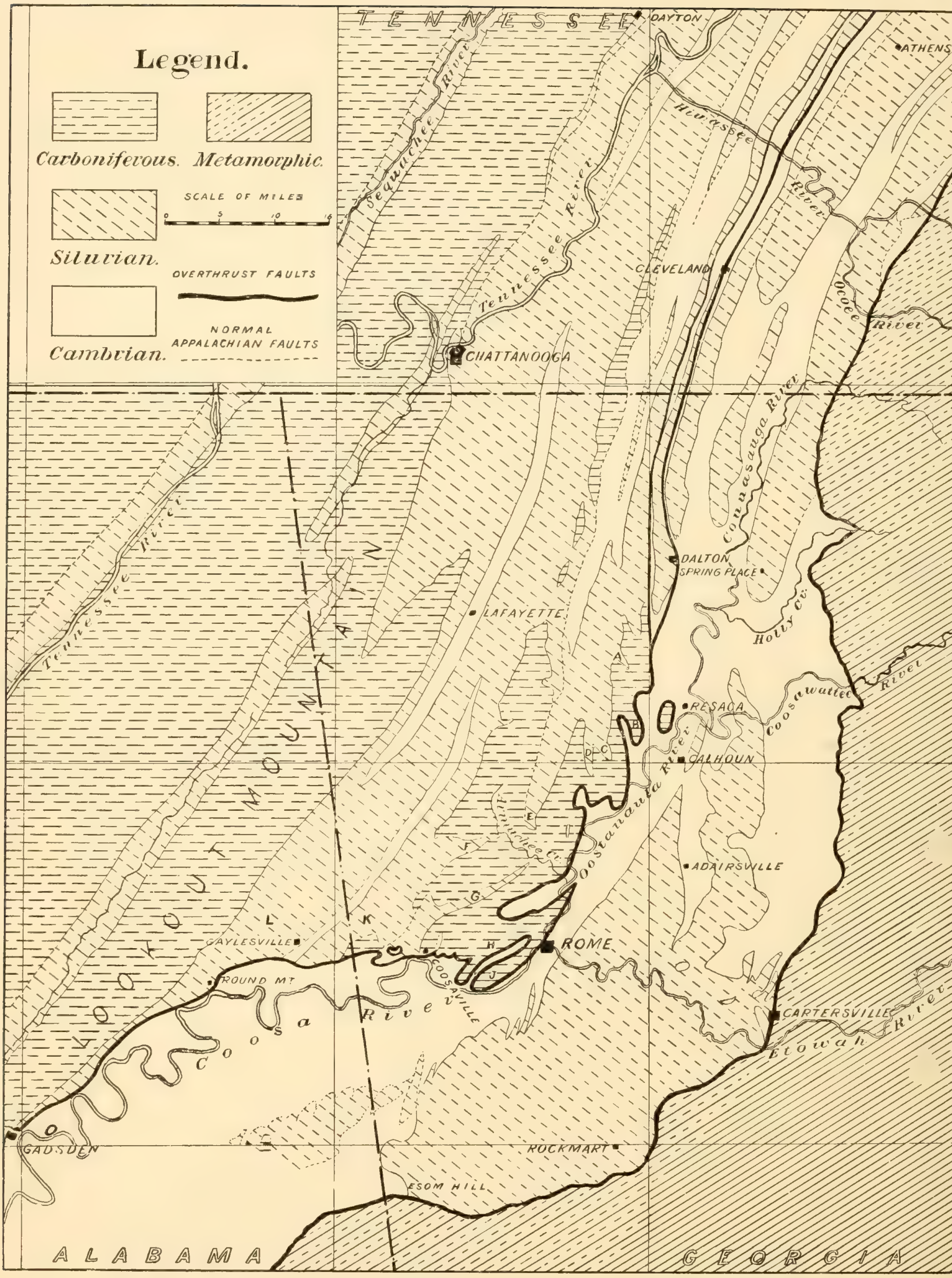
As already stated, the rigid mass *B* presents its weakest points where the compressing force exerts a shear across the beds—*i. e.*, on the sides of the folds *H* and *L*. But the point *H* is in the line of least resistance, since it is nearest to the region of application of the compressing force, and hence the mass of material to be moved is less than if the break were to occur at *L*. After passing the central rigid mass the line of least resistance follows the upper beds of minimum rigidity *C* till another fold is reached where it passes

*Report on Experiments in Structural Geology; by Bailey Willis (unpublished).

through the upper rigid bed *D*. Erosion of the latter might determine the point at which the line would emerge at the surface.

If the Coosa shales, represented in the diagram (figure 3, plate 3) by the basal member *A*, were not of sufficiently low rigidity to take up the compression by close folding, faults of steep hade and consequent great depth would be formed. Again, if the Knox dolomite, *B* in the diagram, were not sufficiently rigid to transmit the compressing force from *K* to *H* under the superincumbent load, it would be thrown into a series of normal Appalachian folds; and finally, if the difference in rigidity between the Floyd shales *C* and the Coal Measure sandstone *D* were not sufficient to determine the line of least resistance in the former, the fracture would emerge at the surface with a steep hade and form a normal east Tennessee fault.

WASHINGTON, D. C., *December*, 1890.



MAP OF ROME AND CARTERSVILLE THRUST FAULTS.

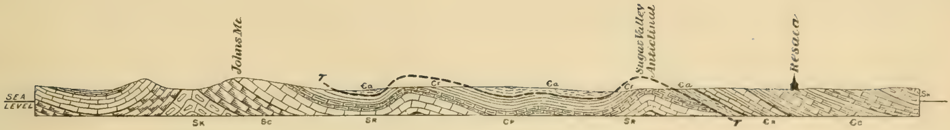


Fig. 1. RESACA SECTION.

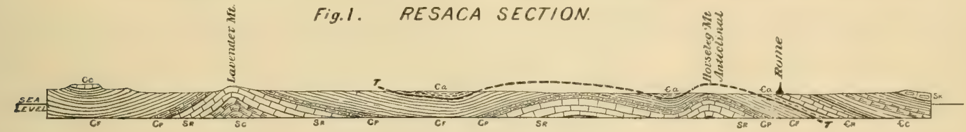
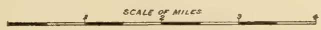


Fig. 2. ROME SECTION.



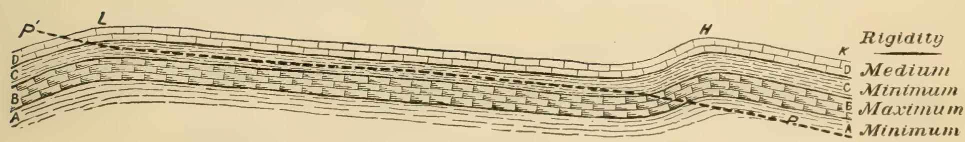


Fig. 3. THEORETICAL POSITION OF THRUST PLANE.

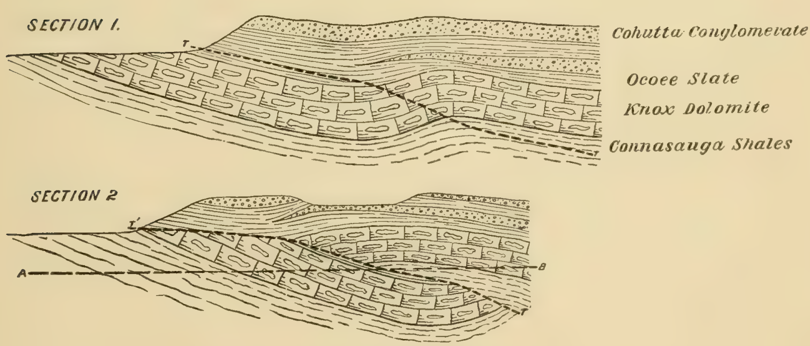


Fig. 4. HOLLY CREEK SECTION—IDEAL—
(1) before (2) after horizontal thrust.

ACTUAL AND IDEAL SECTIONS OF ROME AND CARTERSVILLE THRUST FAULTS.

MOSS ENG. CO., N. Y.

DISCUSSION.

Mr. C. D. Walcott: In northern Vermont a somewhat similar overthrust fault occurs, by which the basal strata of the Cambrian have been thrust over upon the Trenton limestone, Hudson shales, etc. It was in this area that Professor Jules Marcou noted the presence of Lower Silurian fossils, and the theory of "colonies" was introduced by him to explain the occurrence of the Primordial fauna above them. A misinterpretation of the geology east of the Hudson river arose from a misunderstanding of the overthrust fault. Professor Amos Eaton regarded the shales (which are now known to be of lower Cambrian age), where they were thrust over upon the Chazy limestone, as having been unconformably deposited upon the limestone. Dr. Ebenezer Emmons, a pupil of Eaton, adopted the view of Eaton as to the unconformity between the shales and the limestones and, also, considered a band of calciferous sandrock above as resting unconformably upon the slates. It was upon this evidence that he first based the view that the Taconic slates were pre-Silurian in age and that the fossils in them belonged to a fauna inferior to that of the Silurian. I studied the typical locality at Bald mountain, Washington county, New York, and found that the superior beds were those of the *Olenellus* zone and that they had been forced by an overthrust fault upon the Calciferous and Chazy. This sytem of overthrust faults, extending with more or less continuity from Alabama to the St. Lawrence river at Quebec, has added immensely to the intricacy of the geology and led many geologists into error, owing to their misinterpretation of the phenomena.

Professor W. M. Davis: If I have correctly understood Mr. Hayes, he finds reason to think that the overthrusts which he has so ably worked out were produced at a later date than that of the general folding of the region, and that these two disturbances were separated by a period of time long enough for the accomplishment of a considerable amount of erosion. If this be the case, I would suggest the following reasons for regarding the overthrusts as of post-Triassic date: In southeastern Pennsylvania, in the neighborhood of the Triassic belt, whose monoclinal dip is northwestward, the strongly compressed folds of the underlying Paleozoic formations are somewhat overthrown, causing a prevailing and steep dip to the southeast. It is physically necessary that the underlying formations suffered an angular movement along with the overlying Triassic beds, when the latter were given their monoclinal dip; it is reasonable, therefore, to regard the prevailingly overthrown dips of the Paleozoic formations not as a feature given to them at the time of the general Permian folding, but at the later time of the post-Triassic tilting. It is, moreover, reasonable to look to a thrust from the southeast as the cause of this later disturbance; and such a thrust may be also accountable for the extraordinary dislocations described by Mr. Hayes.

It appears, further, that some clue to the original westward extension of the overthrust mass in Georgia may be found by examining the arrangement of the rivers of the region. The overthrust there produced a structural unconformity, and streams whose courses had been taken in the overlying mass would be superimposed upon the lower mass as they cut their channels down to it. It would therefore be interesting to learn if the streams of the area next west of the present margin of the overthrust manifest a want of adjustment to the structures that they traverse, such as characterizes superimposed streams.

Mr. Bailey Willis: We may explain by reference to the geologic map of the United States the relation existing between faulting and the arrangement of strata in the vertical column in the Appalachian region. Accepting the scale of rigidity of strata, as indicated by Mr. Hayes, we may show that faults are important where the load is small on the bed of maximum rigidity, the Knox dolomite, and that faults are insignificant where this load is great. Furthermore, regions of great faulting are regions of broad gentle flexures; regions of little faulting are regions of numerous small folds, closely appressed. These relations show that the alternative of the formation of a fold or a fault in a given bed is determined by the amount of load to which the bed is subjected.

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THE STRUCTURE OF THE BLUE RIDGE NEAR HARPER'S FERRY.

BY H. R. GEIGER AND ARTHUR KEITH.

(*Read before the Society December* 31, 1890.)

CONTENTS.

Description of the Region.

Geographic Position.—The region discussed in this paper comprises a thousand square miles around Harper's Ferry, about equally divided between Virginia, West Virginia and Maryland.

Topography and general Geology.—The topographic features of the region are, briefly, two mountain lines and three valleys. In order, from west to east, they are Shenandoah valley, Blue ridge, Middletown valley, Catoctin mountain, and Leesburg valley. The position of the ridges is shown on the geologic map by the black areas, the sandstones and the ridges being nearly everywhere coincident.

The last valley is composed of Mesozoic rocks and does not concern the question under discussion; the middle or Middletown valley is composed of schists, injected with granite dikes, and will only be alluded to briefly; the first or Shenandoah valley is occupied by the Potomac and Shenandoah rivers, and is almost entirely floored by the lower Silurian limestone.

Of the two ridge lines, Catoctin mountain on the east is a single ridge and for the most part formed of sandstone. Over its southern third the summit is made of epidotic schists, and the sandstone retreats to the eastern side. The other mountain line, the Blue ridge, is single more in name than in fact, and usually is a double ridge, with summits of sandstone. This sandstone, like that of Catoctin, leaves the summit to the epidotic schist in its southern part and retreats to the western slope. The main line of what is called Blue ridge in Virginia here laps past the South mountain of Pennsylvania and Maryland. After paralleling each other for twenty miles, each dies away, while the name ("Blue ridge") jumps from one to the other.

West of South mountain and the Blue ridge there is a series of lesser knobs and short ridges in a fairly continuous line. These, like the main ridges, are capped with sandstone. Between the sandstones of the main and lesser ridges and the valley limestones there are calcareous and argillaceous shales. Between the Blue ridge and South mountain there are schists containing eruptive granite, just as in the Middletown valley east of South mountain.

Surveys in the Region.

The problem of the geologic age of the belt of rocks upon which Harper's Ferry is situated was first approached by the U. S. Geological Survey in 1883. Then the senior author examined the Blue ridge at Balcony falls and in the adjacent country. In subsequent years additional information was gathered at many points by him, and during the last summer by the junior author. Other members of the Survey, especially Messrs. McGee and Darton, have at various times made widely separated sections.

The Problem of the Area.

Views of the Authors.—The general conclusion that the Blue ridge sandstones were not Potsdam, but later, was stated by the senior author and discussed in the Survey, but it was considered only tentative on account of its radical departure from accepted views. The work of the junior author has been to verify and elaborate the stratigraphy deduced by the senior and to prepare the present paper.

Former Views.—The mutual relations of the Shenandoah limestone and the shale and sandstone of the ridges were considered by the Rogers brothers and Lesley, who studied the formations over wide areas, to be limestone on top, shale below that, with sandstone at the bottom. The limestone was considered Cambro-Silurian (Chazy-Calciferous), the shale and sandstone Potsdam. This opinion has been accepted by subsequent geologists and emphasized in various publications. The senior author, however, was unable to verify the accepted ideas and concluded that the series stood in reality sandstone on top, shale below that, with limestone at the bottom. To these rocks the present discussion is limited.

General Relations of the Beds.

On a general view of the formations in question, it is obvious that the Shenandoah limestone dips eastward under the shale and sandstone of the ridges. This is in the great majority of cases true and is commented on by W. B. Rogers in various parts of his reports. To explain it, earlier geologists have beer obliged to consider the series overturned, an *actual* easterly dip thus representing a *theoretical* westerly dip. In some sections across a single sequence of the formations this could not be gainsaid, but a repetition of the beds brings out their actual relations and they are obviously not overturned, but normal.

The limestone of the Shenandoah valley forms a wide series of open and closed folds, disappearing under the mountain with easterly dips. The mountain sandstone and shale form synclines throughout, with the single exception of Catoctin mountain, where the syncline is in places bisected by a fault. These synclinal axes are prolonged from the mountain ends into synclines of the Shenandoah limestone and the parallel bands of rock swing around the mountain ends.

On structural evidence, therefore, the sandstone is higher than the limestone. To prove anything else requires the evidence of fossils, but none have been found outside of the Shenandoah limestone. To this datum, then, we must refer the sandstone and shale by structural relations alone.

To determine the *exact* structural relations, the areas of the formations have been carefully worked out and large numbers of observations have been made as to the attitude of the beds.

Areal Distribution and Structure of the Rocks.

Symmetrical Distribution of Rocks.—The accompanying map (plate 4) shows the distribution of the rock-masses in practically all the detail of nature. Inspection of the areas of distribution, especially in the northern part, discloses a symmetry among them ; belts of one rock encircle others. The symmetry indicates a definite relation between the beds involved, and its precise nature is brought out by the accompanying sections. The sections (plate 5) are at intervals of one to six miles, as shown on the map by broken lines, and are so placed as to bring out all material changes of structure.

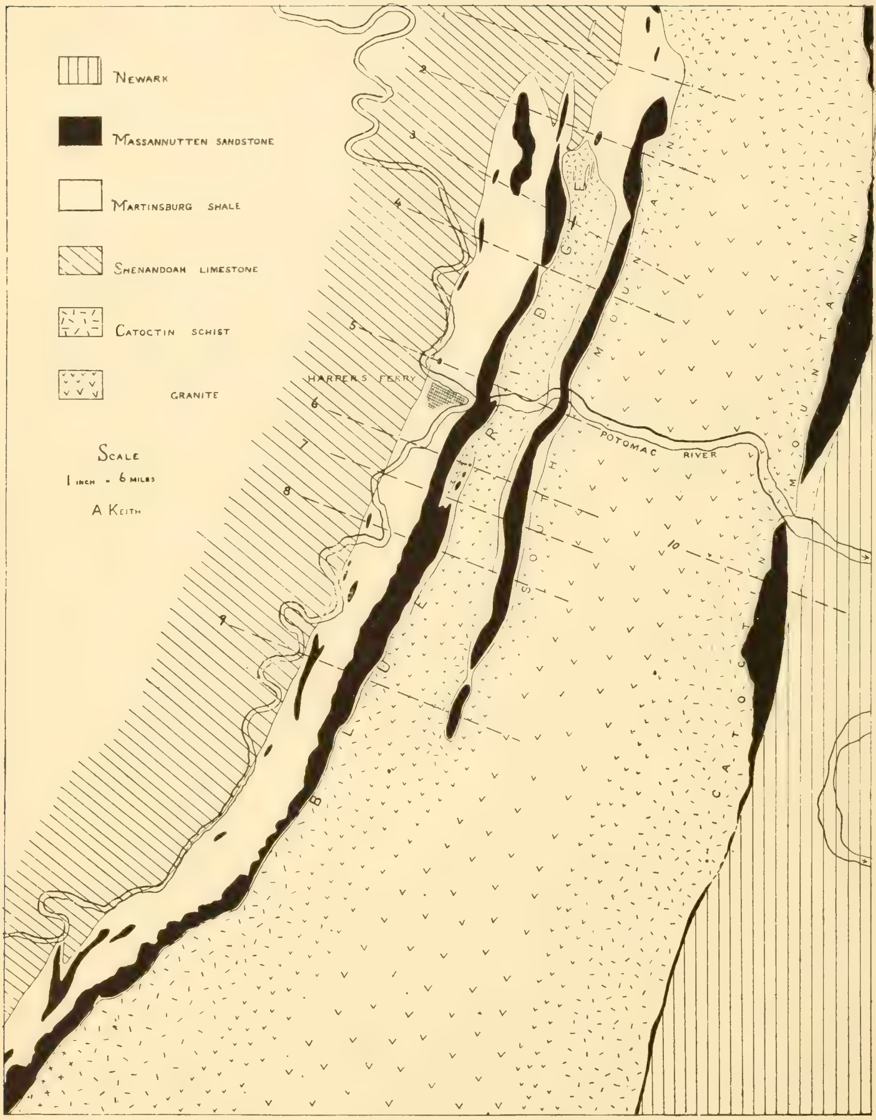
Synclinal Structure of Ridges.—At a glance it is apparent that the synclinal type prevails in the mountains. There are some sections of close folds that are not in themselves decisive of structure, but a few miles away, along the same outcropping line, all doubts vanish and the structure is simple. This is notably the case at the Harper's Ferry gaps in the Blue ridge and South mountain.

The clean-cut Potomac section is so folded and complex as to be open to discussion at least. But in three miles either northward or southward along the Blue ridge, indecision is replaced by certainty when the tangle of the gap section is transformed to open normal folds. Southward the folds continue open throughout; northward they open and close alternately.

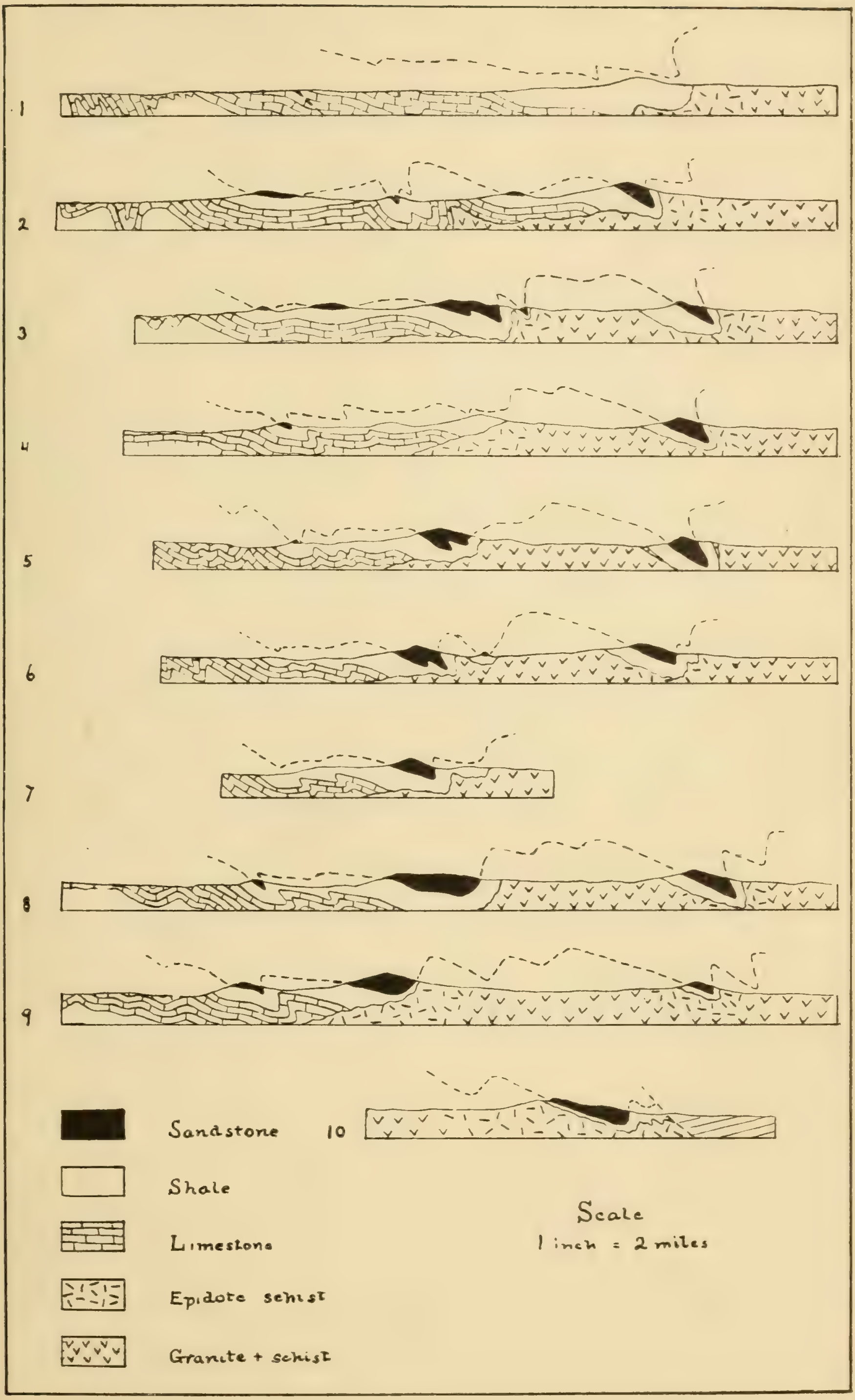
South mountain presents the same synclinal features. Northward from the Potomac, erosion cuts three times through the sandstone belt into the underlying slates. Eight miles southward from the Potomac, the closed syncline of the river section is cut through by erosion. South of this gap a patch of the sandstone is left in Short hill before the axis finally pitches upward and South mountain disappears.

On Catoctin mountain the synclinal sandstone is entirely cut through by the Potomac, leaving the underlying slates along the surface. Both northward and southward from the river the structure is the same. The synclinal axis pitches down until in three miles its eastern half is cut off by the post-Newark fault. Some distance north, in Maryland, Catoctin and South mountains nearly if not quite unite.

The lesser sandstone knobs before mentioned are mere remnants in a general synclinal axis. Some parts of the axis are flat, some are closely folded. In many cases no ledges occur to furnish dip observations, but the sand-



GEOLOGIC MAP OF HARPER'S FERRY REGION.



SECTIONS THROUGH HARPER'S FERRY REGION.

stones are caps of hilltops surrounded by slopes of shale, so that they can be nothing but synclines in structure.

Topographic Forms express Rock Character.—The difference in continuity between the portions of the major and the minor ridges is the expression of a difference in texture of the retaining sandstones. The continuous lines are made by a white and gray sandstone, often a silicious conglomerate, which is of great durability; the interrupted lines are formed by a fine white sandstone, which is less silicious and consequently more subject to erosion. The effect of this textural difference on the topography is exaggerated by external relations in most places. Adjacent to the fine sandstone is the easily eroded limestone. Over this the Shenandoah river plays so that this sandstone is readily within reach of erosion. The heavy sandstone, on the other hand, is usually flanked by an area of epidotic schist, which is exceedingly hard and tough, and is also defended on the other side by the lesser sandstones. The subordinate position thus maintained by the outer sandstone has led geologists to ignore its importance; but the value of careful mapping of both types can hardly be overestimated. Each occurrence multiplies the chance for observing the structural relations in a given area and hence strengthens the conclusions based on structure.

The distinct difference between the types would indeed suggest a difference in age, and Rogers has represented them as different. But this distinction of type, like most others, is accompanied by an intermediate gradation, and one sandstone visibly changes to the other in one continuous line. This is the case at the northern end of the Blue ridge proper, and is made manifest at a distance by the gradual tapering of the ridge.

Significance of Structural Details: Superposition of Shale and Sandstone.—The sections shown in plate 5 are constructed from observed dips. From these sections it is plain that the shale-sandstone series rests on the limestone, apparently deposited there as sediment. If deposition gave them their present position, *i. e.*, if the present sequence is original, they are unquestionably Silurian. Can they by any process have attained that position so as to simulate deposition? If so, what are the attendant features elsewhere, and are they present here?

Possible Faulting.—There is one structure able to produce similar effects, *i. e.*, faulting succeeded by later folding. In this case the plane of overthrust would afterward be folded with the adjacent beds. Such a structure has been discussed by Mr. Hayes at this meeting of the Society.* It is decidedly an exceptional structure and as such requires the best of proof, either fossils or unconformity of rock-masses. Fossils of early forms in the overlying beds contrasted with late forms in the underlying beds are of course, as Mr. Hayes states, final proof. Without fossils, visible unconformities of texture

* This volume, pp. 141–154.

and dip in adjacent beds and wide differences in adjacent sections are equally good proof. Both have been described by Mr. Hayes, and both have been observed by the junior author.

What is the case here? Fossils occur in the Shenandoah limestones showing their equivalence to the Chazy-Calciferous of New York. Outside of the limestone none have been found; therefore we must look for unconformity to prove that appearances are not true, and we must find it between the limestone, the datum formation, and the sandstone, which is the top of the section.

Actual Conformity.—Of unconformity, however, in that place there is not the least suggestion. Between the shale and the granite-schist series east of the Blue ridge there is unconformity of the ordinary type of deposition, but that does not affect the question. (*a*) In *individual* sections the limestone is interbedded with shale, the sandstone with the shale and the shale with the sandstone. (*b*) It is, moreover, the same horizon of the limestone in contact with the shale. Most strata of the limestone, it is true, cannot be positively identified, but a thin bed of white marble and slate can be, and that occurs repeatedly only 400 feet below the shale. (*c*) The *general* section is a unit from one end of the region to the other; limestone, 500–600 feet of shale, sandstone. Fifteen different sandstone areas next the limestone along thirty-five miles give the same sequence. This thickness of shale is small, but it is very uniform, and by its very smallness makes the uniformity more certain, because it is more accurately measured and would be more easily removed by a fault.

Limitations of possible Faulting.—The possibility of a fault is practically removed, even where there is only a single sequence of limestone and shale. (*a*) Where, as in the sections shown in plate 5, there are four or five repetitions in a direct cross-section of as many miles, the case is so extreme that the hypothesis of a fault is entirely excluded. In order to have existed without impairing the symmetry of the folds the fault must have followed the course of the shale bed 500 feet thick. (*b*) The present width of this possible fault plane would be three and a half miles at the end of the Blue ridge, with the corrugated surface of the shale bed. Its actual width, measured along the shale bed, would be five miles. This is entirely within the reach of the great overthrust faults known in the Appalachians, so far as mere distance of thrust is concerned, but the character of thrust is entirely different. (*c*) Various broad thrust planes in Tennessee studied by Hayes and the junior author show a marked unconformity in stratigraphy along the line of break. While the difference of dip rarely is much, the rocks of the down-thrust lie along the bevelled edges of the up-thrust and *vice versa*. Sometimes one, sometimes the other is bevelled, but the over and under series bear no relation to one another. Here the case is quite different. Instead of unconformity and bevelled edges there is perfect correspondence on either side of the supposed fault, not in a single section only, but in all adjacent to the limestone, both along and across the folds. A great fault can with difficulty be *imagined* that would trim the bed so neatly; certainly none has been *observed.*

Faulting an Assumption.—With all structural and stratigraphical facts the reverse of those connected with faults, and with the lack of fossils to demonstrate a fault, it is clear assumption to say that there is one. There is nothing to indicate a fault; therefore we are obliged to return to the view that the beds were sedimentary deposits in their present relations—limestone under the shale and sandstone.

Analogous Sections.—Region west of the Blue Ridge.—This view is the first and natural one, and is supported by the existence toward the west of a similar series in a similar attitude—*i. e.*, the Shenandoah limestone, the Martinsburg shale (equivalent to the Hudson river), and the Massanutten sandstone (equivalent to the Medina). Comparison of these sections makes the Blue ridge shale Hudson River and the sandstone Massanutten or Medina.* It is through a precisely similar comparison that these sandstones were called Potsdam, and the lithological correlation is in one case as strong as in the other.

Homology between Massanutten Mountain and the Blue Ridge.—Additional sections of the Blue ridge to support our view are readily found in other places. Rogers frequently states that the sandstones of the Blue ridge appear to be above the limestone. The same general relation holds all along the Massanutten mountain and adjacent points in the Blue ridge. The structure is an anticlinal valley of Shenandoah limestone between two synclinal ridges. The Massanutten synclinal is accepted Silurian; from its structure the Blue ridge is the same, and no fossils have proved the opposite.

Sections at Turk's Gap, Buchanan and Christiansburg.—Twenty-five miles southwestward, at Turk's gap, two flat synclines of sandstone nearly cover the Blue ridge. Sixty miles southwestward, at Buchanan, the Massanutten section is duplicated—an anticlinal of limestone between a Silurian sandstone syncline and the eastward-dipping Blue ridge sandstone. Forty miles farther southwestward, near Christiansburg, the Blue ridge sandstone rests on shale and that in turn on the Shenandoah limestone, the whole series dipping southeastward 10 degrees. These are instances taken from numerous occurrences, and their use here is merely to corroborate. None the less, these facts, both in nature and closeness of correlation, are of the same grade as those cited by Rogers to support his view.

Contrasted Sections, as at Balcony Falls and Dublin.—It will seem strange to most geologists that Rogers and others dealing with the question should

*The names "Massanutten," "Martinsburg," and "Shenandoah" are derived from Massanutten mountain, Martinsburg, and Shenandoah river, all in West Virginia. The mountain, town and river are characterized respectively by the sandstone, shale, and limestone.

have embraced a view so at variance with these facts. It is due to them to say that not all the facts are against them. In various portions of the Blue ridge there are sandstones dipping northwestward or toward the valley limestone, and the facts are susceptible of the interpretation that the sandstones are beneath the limestone. The section at Balcony Falls appears to show an *underlying* sandstone. One unequivocal case of underlying sandstone has been found by Darton five miles east of Dublin, where a visible anticline of sandstone lies under an extensive arch of valley limestone. Without doubt other cases will be demonstrated by closer study, and doubtful cases are already known.

Existence of two Sandstones.—It seems from the foregoing facts that there are *two* sandstones, one above and one below the valley limestone. There is nothing unusual about such an arrangement; among the fossiliferous series it is very common. Three or four times in the vertical column the same lithologic character recurs; but this simply indicates a renewal of similar conditions of sedimentation and has no bearing on age. There is no reason to suppose that these conditions did not exist before the limestone was deposited. Among the fossiliferous rocks the fossils enforce a discrimination of the sandstones; in the Blue ridge they do not. In their absence nothing but structural evidence can discriminate, and that, in the case of Rogers at least, was forbidden by the amount of ground to be covered. The mistake was made of correlating distinct and distant sections with insufficient connection by areas. It was, apparently, enough that they contained a group of rocks similar in texture and lay in the same topographic belt. In other words, instead of structure, lithology was made the basis of correlation, in spite of its unreliability in adjacent areas.

Certain cross-sections were taken as typical, and from them a stratigraphy was deduced. Into this mold the other observations were poured with the inevitable result that some of them, to put it mildly, lost their original character. Rogers' published sections of the Blue ridge at Harper's Ferry and Ashby's gap are distinctly wrong. In the former the limestone does not dip northwestward and the shale under it, as represented; nor does any sandstone bed reach water level until the main ridge is reached; nor is the sandstone-shale series a simple monoclinal sequence, but a highly contorted synclinal depression. His section a little south of Harper's Ferry gives the open syncline of Blue ridge as it is, but adds thereto a series of vertical sandstones that have no existence whatever. In his section at Ashby's gap, at the southwestern corner of the region under discussion, a synclinal ridge-cap is turned into a monoclinal bed; the low southeastward dips on the main ridge are shown, but the equally plain northwestward dips are not.

Rogers' sections show that he appreciated the want of harmony of his different observations and the difficulty of reconciling them. In view of the obstacles to unity that he found, it would be extremely hazardous in us to state that all the Blue ridge sandstones are upper Silurian. It is perfectly reasonable that Cambrian sandstones exist in this topographic line. They exist in Tennessee of various types, and with equal certainty Silurian sandstones are almost side by side with them. In Tennessee they have been confounded; why not in Virginia? To establish their existence here, no single section, much less a single sequence of the beds, will suffice. Nothing in Appalachian geology is less certain than a single sequence. A profound fault may cut it without a trace; the beds may be turned upside down; an interval of erosion or of non-deposition may intervene and no record be left. Each of these is of frequent occurrence, and each may produce the same section. In detailed work along the outcrop lies the only structural proof.

In this region above most others nature has concentrated the means of proof, and by frequently repeating the phenomena has clarified and emphasized them. The responsibility thrown on a single section has been diminished until error is practically eliminated.

Summary.

To sum up, there is no *à priori* reason to call these sandstones either Potsdam or Silurian.

The series lies in synclines above the Shenandoah limestone.

The beds grade from one to another and are conformable by dip.

The series is the same along the strike throughout the area. Apparently this is their original position as sediment, and they are Silurian. If this position was acquired after deposition, it could only be by means of a remarkable fault with none of a fault's characters and nothing to suggest its existence.

In Tennessee there are both Cambrian and Silurian sandstones in proximity. In Virginia the facts are discordant in different areas and probably there are two sandstone horizons.

Here the net of facts is close and all point to one conclusion: our contention simply is—*here* there are upper Silurian sandstones.

Washington, D. C., *December* 28, 1890.

DISCUSSION.

Mr. C. D. Walcott: In the Adirondack region of northwestern New York the Potsdam sandstone rests on pre-Cambrian rocks and is succeeded by the Calciferous, Trenton and Hudson strata. On the southwest the Trenton limestone is in contact, by overlap, with the pre-Cambrian rocks, not having been removed by erosion; and above it we find to the westward the Lorraine shales and Oswego and Medina sandstones. Along the western side of the Green mountains and southward through New York and New Jersey we have Cambrian sandstone and Lower Silurian limestone and shale in successive order, while in the Blue ridge section, described by Messrs. Geiger and Keith, the succession is, limestone, shale, sandstone, as in the Silurian section of New York just mentioned. In the latter case erosion has evidently not cut through the Silurian limestone to the Cambrian; and the section is that of an overlapping deposit upon a sloping pre-Paleozoic shore-line, similar to that about the Adirondack region. From these facts I think it probable that the interpretation of Messrs. Geiger and Keith is the correct one.

Professor C. H. HITCHCOCK: If the authors allow that the reference of the quartzites next the crystallines to the middle Silurian applies only to the region of Harper's Ferry, they may be correct. I understood them, however, to claim the reference of the whole of W. B. Rogers' number 1 to this horizon, insisting that no reliance should be placed upon the sections at Balcony Falls and near Christiansburg, where the sandstones or quartzites underlie the lower Silurian limestones. I am familiar with this part of the great valley of Virginia, and should interpret the structure as Rogers and Campbell have done, both by reason of the stratigraphy, and because fragments of the crystalline rocks further east are constituents of the basal conglomerates, which in their turn underlie the limestones. The presence of fragments of the older rocks in the derived sediments affords a better criterion for the determination of the succession of the terranes on the western flank of the Blue ridge than their dips. One can explain the presence of eastern dips by inversions or faults if necessary, but cannot understand how a composite sediment can be older than its constituent rounded pebbles. Thirty years since our best geologists overlooked this obvious principle in explaining the structure of these same rocks in western New England and referred the quartzites to the Medina; to-day there is not a single geologist familiar with the ground who would accept the early views of Logan, Hall and Dana in reference to this point. Hence these Harper's Ferry outcrops must represent only local dispositions.

Major JED HOTCHKISS: Can the authors of the communication inform us concerning the age and relations of the limestones frequently found east of the Blue ridge?

Mr. KEITH: Limestones sometimes occur as small lenses in slate over the Archean area east of the Silurian limestones of the Shenandoah valley. In one case (near Sharpsburg) the Silurian limestones rest on shales which may be Cambrian.

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NOTE ON THE GEOLOGICAL STRUCTURE OF THE SELKIRK RANGE.

BY GEORGE M. DAWSON, ASSISTANT DIRECTOR OF THE GEOLOGICAL SURVEY OF CANADA.

(*Read before the Society December* 29, 1890.)

CONTENTS.

INTRODUCTION.

General Features of the Cordillera.—The Cordillera, or Rocky Mountain region of the Pacific coast, for a length measured by seven degrees of latitude in the southern part of the province of British Columbia, is narrower than elsewhere, having in this part of its course a width not much exceeding 400 miles. The principal geographical features of this southern portion of the Cordillera in British Columbia are now pretty well known, and the general geological outlines have also been drawn in, so far as this can be done from reconnoissance work. The districts which have been more closely studied are few and limited in size.

Enough is known to show that this part of the Cordillera offers a geological problem of great complexity, such as to require for its solution, even under the most favorable circumstances, long and careful research. In addition to the difficulties of structure to be expected in any great mountain system, special difficulties are found in the degree to which regional metamorphism has been carried, in the occurrence of great volumes of contemporaneous volcanic material at various stages, and (partly no doubt as a consequence of the last) in the extreme paucity of fossil remains. Still further, the circumstance that the region as a whole must be described as more or less densely wooded, contrasts it very unfavorably, from a geologist's point of view, with the southern and open parts of the Cordillera, where he who runs may read many of the main structural facts.

Up to the present time the horizons which have in British Columbia been actually fixed by paleontological evidence may be summarized as follows:

1. Tertiary (probably Miocene).
2. Cretaceous (various stages, probably extending from the Laramie as far down as the Neocomian).
3. Alpine Trias.
4. Carboniferous.
5. Silurian (*Halysites* beds).
6. Cambro-Silurian (Trenton-Utica and perhaps somewhat lower).
7. Middle Cambrian.
8. Lower Cambrian (*Olenellus* beds).

Of these horizons, all but the Miocene have been recognized in the Rocky Mountains proper, or eastern range of the Cordillera. On the coast no fossils definitely older than the Carboniferous have yet been detected. In the interior plateau, fossils referable to the Miocene, lower Cretaceous, Alpine Trias and Carboniferous have been rather sparingly found, while in the mountain region of the Gold system, including the Selkirk, Purcell, Columbia and other ranges, we are as yet almost entirely without paleontological evidence.

Surveys in the Interior Plateau Region.—The writer has been engaged for some time in a detailed examination of an area of about 6,400 square miles in the interior plateau region, the materials for a geological map of which have now been obtained and are in course of elaboration. In connection with this work, and more particularly to assist in explaining the complexities of the older rocks of this area, it became desirable to ascertain, so far as possible, the relations of these rocks to those of the Rocky Mountains proper, across which one line of section has already been carefully worked out by Mr. R. G. McConnell.

With this object in view a preliminary examination was made last autumn across the intervening Selkirk range, on the line of the Canadian Pacific railway. This examination was necessarily confined to the vicinity of the railway and still requires to be supplemented by much detail, to be obtained only by mountain climbing, and by the study of a belt of some width on both sides of the line. As, however, we have heretofore been almost without information on the geological structure of the Selkirks, it is believed that the observations made may not be without interest, even though given subject to future correction in detail. This range, where it has been rendered easily accessible by the construction of the railway, has already become noted for its magnificent Alpine scenery, while some of its peaks and glaciers have become the subjects of serious exploration by well-known Alpine climbers from England and Switzerland.*

Geological Features of the Interior Plateau.—In that part of British Columbia which has been called the interior plateau the oldest stratified rocks are gneisses and mica-shists, which from their lithological character are assumed to represent the Archean. The relations of these to the overlying Paleozoic strata are best known on the eastern border of the plateau region, where they are frequently and well shown. With these crystalline schists occur certain old granitoid rocks, which may represent either portions of the schists in which the bedded structure has been obliterated or very ancient intrusions that, together with the enclosing crystalline schists, have subsequently been affected by heat, pressure and other agencies. Besides these there is in the same region at least one later series of distinctly intrusive granites, which is probably newer in date than most of the Paleozoic rocks. In the Coast range, on the western side of the interior plateau, a similar "complex" of crystalline schists and granites occurs, of which part at least may be of the same age with that just alluded to, though in this case some of the intrusive granites are known to be post-Triassic in date and others are later even than the Cretaceous.

Stratigraphy.

The General Section.—The section given in the first column of the annexed table represents the rocks met with near the eastern border of the interior

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*Such geological indications for the Selkirks as have been published may be found in the following works:

Report on the Geology of the Country near the Forty-ninth Parallel of North Latitude, by H. Bauerman. This is the result of observations made in 1859–'61, in connection with the expedition engaged in fixing the southern boundary of British Columbia in these years, but was first published in the Report of Progress of the Geological Survey of Canada for 1882–'84.

Summary Report of the Operations of the Geological Survey for the year 1887, by Dr. A. R. C. Selwyn. This contains a brief note on the character of the rocks near Illecillewaet.

Explorations in the Glacier Regions of the Selkirk Range, British Columbia, by Rev. W. Spotswood Green; Proceedings of the Royal Geographical Society, vol. XI, 1889. Mr. Green here gives a short geological note (p. 167) and refers to the determination by Professor T. G. Bonney of some of the rocks brought back.

Notes on the Geography and Geology of the Big Bend of the Columbia, by Professor A. P. Coleman; Trans. Royal Soc. Can., vol. VII, sect. IV, 1889. In this paper the general geological character of districts visited by the author are described and the results of a petrological examination of a number of rocks are given.

Brief mention has also been made by the writer of the rocks of the Selkirks and neighboring ranges in Descriptive Sketch of the Physical Geography and Geology of the Dominion of Canada, 1884; Mineral Wealth of British Columbia (Annual Report Geol. Surv. Can., new series, vol. III); and elsewhere. A somewhat more detailed account has been given by him of the geology of a part of the western border of the Selkirks, resulting from a reconnoissance made in 1889 and published in 1890 in his Report on a Portion of the West Kootanie District (Annual Report Geol. Surv. Can., new series, vol. IV).

Provisional Comparative Table of Formations met with (1) *in the eastern Border of the Interior Plateau of British Columbia,* (2) *in the Selkirk Range, and* (3) *on the western Side of the adjacent Portion of the Rocky Mountain Ranges.*

	1. Section on Kootanie and Adams lakes.		2. Section in the Selkirk range on line of Canadian Pacific railway.		3. Section in the Rocky Mountains (west side of range; McConnell).	
	Feet. 6. Greenish and gray schists, with limestone .... 2,000 5. Limestone or marble, with black, glossy argillites and some gray schists... 2,500		*Feet.* Quartzites with gray schists and some limestone. Black shaly argillites, limestone and gray schists.		*Feet.* *Halysites* beds. Dolomites and quartzites .... 1,300 or more. *Graptolite*-bearing shales. Black fissile argillites, with some limestone 1,500	CAMBRO-SILURIAN AND SILURIAN.
Adams Lake series.	4. Chiefly greenish, with some gray schists .... 4,050 3. Chiefly gray, with some greenish schists 8,550	*Selkirk series.*	Gray schists and gray quartzites, with some quartzose conglomerate and interbedded blackish argillites, the last chiefly toward the base 25,000	*Castle Mountain group.*	Greenish and gray calc-schists and greenish and reddish shales and slates, with some dolomitic limestone .... 10,000 (probably).	CAMBRIAN.
Nisconlith series.	2. Black shaly or schistose argillite, with some limestone .... 1,000 or more.	*Nisconlith series.*	Blackish argillite-schists and phyllites, generally calcareous, with some beds of limestone and quartzite 15,000	*Bow River series.*	Dark argillites, with some quartzites and conglomerates, the latter particularly toward the summit. Base not seen .... 10,000 or more.	
Shuswap series.	1. Mica-schists, gneisses and marbles .... 5,000 or more.	*Shuswap series.*	Gray gneissic rocks and coarse mica-schists .... 5,000 or more.			ARCHEAN.

plateau region and is based on observations made on Kootanie lake in the western flanks of the Selkirks, supplemented by a section found on and near Adams and the Shuswap lakes, about 150 miles to the northwest of the first-mentioned locality. The lowest rocks in this column are those referred to the Archean, the thickness stated being merely that known to occur on Kootanie lake. The rocks included in the Adams Lake series, consisting of gray and green schists, and forming so large a part of the entire thickness, have been merely referred in a general way to the Paleozoic. In their typical locality they appear to be distinctly traceable on their line of strike into contemporaneous diabase and diorite rocks, which are often agglomerates, and pass into volcanic ash rocks, where their constituents become finer. The peculiar lithological character (which, taken by itself, might be supposed to indicate that the rocks should be classed as upper parts of the Archean) of these Adams Lake schists is thus believed to depend chiefly on the dynamic metamorphism resulting from extreme pressure which has affected the volcanic components of the Paleozoic, where these have been included in the strict flexures of the mountain region of the Gold system. No direct paleontological evidence is, however, forthcoming with respect to the age of the rocks of this first column of the table.

The third column in the table represents Mr. McConnell's published section in the Rocky Mountains proper, in which certain horizons, ranging upward from the lower Cambrian, are definitely fixed by fossils. It was found, in working out the section in this part of the Rocky Mountains, that a considerable difference exists between the section of the eastern as compared with that of the western part of the range, the present width of which (whatever that originally occupied by the rocks composing it may have been) is about sixty miles only. The particular feature of this change which is interesting in the present connection is that observed in the Castle Mountain (Cambrian and Cambro-Silurian) group, which, although it is on the east essentially a limestone formation, is found on the west to consist in large part of greenish calc-schists and greenish and reddish shales and slates.* No granitic rocks or true crystalline schists are seen in any part of this section.

The section represented by the middle column in the table is that now obtained for the Selkirks. It occupies, geographically, as it does in the table, a position intermediate between that of the eastern border of the interior plateau and that of the Rocky Mountains. In this, as in the section given in the first column, no horizons have yet been fixed paleontologically, and the position given to the rocks therefore depends principally on the comparison of the section with that known in the Rocky Mountains proper. It is probable, from the composition and condition of the rocks, that they may yet be found to hold fossils; but in the meantime it is believed that the lithological

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*Annual Report Geol. Surv. Can., 1886, pp. 24D, 25D.

resemblance of the formations to those met with in the Rocky Mountains is in itself sufficient to enable some important general conclusions to be arrived at respecting the rocks of the Selkirk range, while the analogy of the rocks of the Selkirks to those of the first section is also such as to afford some clue to the age of the formations represented in it.

The Shuswap Series.—The lowest crystalline, and presumably Archean, rocks largely represented in the western portion of this part of the Selkirk range are evidently referable to the Shuswap series of the first section. They consist chiefly of gray gneisses, varying from nearly massive to quite schistose, and in the latter case frequently having their division-planes thickly covered with glittering mica. They are both hornblendic and micaceous, but the last-named mineral usually preponderates. Orthoclase is apparently the most abundant feldspar, quartz is nearly always well represented and garnets are not infrequent. In many places nearly half the entire mass of the rocks exposed consists of intrusive or vein granite, with pegmatitic or graphitic tendencies.

The Nisconlith Series.—Overlying the basal holo-crystalline series in the Selkirk section is a mass of rocks of which the thickness is estimated at 15,000 feet. These are dark-colored and generally blackish argillite-schists and phyllites, representing various stages in alteration between true argillites and micaceous schists. The rocks are usually rather finely fissile, with glossy and sometimes wrinkled surfaces, but often with much minute yet visible mica on the division-planes. These planes are in some cases evidently due to cleavage, but are often true bedding-planes. The rocks are usually calcareous, and frequently hold thin layers of dark-bluish or black impure limestone, together with occasional layers of dark quartzite. The coloration is evidently due to carbonaceous matter, and pyrites crystals are very common in certain zones. The only notable diversity met with in this otherwise homogeneous mass of rocks is found towards the base, where (at the lower end of Albert cañon) a bed of pure blue-gray crystalline limestone thirty feet or more in thickness occurs, and a short distance still lower in the section, a series of beds over 1,000 feet in thickness, consisting chiefly of granular pale-gray quartzites. The quartzites are sometimes flaggy and generally more or less micaceous, and are interbedded as well as overlain and underlain by blackish micaceous argillites and layers of coarsely micaceous pale schists.

These rocks undoubtedly represent the Nisconlith series of the first column, of which no extended sections have yet been found in the interior plateau, while to the eastward they certainly correspond in the main with the Bow River series of the Rocky Mountains, for which a thickness of 10,000 feet was there ascertained, though the base of the series is never exposed in the Rocky Mountains.

The Selkirk Series.—Between the foregoing series and the next overlying mass of beds in the Selkirk section no distinct line of division, even of a lithological character, has been observed, there being apparently, on the contrary, a considerable thickness of passage beds, in which the dark schists of the lower series alternate with gray quartzites and gray glossy schists characteristic of the upper series. The estimated thickness of this overlying series is 25,000 feet; and of its rocks the higher central peaks of this part of the range, comprising mounts Sir Donald, Macdonald, Tupper, Hermit, Cheops, Ross peak and others, appear to be wholly composed. Lithologically, it consists of a great volume of gray schists and gray quartzites, which are occasionally somewhat dolomitic. The quartzites probably preponderate, and vary in color from nearly white to gray and greenish-gray, being seldom dark in tint. They often, however, weather to pale brownish colors and pass into coarse grits and fine-grained conglomerates; and these grits and conglomerates have become more or less schistose in structure as a result of pressure, which has also led to the development in them of much fine silvery mica. The schists vary in color from pale neutral-gray to greenish-gray, and from dull to silvery and lustrous, being in many cases apparently true sericite-schists. They are sometimes wrinkled and contorted, particularly on the east side of the main synclinal, where also they occasionally become coarsely micaceous. To the east of this main synclinal and beyond the great fault shown in the diagrammatic section (p. 174) they are more crushed and altered and more highly micaceous than elsewhere, probably as a result of the dynamic conditions to which they have been subjected in this region.

The rocks of this great series appear to represent the Adams Lake series to the west, while they undoubtedly correspond, at least in a general way, to the Castle Mountain group of the Rocky Mountain section on the east, for which group Mr. McConnell ascertained a minimum thickness of 7,700 feet, but found reason to believe that its total volume in the western part of the range approached 10,000 feet.

It will be understood from what has already been said that the line indicated between this and the underlying series in the Selkirks is based entirely on general lithological differences, while there is every reason to believe that a plane of division drawn to correspond with that between the Castle Mountain and Bow River series in the Rocky Mountains would lie several thousand feet above the recognized summit of the Nisconlith series in the Selkirks. In the Rocky Mountains, the lower Cambrian (*Olenellus*) fauna is known to be common to the lower part of the Castle Mountain and upper part of the Bow River series;* the separation being there made at the base of the distinctly calcareous upper part of the Cambrian, while certain rather characteristic quartz-conglomerates observed in the upper part of the Bow

*This fauna is known to characterize several thousand feet of the Castle Mountain series, and has been found as well about 3,000 feet down in the upper part of the Bow River series.

River series of the Rocky Mountains are paralleled by similar conglomerates which abound in the upper series of the Selkirks. No unconformity has been observed between the upper and the lower masses of strata in either place.

Though in the Selkirk section the lower of the two great series which have been described resembles the Nisconlith of the interior plateau so closely as to warrant extending the same name to it, the fact that the overlying member of the section differs considerably from the Adams Lake series of the interior plateau, while on the other side it probably represents not only the whole Castle Mountain group but also the upper part of the Bow River series of the Rocky Mountains, renders necessary the application to it of a provisional distinctive name. It is therefore proposed to refer to this rock-mass as the *Selkirk Series.*

General Relations of the Cambrian.—Regarded as a whole, we find reason to believe that the Selkirk section exhibits a great Cambrian formation which (by analogy with the Rocky Mountains) includes the lower part of the Cambro-Silurian and reaches down from it to and far beneath a horizon at which the *Olenellus* or lower Cambrian fauna has been found, with an aggregate thickness of about 40,000 feet.

The comparatively pure limestones of which the Cambrian of the eastern part of the Rocky Mountains is composed are replaced in the western part of that range by rocks largely clastic in origin. This change in lithological character appears to continue and to become still more marked and to be accompanied by increasing thickness in the Selkirk range. Much of the clastic material is silicious, and the introduction of an increased proportion of such material may be explained by considering it as a result of approach to the shore line of Archean rocks on the west. While the principal development of contemporaneous volcanic products, whether in the Paleozoic, Mesozoic or Tertiary, is confined to a region west of the local Archean axis, the writer is inclined to believe that a portion of the remarkable difference found to occur in the western extension of the Cambrian may be due to the inclusion in its rocks, on this side, of volcanic ash deposits or other fine-grained volcanic materials, of which the composition was such as to favor the subsequent production of sericitic or sericite-like schists.

Speaking generally, the great Cambrian formation of the Rocky Mountain and Selkirk ranges shows many points of resemblance to the Cambrian and so-called "Algonkian" rocks of Utah and Nevada, the resemblance being particularly close in some respects to the series shown in the well-known Wasatch section, in which more or less distinctly micaceous schists are also found. It is, further, not at all unlike the Cambrian of Wales, which, though the organic remains are chiefly confined to some upper beds, has a thickness of 25,000 feet and is believed to exceed this in Shropshire.* The provisional

* Text Book of Geology; Geikie, 2nd edition, 1885, p. 651.

estimate of the thickness of the Cambrian arrived at in the Selkirks is, however, greater than that elsewhere known.

In a late paper on the stratigraphical position of the *Olenellus* fauna,* Mr. C. D. Walcott has suggested that the Bow River series of the Canadian Rocky Mountains may be regarded as "Algonkian." He does not, however, appear to have been aware of the fact above alluded to, that the *Olenellus* fauna characterizes both the upper part of this series and the lower part of the Castle Mountain group. With this circumstance in evidence, together with the apparently complete stratigraphical conformity of the two series, the writer cannot but regard it as more in consonance with the conditions, so far as these are known, and therefore as more philosophical to include, for the present at least, the whole of this great conformable mass of rocks, to its base, under the name Cambrian. In Utah and Nevada, where Mr. Walcott's observations on the western Cambrian have chiefly been made, it seems that the beds classed as "Algonkian" likewise in general conformably underlie those in which the *Olenellus* fauna is known, the conditions being apparently in most cases similar to those here described. On the propriety of the use of the new term in regions with which he is not personally familiar the writer wishes to offer no opinion, but he may take the opportunity of stating that he has met with no rocks in Canada to which its application can at present be considered appropriate, either in the interest of precision in the expression of facts already ascertained, or because of the discovery of heretofore unrecognized relations as between the older formations.

So far as could be definitely ascertained in the course of the rather hasty examination upon which this paper is based, the lowest beds of the Cambrian in the Selkirks (seen not far east of Albert Cañon station) are in angular conformity to the Archean rocks (seen to the west of the same station). The actual junction, however, remains to be studied, as there is here a gap in the section on the line of railway. In the meantime it may be stated that, notwithstanding the appearance of conformity, there is reason to believe that a great break in time is here passed over; for, although coarse, glittering micaceous schists are found in some parts of the Cambrian, the rocks of the lower series differ markedly even from these in their completely crystalline character. The essential diversity in age of the two series is further shown by the circumstance that the highest rocks of the Archean here met with do not include the notably silicious beds, the calcareous gneisses and the marbles which characterize the upper parts of this system as exposed on Kootanie lake and near Shuswap lake. It is also found that the very numerous granitic veins which everywhere cut the Archean rocks do not enter the overlying Cambrian strata, while a large quantity of pale-pur-

* Am. Journ. Sci., 2nd ser., vol. XXXVIII, 1889, p. 32.

plish, slightly opalescent quartz occurring in the conglomerates and quartzites of the Cambrian seems undoubtedly to have been derived from the denudation of these very granitic veins.

Newer Rocks.—On the eastern side of the Selkirk range certain rocks occur which are supposed to be equivalent to the *Graptolite*-bearing shales and *Halysites* beds of the adjacent Rocky Mountains. As, however, the reference of these beds must as yet be considered doubtful, on account both of the absence of fossils and of the unusually disturbed character of this part of the section, nothing more need here be said respecting them.

The Devono-Carboniferous, Carboniferous, Triassic and Cretaceous strata entering into the composition of neighboring parts of the Rocky Mountains are nowhere seen in this part of the Selkirks.

Structure.

Respecting the structural features of the section as a whole, little need be added, as, in so far as these may be considered to have been determined, they are rather simple. The western part of the Selkirk range, for a width of about seventeen miles, is essentially composed of Archean and granitic rocks, which, it may be added, are continued to the west of this part of the Selkirks across the Columbia range for a further distance of about forty miles. These rocks often lie at low, undulating angles, though they are occasionally much contorted. Above these, to the eastward, is the lower member of the Cambrian which has been referred to as the Nisconlith series. This forms a synclinal, of which the western side lies at a low angle, while the eastern side is steep, the axis being found near Illecillewaet station. To the east of the synclinal is a rather sharp anticlinal, the summit of the dark-colored beds of the Nisconlith series passing out of sight on the eastern side of this fold near the 413th mile-post on the railway.

The next great synclinal, which coincides with the highest parts of the range, appears to have a transverse width of about thirteen miles. The rocks con-

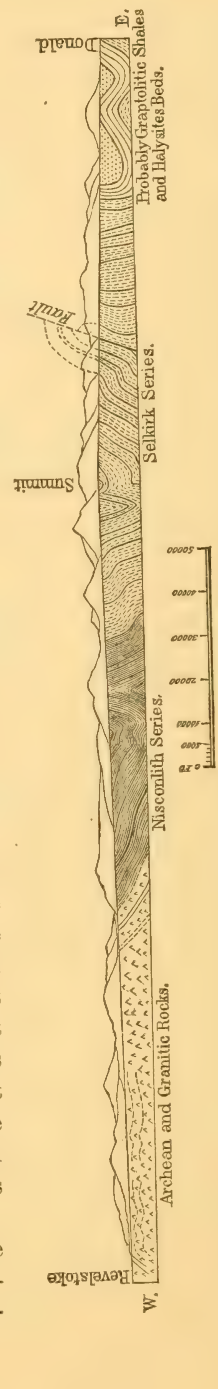

FIGURE 1—*Sketch section through the Selkirk Range, British Columbia.*

tained in it are those of the Selkirk series, which is believed to represent the upper part of the Bow River series, together with the whole of the Castle Mountain group of the Rocky Mountain section. The position of the main axis of this synclinal nearly corresponds with Loop creek, on the railway, to the west of Glacier station, while a subordinate synclinal trough runs immediately to the east of the same station and nearly coincides with the actual watershed in the pass.

The eastern edge of this synclinal is believed to be bounded by a great fault, which is supposed to cut the line of railway near Cedar creek (about a mile and a half below Surprise creek) and to run on southward along the upper part of Beaver valley. This fault seems to have the character of a number of those found by Mr. McConnell in an adjacent part of the Rocky Mountains, viz., that of a fractured anticlinal, thrust up on the west side in consequence of pressure acting from that direction.

To the east of this great fault, the section shown in figure 1 must yet be considered largely hypothetical, as the structure here becomes more complicated and there is reason to suspect further extensive faulting. There are, however, grounds for the belief that, in a wide additional synclinal on this flank of the range, together with the repetition of a great part of the Selkirk group, still higher strata representing the *Graptolite*-bearing shales and the *Halysites* beds of the Rocky Mountains are included. The section ends on the east at the upper Columbia valley, the line of which is coincident with an important anticlinal exposing rocks of the Castle Mountain series, which dip westward into the base of the Selkirks and eastward into the opposite base of the Rocky Mountains.

Thickness.

If the writer is correct in attributing a total thickness of about 40,000 feet to the Cambrian (with such part of the Cambro-Silurian as may be included in the upper portion of the Castle Mountain group) of the Selkirk range, the entire thickness of the Paleozoic obtained by adding to this that of the remaining higher members of the adjacent part of the Rocky Mountains would be about 49,000 feet. Supplementing this with the thickness of the Kootanie and other formations of the Cretaceous, seen either in the Rocky Mountains or in the neighboring foot-hills toward the east, we obtain a total of 69,000 feet.

Though, however, the sections which give this enormous aggregate are all comprised within a distance, measured across the axis of disturbance, of little more than 100 miles, it is improbable that the whole of the beds in their maximum thickness ever formed a single column. The Cambrian evidently thickens greatly at its western margin, where not only has the upper part of the Paleozoic not yet been found, but where also there is reason to believe that the very thick Cretaceous formations never extended. It must further be borne in mind that the actual width of 100 miles measured across this folded and faulted region represents a zone of very probably double this width of the surface as it was antecedent to the great folding and faulting. In this zone the line of maximum sedimentation appears to have moved progressively eastward, or away from the local Archean land, in the later periods.

DISCUSSION.

Dr. J. W. Spencer: I desire to again* claim priority for the name Algonkian, on the ground that before its publication I had used the term "Algonquin" to designate an episode in the Quaternary history of the region of the Great Lakes.

Mr. G. K. Gilbert: While the two names referred to by Dr. Spencer are based on the same root, one has the adjective form and the other the nominal, and confusion is thus avoided. The simultaneous and unobjectionable use of nouns and adjectives etymologically identical for different elements of geologic classification is illustrated in the case of the "Huron shale" and the "Huronian system," and in that of "Erie clay" or "Erie shale" and the "Erian period" or system. The use of "Erie shale" for a Paleozoic formation conflicts with the use of "Erie clay" for a Pleistocene formation, but neither conflicts with Sir William Dawson's term "Erian."

* Cf. Bull. Geol. Soc. Am., vol. 1, 1889, p. 238, note.

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GRAPHIC FIELD NOTES FOR AREAL GEOLOGY.

BY BAILEY WILLIS.

(*Read before the Society December* 30, 1890.)

CONTENTS.

IMPORTANCE OF RELATIONS IN SPACE TO GEOLOGIC STUDIES.

Some years ago a coal property in Washington territory was offered for sale by shrewd speculators, who valued the land at $1,100 an acre on account of the great thickness of workable coal said to occur in several veins. The property was not developed, but the number of coal beds and a total thickness of good coal of more than one hundred feet were confidently stated from exposures of the folded coal measures in a cañon 400 feet deep, which traversed a plateau whereon glacial drift and primeval forest obscured the strata. Of these natural conditions the speculators skillfully took advantage; they opened the coal beds on the cañon sides at points which were not intervisible, and they cut a labyrinth of paths through the forest leading from one opening to another. On the cliffs these paths were unpleasantly narrow; in the underbrush of the plateau they wound about in such manner as to exaggerate the impression of distance. It was shrewdly calculated that any geologist by these means topographically misled might be geologically confused and led to count a single coal bed seen at different openings as several beds. And this calculation was justified by the result. An expert of high standing, whose experience and reputation fairly commanded confidence, reported the coal at nearly three times its actual thickness, and $750,000 was paid on his mistake. The error in stratigraphy followed from ignorance of the local geologic structure, both avoidable had the geologist determined relations of distance and direction among observed sections.

The point of this story is the point of this article: A knowledge of relations in space among geologic facts is essential to the solution of problems of stratigraphy and structure, and it follows that the geologist must locate his observations on a map either prepared in advance or surveyed simultaneously with his work. The possession of an adequate map constitutes the ideal initial condition for geologic work.

Definition of an adequate Map for Geologic Purposes.

General Definition.—An "adequate map" is one which accurately describes the character of the features delineated: it is so characteristically true to the facts of topography and culture that it offers many tie-points, *i. e.*, many points which can be definitely recognized as the representatives of specific locations on the ground. Such points are essential to the location of a geologist's observations of outcrops, strikes and dips, or formation boundaries, which may be of very limited extent but which must be placed on the map with such accuracy that the error, reduced to the scale of the map, is insignificant. Such tie-points are bends of roads, cross-roads, crossings of roads and streams, sharp turns in streams, stream junctions, springs, mountain peaks, ridges, gaps, spurs, abrupt changes of slope; in a word all characteristic features.

Maps are sketches fitted to a geometric control. If we compare them with works of higher art, we may liken the painfully exact military maps of Europe to miniature portraits, while some American maps, produced under demand for quantity rather than quality, suggest paintings executed with a palette knife. The difference lies in the minuteness of control, in the number of points accurately determined per square inch of map.

Methods of Control.—The measurements which constitute control are obtained by two methods, triangulation and meander, each of which has its advocates, each of which requires certain natural conditions for economic working, but which in most regions can advantageously be combined.

Unsupported triangulation affords few tie-points; stations and intersections are fixed without appreciable error to the scale of the map, but roads, streams and contours, if the last be employed, are generalized according to the handwriting of the topographer rather than to the character of the topography. The geologist who is obliged to use such a map should be fitted to locate himself by direct reference to the geometric control, and he should check the generalizations of the map by such references.

A meander line fitted to a scheme of triangulation supplies tie-points within a belt of varying width. If it follows a road or stream each change of direction provides a tie-point, and the elements of relief within the topographer's view are fixed usually beyond his power to generalize out of recognition. Thus the number of tie-points increases much faster than the number of miles of meander run; and the value of the map is rapidly augmented as the net-work of meander lines is made finer. Thoroughly satisfactory maps can be made by this method. The first example of this class of work which came to my notice was the Greenville, Tennessee, atlas sheet of the U. S. Geological Survey series; it represents a thousand square miles of the valley of Tennessee, where the present relief is a dissected base-level in limestone, overlooked by strike ridges of sandstone and shale. All the roads were meandered, the total distance being about 1,200 miles, a season's work for one topographer. The southeastern corner of the sheet is mountainous and without roads. Here the topographer was confined to sketching to fill in his triangulation, and the resulting map is so inadequate that the geologist was obliged to correct the base by meander lines run on foot. Other maps of this desirable character have been and are being made by those topographers who appreciate the possibility of putting character into their work. Such men raise their profession from the dead-level of mechanical generalization to an art which expresses important geographic truths. And these geographic facts are but the latest expression of geologic processes, which it is the province of the geologist to interpret. But the topographic artist has been a rare being, and while we may felicitate ourselves upon the prospect of his becoming more numerous, we still have to work with the inartistic product.

Procedure with an inadequate Base.

The general Question.—How can the geologist best proceed in the field with a map which does not afford tie-points for his observations; or, in other words, given an inadequate base, what method of field work leads most satisfactorily to the development of a geologic map? To this question thus broadly stated no intelligent answer can be given. Account must be taken of the geologic problem, of the aspect of its presentation and of the characteristics of the geologist. The student of crystalline rocks, accustomed perhaps to the limited outlook in a Michigan forest, cannot well devise details of methods for him who studies stratigraphy and structure on the treeless plains of the west. Nor can he whose stratigraphic work in the settled states is facilitated by roads prescribe methods for the investigator of volcanic geology in uninhabited mountain ranges. Each must adapt to his own environment the means of recording and arranging observations, but he will certainly do so more intelligently if he avails himself of the experience of others, whose training and experiments may contain positive or negative suggestions.

Believing this, I propose to give here for what it is worth the experience of the Appalachian division of the United States Geological Survey with graphic methods of mapping formations.

Appalachian Work in the U. S. Geological Survey.—The Appalachian Paleozoic province presents stratigraphic and structural problems under an aspect which is familiar to all of us. Relief is seldom emphatic, heights have usually struck an average elevation through successive base-leveling, soil covering is the rule, vegetation flourishes everywhere, and cultivation assists in obscuring geologic facts: these are obstacles to rapid work, whatever the problem. On the other hand, relief and structure are intimately related as effect and cause, the factors of the problems, multitudinous as they often are, are crowded together in small space, every part of the region is easily accessible, roads and houses permit facilities not else available: these are aids to successful work.

The geologists of the United States survey who entered this province prior to 1886 were trained in western fields and did not at first devise the best methods of work. The amount of geology per square mile was embarrassing to them; the facilities afforded by culture were not appreciated. It seemed, moreover, a fair assumption that the Rogers brothers, Safford and others had solved the geologic problems of the region and that to resurvey their fields was but to confirm their results, which must be done in detail and with great accuracy. Triangulation for detail was forbidden by the absence of marked features of relief or culture, and meander methods were a necessity in the absence of adequate maps.

Stadia Transit Method.—The special conditions and the fact that the purpose of the work was section-measurement led to the selection of a very accurate method based on stadia measurements of distances. The instrument used was a light transit, mounted on tripod and leveling screws, carrying a telescope with a vertical limb and fixed stadia wires. The stadia rod was 12 feet long and graduated by experimenting with a base measured by a steel tape; there were two movable targets, which were adjusted by the rodman on signals from the surveyor until the interval between them was proportioned to the space between the stadia wires of the telescope; the number of divisions on the rod included between the targets then corresponded to the distance from transit to rod. The maximum distance measurable with this instrument and rod was 1,500 feet. A much greater reach might have been obtained with a longer rod, but it was not deemed desirable.

The operation at any one station was as follows: the geologist set up and leveled his transit, received from the rodman the distance reading of the last sight and platted his topographical and geological notes accordingly. The rodman set a target to the height of instrument and went on to select the next station. When ready the rodman called, the geologist observed and noted the course and slope of the new sight, by signals adjusted the targets to the stadia wires, and then rejoined the rodman.

By repetitions of this process, with more or less delay for misunderstandings on account of the distance frequently separating the geologist and rodman, the meander line progressed at the rate of 3 to 6 miles a day.

The record consisted of two parts containing similar information: the one part composed of figures and verbal notes; the other part representing approximately the map to be platted from these figures. The final interpretation of the whole record constituted the office work.

This required for each sight the reduction of slope distance to its horizontal projection and a calculation of elevation of each station. The course and distance being platted, the geologic facts could be indicated and the sections developed. This labor proved very onerous; unnecessary mechanical accuracy of delineation absorbed time that should have been given to thoughtful study. The end in no sense justified the means, for the method was adapted to the accurate coördination of a mass of facts in a small area, as in a mining survey, not to generalizations in stratigraphy and structure.

Adoption of graphic Methods.—It has already been stated that the record of stadia work was in two forms: the one numerical, the other graphic. The former occasioned most of the office work, the latter contained the pith of the geologic information. It followed that in casting about to devise a method for mapping formations, we sought to get rid of the figures and to improve the sketch to the standard required for a final plat fit for transfer to the map. To do this required the adoption of some means other than the stadia of measuring distances, and of means for sketching directions and distances more accurately than had previously been done.

For measuring, two instruments have been successfully used: the one the wheel of a buckboard or sulky with some attachment for marking its revolutions; the other a pair of legs, usually those owned by the geologist. With the former the unit of measurement is a "wheel," *i. e.*, the circumference of the wagon wheel; with the latter the unit is a pace, a function of the individual. These vary in different instruments and require reduction to a common scale before combining different pieces of work.

Measurement with a wheel is an old method, improved within the last few years to meet the demand of the topographic division of the United States Geological Survey for an efficient means of traverse work. Mr. Henry Gannett says of it:

"As nearly all traversing is done along roads, distances are measured in this work mainly by counting the revolutions of a wheel—usually one of the wheels of a buggy or buckboard. Various forms of odometer for automatic counting have been in use. The old pendulum odometer was first tried and unqualifiedly condemned. The form now in general use is that devised by Mr. E. M. Douglas, of this Survey. For working this a cam is placed on the inside of the hub, which, by raising a straight steel spring, carries the index forward one division for each revolution of the wheel. The odometer registers to ten thousand. This form is the most trustworthy that has yet been devised, but is not altogether satisfactory, and the majority of traverse men prefer to count the revolutions of a wheel directly. The arrangement by which a bell is rung at each revolution is a very common and effective device. From an extended experience covering many thousands of miles of measurements it has been demonstrated that as a working method of measuring distances the wheel is greatly superior upon roads to the stadia. Moreover, it is nearly if not quite twice as rapid as the stadia method." *

The attachment of the Douglas odometer to the wheel varies with the ingenuity of individual users: it may be placed on either axle, when its connection with the wheel is then most direct; or it may be placed beside the seat of the vehicle and connected with the wheel by wires working a system of levers. The latter arrangement requires nice adjustment but raises the odometer out of the reach of mud, places it within convenient observation and enables the observer to judge the regularity of its register by the click of the ratchet.

Pacing, as a means of measuring short spaces, we are all familiar with; but pacing mile after mile, day after day, for continuous record is not a common practice. It was only after experience had demonstrated both the necessity and practicability of pacing that I gave the method practical consideration. Where the wheel can be driven it has the advantage; but where the wheel must stop, the pace becomes a convenient and indeed indispensable unit of measure, which never fails one who has practiced it. It may be confidently stated from repeated experiences that there is no condition of surface, of slope, or of obstruction, over or through which a man cannot pace, with a reasonable approximation to the true distances, provided the ends of the meander line are so tied to some control that the scale of the meander plat can be independently determined. Systematic pacing for geologic record was first used by the Canadian Survey and in the United States by Brooks and Pumpelly in the Lake Superior region. The United States Land Survey there divided the country into square miles and within these north or south straight

* Unpublished MSS.

lines were paced at regular intervals. The accuracy of the pacer was checked at each section line, and woodsmen selected for the work became very expert, keeping count of regular steps through underbrush, through windfalls, and even in deep snow on snow-shoes. It was found expedient to adopt an arbitrary pace, 2,000 to the mile, and outcrops were located as so many west and so many north from the southeastern corner of any particular section. Where the notes of different observers were to be studied by one geologist a uniform pace was desirable, and it is probable that the short pace, 2,000 to the mile, is a more regular unit of measure than a longer stride; for, being shorter than a man's average step, it would be less affected by the varying conditions of the ground; certainly no one who attemps to stride beyond his ordinary step can pace regularly for any long distance. Yet few men care to train themselves to a definite short step, and it is not necessary where the distances paced are at once recorded in a plat of known scale, since the unit of measurement then becomes a matter of indifference. It is only necessary that the pacer should know and record his average step, and this can be ascertained by counting paces for half a day in walking a known distance or by platting a day's route to an assumed scale and correcting it by a map of known scale.

The principal difficulty in pacing is to keep a correct count of steps, and to avoid this we have found it desirable to count every fourth step only, while yet giving to each footfall a digit or number. The mind readily recognizes a certain rhythm or time-beat on the fourth step, and it will unconsciously repeat the total number of paces in time with successive steps, adding one for each completed pace of four steps. Thus, starting out the left foot first, the rhythm runs: Left, right, left, one, or 0, 0, 0, 1, 0, 0, 0, 2, etc.; and further on, left, right, thirty, five, or 0, 0, 3, 5; still further, left, four, fifty, two, or 0, 4, 5, 2; when more than a thousand paces are numbered, one, three, seventy, eight, or 1, 3, 7, 8; the next pace, 1, 3, 7, 9; then, 1, 3, 8, 0; and 1, 3, 8, 1, etc. Thus each step repeats the appropriate figure and the four together give the total number of paces; the units change with every fourth step, the tens only with every fortieth step, and the hundreds and thousands each in their degree with less frequency. The repetition, unconscious though it comes to be, fixes the total number beyond the possibility of loss.*

The means of measurement being adopted, the method of recording is the next step; of these there are two: the plat on the traverse plane-table, and the plat in the note-book.

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* These methods of measurement suffice for the geologist on wheels or on foot, but they fail him on horse-back. In discussing this paper Dr. G. M. Dawson described a method of "time survey," which consists in riding a horse at a steady walk and noting the exact time consumed in riding over each course. The time unit of the plat is a function of the gait of the horse and is influenced by variations of the latter, and errors may creep in through disregard of momentary halts; every check should be noted. But when carefully watched the time survey is accurate to about one-fortieth of the distance. Dr. Dawson also referred to experience with a boat log in lake surveys.

The traverse table was devised by Mr. Gannett for the purpose its name indicates. He describes it as follows:

"The plane-table used for traversing is of the simplest possible form, consisting of a board 15 inches square, into one edge of which is set a narrow box containing a compass needle three inches in length. The table is supported by a tripod of light construction without leveling apparatus, the level of the instrument being effected by the legs of the tripod. The table is adjusted in azimuth or oriented by means of the compass needle, movement in azimuth being provided by simply turning the table on top of the tripod head. There is no clamp to the azimuth movement, the table being held in place simply by friction. The alidade consists of a brass rule 12 inches long, with raised sights hinged to turn down when not in use. Ordinary drawing paper backed with cloth is used for plane-table sheets and is attached to the board by thumb tacks." *

The operation of traversing with this instrument is very simple. At each station the table is oriented by bringing the compass needle to a mark on its short scale; the area of the map is usually too small to show any convergence of magnetic meridians, and if the magnetic declination be constant it follows that at each station the position of the table is parallel to all those preceding it. Courses sighted and drawn with the alidade, whether successive foresights or alternating foresights and backsights, therefore depart from each other with angles equal to those included by the directions on the ground, and the lengths of the sights being laid off to scale, the plat is a figure mathematically similar to the traverse on the ground. On this plat geologic observations can at any instant be indicated in their proper relations. It is customary to foresight to bend of road, tree, fence-corner or any other distinct object, to wheel or pace to the thing sighted, thence to wheel or pace to a convenient station and set up the table. At this station the operations are: (1) to orient the table, (2) to scale off the first foresight, (3) to sight and draw the backsight and scale it off, (4) to sight and draw the next foresight, (5) to sketch in topography or geology, and then to proceed. Time is economized by occupying alternate stations only, and geologic relations are developed as fast as the traverse line is extended. I believe that this simple instrument will prove to be of great value to geologists and will save time, labor and money in the extensive work of geological mapping.

But notwithstanding the simplicity and accuracy of the traverse table, geologists who do not wish to carry a mounted instrument of any kind have tried to accomplish the same object with only hand compass and note-book. To do this is to reduce instrumental impedimenta to a minimum, but the observation and recording of the traverse requires more care than on the plane-table. Given an ordinary clinometer compass with square base and sights and a note-book ruled in squares, the operation at any station is as

* Unpublished MSS.

follows: (1) to foresight by holding the compass in the right hand or on the note-book at half arm's length and at a convenient height for alignment with the object sighted and for reading the course; the compass sights may be closed or raised for this alignment and additional accuracy is perhaps obtained by sighting the longer side of the note-book placed parallel to the compass sights; (2) to record the foresight by drawing a line on the note-book page at the observed angle from a meridian previously assumed; a small horn protractor is useful for this purpose, but it is only necessary for long sights, such as those taken to locate distant points by intersections. It is easily possible to estimate the angle of the observed course with sufficient accuracy for sights of a quarter of a mile or less by bearing in mind the angles made by the diagonals of various parallelograms; thus the diagonal of a square is at 45°, that of a rectangle 2×3 is at 34° and 56°, that of one 1×2 is at 27° and 63°, that of one 2×5 is at 22° and 68°, that of one 1×3 is at 18° and 72°, that of one 1×10 is at 6° and 84°, etc. These diagonals are easily noted on the reticulated page. If a protractor is used it should have one straight side with a scale on it; if there is no protractor a convenient ruler can be made of a page of the note-book torn out and folded parallel to one set of lines; the folded edge will be straight and the lines at right angles to it give the scale. It is obvious that errors of angular notation are more serious the longer the sight laid down; hence more care is needed on long sights or on a large scale than on short sights or on a small scale. The limits of scale which have been found desirable for field platting in the Appalachian field are one and two miles to the inch; the smallest scale on which legible notes can be written is the best. As the meander thus noted is extended, geographic and geologic notes fall into place along it.

Summary of Methods.—In the foregoing paragraphs I have sketched three ways in which members of the Appalachian division keep geologic field notes; first by direct notation on an adequate base, where such is available, second by notation on a meander run with traverse plane-table and odometer or pacing measurement, third on a meander surveyed without mounted instruments and platted on the note-book page. It remains to indicate what the use of such methods accomplishes.

In any comparison of methods for the determination of efficiencies, two factors must be considered for each method under like conditions. These are quantity and quality of work. Under the conditions of stratigraphy, structure and culture existing in the Appalachian province, the quantity of work which can be accomplished with graphic methods of keeping field notes is best estimated by stating the number of miles of meander line that, with topographic and geologic notes, can be platted daily. Using the odometer attached to a buckboard with two horses and a driver, we estimate the average product at 15 miles a day after two years' experience. Pacing for the same record averages seven and does not exceed ten miles a day. Our experience further shows that these averages added to the distances from and to lodging places, lunch being taken afield, form a sufficient day's travel for horses or men, when performed day after day throughout the field season. Thus the quantity of product by this method is about equal to the endurance of means of transportation.

Quality, if we consider the work of different men, is a very variable factor; but if we compare the value of graphic notes with that of written notes taken by the same man we shall get a definite result. We find that graphic notes are more concise, more definite, more accurate than verbal notes; graphic notes are more easily understood by a fellow-observer, be he chief or assistant; graphic notes directly present facts in visible relations, words do not; graphic notes are capable of immediate transfer to the base map, verbal notes must first be translated into graphic form. He who takes graphic notes in the field arranges facts, one by one, each in its place and in proper relations to all others; he who takes verbal notes forms a mental image of these relations, often an erroneous one, which must be corrected by a subsequent plat. Moreover, the possession in orderly arrangement of all facts observed up to any point in a piece of work enables the observer to plan ahead and directs his attention to missing links in the chain of evidence. Hence graphic notes, even if more slowly taken than verbal notes, are usually more complete and save waste and repetition of field work.

In the office there can be no question of the saving of time accomplished by graphic methods of field work.

In one instance two adjacent atlas sheets covering 1,000 square miles each, which presented structural problems in terms of similar stratigraphic units, were surveyed by a geologist and his assistant; the notes recorded in the one consisted of statements of distances wheeled off on roads and the corresponding geologic facts—a verbal record; the notes taken in the other were all platted directly in the field. Field work for the former was 34 days, for the latter 30 days. Office work for the former consumed four weeks, for the latter but two weeks.

The preparation of maps is but routine work, the aim of which is the elucidation and presentation of geologic problems; to reduce the time demanded for routine is to gain time for study and is therefore a step toward improvement in the quality of the final result.

The graphic methods which I have indicated are methods of accurate work; in the Appalachian province they are also methods of detailed work; but this is a condition of special application, not an inherent necessity. Running a meander line facilitates but does not necessitate the observation of geologic facts. Nevertheless it is true that the knowledge that every fact observed can be noted in its proper relations tends toward detailed observation.

The geologist who is forging a continuous chain of evidence becomes apprehensive of missing links, and the visible continuity of his record leads him to close observation; he skips nothing. And herein is a reflex action of graphic methods upon the observer, which is one of their best recommendations. The graphic record invites close attention to the accumulating facts; it is suggestive and directs observation to possible undiscovered facts. Graphic methods make keen observers.

Types of Field Notes.

Verbal descriptive Notes.—Example:

"Above these beds of Clinton ore, which lie in yellowish shales, is a white sandstone, forming the summit of Walden's ridge and its southern slope to the fault on the south. This sandstone is precisely like that observed on Poor valley ridge, Cumberland mountain, but it here lies above Clinton ores and there it underlies them. At the summit of Walden's ridge this sandstone and the Clinton shales with ore are folded in a sharp broken anticlinal and gentle synclinal, which restores the southern dip; this structure is well exposed in the sandstone cliff."

This form of record is often imperatively necessary to supply descriptions of relations or of physical characteristics of rocks which cannot easily be graphically expressed. The description written on the spot has an authority and value no subsequent statement can have, and the verbal form permits comparisons of facts, as the graphic form does not in the same degree.

Verbal Notes for Stratigraphy.—Example:

"Descending Cumberland mountain at White Rocks. Dip of strata 15° to 20° northwestward; aneroid 2,740 feet. The summit and escarpment of the mountain are formed of fine-grained sandstones, cross-stratified and containing layers of quartz pebbles, 1 inch and less in diameter.

715 feet (aneroid) below the summit the sandstone talus covers a light-greenish shale; aneroid 2,025 feet.

Outcrop of yellowish sandstone below shale; aneroid 1,850 feet.

Highest outcrop of compact gray limestone; aneroid 1,780 feet.

Highest outcrop of purple shales; aneroid 1,720 feet."

Such aneroid notes are of value for determinations of thickness of strata where the beds lie flat or at a gentle dip and the observations can be made on a steep slope; that is where the vertical measurement is of principal value and the relations in horizontal plan are not essential to the result desired. Again, given an adequate contour map and a simple problem of stratigraphy and structure, such notes may answer for the location of boundaries and structural facts; but their value is in proportion to the accuracy of the map and the simplicity of the problem, so that they may at any point become valueless through inaccuracies of the one or through unexpected complications of the other.

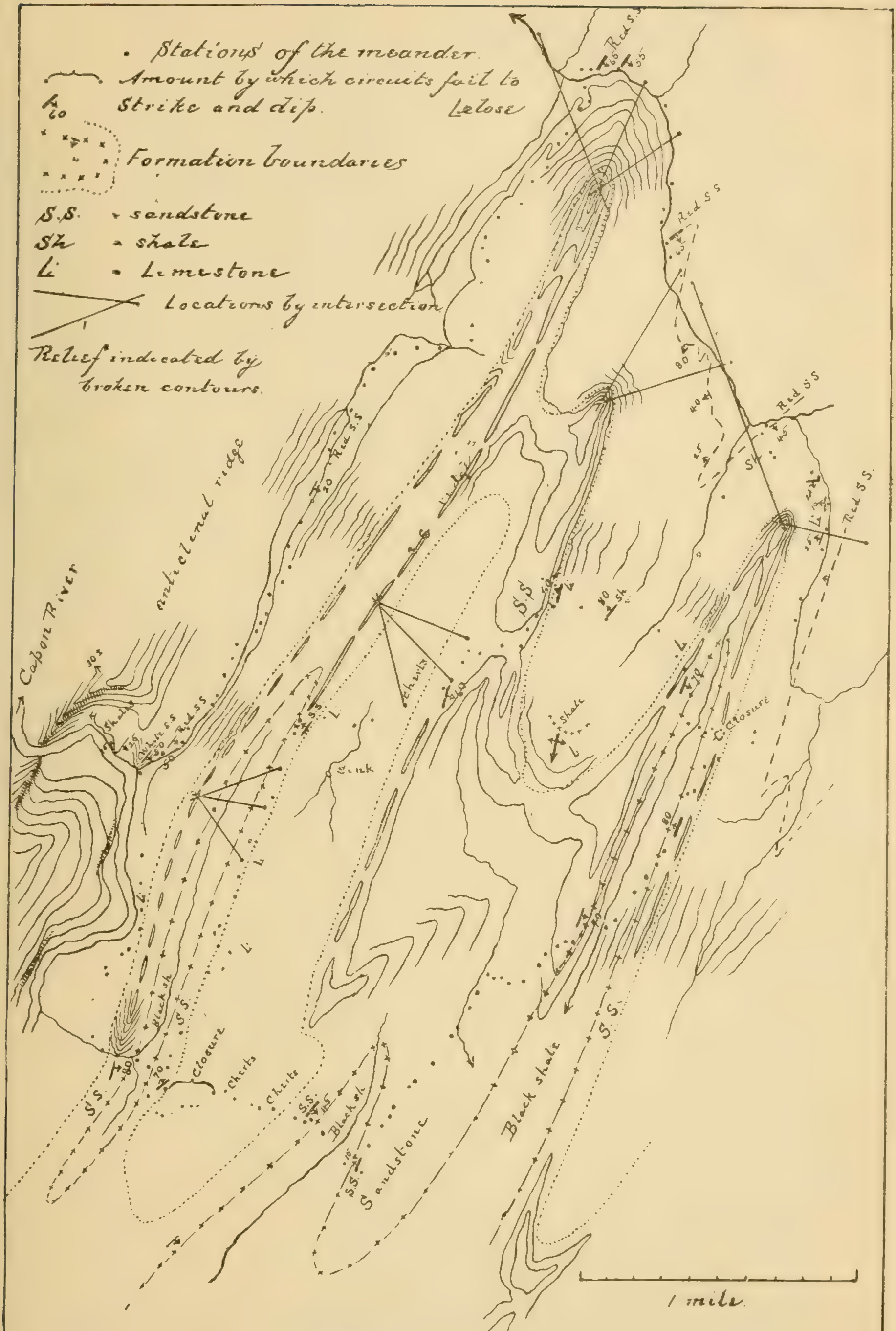
Verbal Notes for horizontal Location.—Example :

"Went from camp 1½ miles ± along river bank ; no outcrops. Turned up south-eastward, ascending crooked ridge ; in ½ mile ± came to outcrop of typical quartzite.

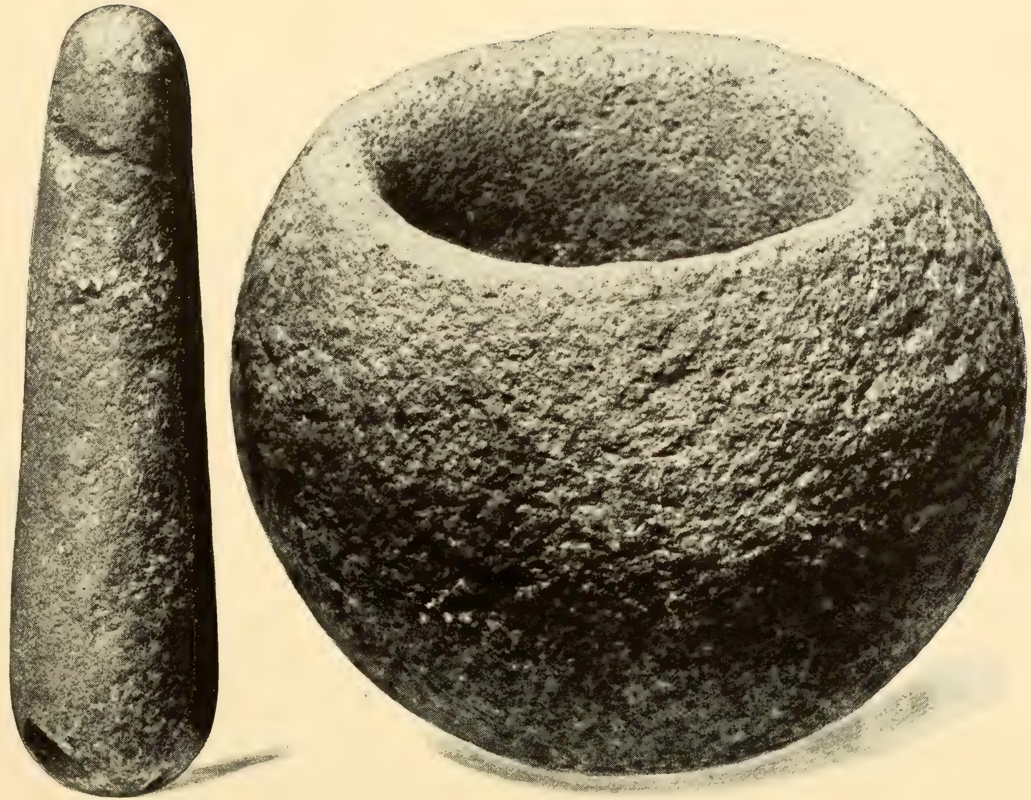
"Followed along the strike, descending to brook ; section well exposed. Up brook, course S. 10° ± W., pass over alternating beds of sandy shale and sandstone, dips varying from 10° to 85° ; in ¾ mile ± heavy sandstone, may represent typical quartzite ; in fifty steps fossiliferous limestone, either under or over quartzite, dips 70° to 90°, structure indeterminate. Collected fossils and returned to camp."

This represents a bad case ; careless work from the start vitiated the value of any possible observation. On the face of the notes it is apparent that the approximate distances are not worth anything, and when the looked-for quartzite was found its existence was established but not its position. The geologist, having observed nothing up to this point, was practically lost ; and being lost, that is, being cognizant only of general relations, he disregarded the details of the brook section. This day's work resulted in a collection of fossils from a limestone which was topographically and geologically undetermined, and was consequently almost wasted. This ineffectual result followed from a loose beginning ; it may serve to point the application of the old saying : "Whatever is worth doing at all is worth doing well."

Graphic Notes.—An example of graphic field notes, taken directly from a field plat drawn in the note-book without the use a protractor, is illustrated in the accompanying plate 6. The original record is in pencil ; a tracing in ink was made, the character of the original being maintained as closely as possible; and this tracing reproduced by photo-engraving forms the plate.



Copy of graphic field notes, platted on reticulated Note book without protractor, from courses sighted with hand Compass and distances paced. 17 miles of meander, 10 (sqr.) miles of area. Two days work. Showing relations of the Oriskany Sandstone and overlying and underlying beds.



MORTAR AND PESTLE FROM AURIFEROUS GRAVELS, CALIFORNIA.

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ANTIQUITIES FROM UNDER TUOLUMNE TABLE MOUNTAIN IN CALIFORNIA

BY GEORGE F. BECKER.

(*Read before the Society December* 30, 1890.)

CONTENTS.

INTRODUCTION.

Human Remains in California.—It is well known that implements and human bones have been reported from beneath the great lava-flows which cover many of the auriferous gravel deposits of California. From the same gravels the partially fossilized bones of extinct quadrupeds have been obtained, as well as many plants. The plants were regarded as Tertiary by Lesquereux; and some at least of the mammals, such as *Rhinoceros hesperius*, are generally recognized as Pliocene, while others, for instance *Mastodon americanus*, occur in the Quaternary if they are not confined to it. It was held by Whitney that the gravels were Pliocene, and this view has met with very general acceptance. The accumulation of the gravels and the eruption of the flows of lava which forms the cap-rock preceded the glaciation of the Sierra, a fact which lends strong support to the determination of age.

The assertion that human remains or implements of any kind are found with such fossils is surprising enough to provoke skepticism; but when it must be added that the implements said to have been discovered in these deposits are most unquestionably neolithic, on a level so far as workmanship is concerned with those in use by the California Indians during the present century, and that the famous Calaveras skull is of no lower type than that of the living Indians of the northwest, it cannot be wondered that many European naturalists and some American authorities refuse to accept as genuine the discoveries announced.

If such an association of remains actually occurs, theories must be modified to fit the fact; but novel facts require evidence as strong as their apparent improbability is great.

I have come into possession of proofs of the occurrences in question which are in some respects more convincing than any yet brought forward. I propose to lay these before the Society and then to make a suggestion as to the method of reconciling these facts with those observed elsewhere.

Geology of Table Mountain.—The history of the Tuolumne Table mountain is briefly as follows: Long before glaciation began in the Sierra the Stanislaus river pursued a course nearly parallel to its present bed, but some three miles further southward. It filled a broad channel with coarse gravels which have since become compact and partially indurated. After these gravels had reached a thickness of some 200 feet there was an eruption of basalt which ran down the channel and covered it with an even-topped sheet of lava often 150 feet thick. The glaciation of the Sierra began after this flow, and seemingly soon after it. During the glacial period of California the Stanislaus, displaced from its former bed, cut a new and far deeper one, so that the river now runs a couple of thousand feet below the top of Table mountain. It must clearly have eroded this great depth since the lava flow, and the lava sheet remains as the cap of a relatively elevated mass.

The gravels of Table mountain have yielded and still yield much gold, and very numerous tunnels have been driven into the mass for the purpose of finding the precious metal. In the course of these explorations fossils, including mastodon remains, have certainly been found. It is also asserted that human relics have been discovered beneath the lava cap.

Instances of the Occurrence of Relics beneath the Lava Cap.

Relics recorded by Whitney.—The following is a brief résumé of the discoveries of human relics reported by Professor J. D. Whitney:* Dr. Perez Snell of Sonora picked from a car-load of gravel, as it was coming out from under Table mountain, a stone grinding implement which was examined by Professor Whitney. Dr. Snell also possessed many other implements and a

*Auriferous Gravels, 1880, p. 264.

human jaw which had been given him by miners, among whom his practice lay, as coming from these gravels. Mr. Paul K. Hubbs, once state superintendent of public instruction in California, was present in July, 1857, when a small piece of a human skull was taken from a sluice in which pay gravel was being washed at the Valentine shaft, near Shaw's flat. The gravel still adhered to this fragment when Mr. Hubbs received it, and the shaft through which the material was brought to the surface was a boarded one, so that the bone (it is believed) could not have dropped into the shaft from near the surface, where also there was no gravel. Mr. Albert Walton, one of the owners of this claim, also states that a mortar was found in the gravel. Mr. Oliver W. Stevens, about 1853, picked from a car-load of dirt at the Sonora tunnel a mastodon tooth containing pyrite and a large perforated marble bead, which came into Professor Whitney's possession and shows that pyrite had filled or encrusted the hole. Stevens made an affidavit as to this discovery. Mr. Llewellyn Pierce made a sworn statement that about 1862 he dug up a mortar in a tunnel on the Boston Tunnel Company's claim, 1800 feet from the mouth of the tunnel and 200 feet beneath the surface, the basalt cap being here over 60 feet in thickness. This last is a very strong statement. Mr. Pierce must have known whether he did or did not dig up this mortar. I know nothing of Mr. Pierce, and it is possible that he may have been fond of practical jokes; but there are surely few men who would carry a joke to the length of deliberately perjuring themselves, and, had Mr. Pierce been capable of such a thing, it is probable that his reputation for untruthfulness would have been notorious. Mr. Pierce, if he is alive, will, I trust, pardon me for treating his credibility as if he were a witness in court. That practical jokes were in vogue in California in early days is certain, and it is unquestionable that Mr. Pierce's affidavit was taken with the express purpose of guarding against the objection that he might not be in earnest.

Mr. Neale's Discoveries.—During the past summer Dr. R. I. Bromley of Sonora called my attention to a mortar in his possession which had been given him as coming from beneath Table mountain. On inquiry I found that the original authority was Mr. J. H. Neale, a resident of Sonora, a mining superintendent by profession, a man of property and of unclouded reputation for veracity—one, in short, who could not afford to perpetrate a deception. Mr. Neale gave me a most intelligent account of his discovery and willingly took an affidavit to the following statement:

SONORA, *August* 2, 1890.

In 1877 Mr. J. H. Neale was superintendent of the Montezuma Tunnel Company, and ran the Montezuma tunnel into the gravel underlying the lava of Table mountain, Tuolumne county. The mouth of the tunnel is near the road which leads in a southerly direction from Rawhide camp, and about three miles from that place. The mouth is approximately 1,200 feet from the present edge of the solid lava cap of the mountain. The course of the tunnel is a little north of east.

At a distance of between 1,400 and 1,500 feet from the mouth of the tunnel, or of between 200 and 300 feet beyond the edge of the solid lava, Mr. Neale saw several spear-heads, of some dark rock and nearly one foot in length. On exploring further, he himself found a small mortar three or four inches in diameter and of irregular shape. This was discovered within a foot or two of the spear-heads. He then found a large, well-formed pestle, now the property of Dr. R. I. Bromley, and near by a large and very regular mortar, also at present the property of Dr. Bromley.

All of these relics were found the same afternoon, and were within a few feet of one another and close to the bed-rock, perhaps within one foot of it.

Mr. Neale declares it utterly impossible that these relics can have reached the position in which they were found excepting at the time the gravel was deposited, and before the lava cap formed. There was not the slightest trace of any disturbance of the mass or of any natural fissure into it by which access could have been obtained, either there or in the neighborhood.

And Mr. J. H. Neale declares upon his oath that the foregoing statement is in every respect true.

JOHN H. NEALE.

Subscribed and sworn to before me this second day of August, 1890.

EDWIN A. ROGERS,
Notary Public.

The larger mortar and the pestle referred to in this statement are illustrated in the accompanying plate 7, which is a photo-mechanical reproduction (by the Moss process) of a photograph of the objects, one-third natural size. The rock of which the mortar is made is andesite.

It would have been more satisfactory to me individually if I had myself dug out these implements, but I am unable to discover any reason why Mr. Neale's statement is not exactly as good evidence to the rest of the world as my own would be. He was as competent as I to detect any fissure from the surface or any ancient workings, which the miner recognizes instantly and dreads profoundly. Some one may possibly suggest that Mr. Neale's workmen "planted" the implements, but no one familiar with mining will entertain such a suggestion for a moment. No workman would dream of planting so large a number of implements, even to deceive a visitor, and he could conceal them only in broken ground. The auriferous gravel is hard picking, in large part it requires blasting, and even a very incompetent superintendent could not possibly be deceived in this way.

It has sometimes been objected to the authenticity of the discoveries of implements in the gravels that the finders, with the exception of Dr. H. H. Boyce, were miners and not scientific men. Now, so far as the detection of a fraud is concerned, a good miner regularly employed in superintending the workings would be much more competent than the average geological visitor. The superintendent sees day by day every foot of new ground exposed, and it is his business to become thoroughly acquainted with its character, while he is familiar with every device for "salting" a claim. The geological visitor finds a mine timbered and smoked. He cannot fully acquaint himself with the ground, and he is usually unfamiliar with tricks. It is therefore an argument in favor of the authenticity of implements that they have been found by miners. In short, there is, in my opinion, no escape from the conclusion that the implements mentioned in Mr. Neale's statement actually occurred near the bottom of the gravels, and that they were deposited where they were found at the same time with the adjoining pebbles and matrix.

Mr. King's Discovery.—Another unpublished discovery has also been made in these gravels which will be in so far more satisfactory to the members of this Society that the discoverer is well known personally to most of them

FIGURE 1.—*Broken Pestle from Auriferous Gravels. One-half natural size.*

and by reputation to every geologist. In the spring of 1869 Mr. Clarence King visited the portion of the Table mountain which lies a couple of miles southeast of Tuttletown, and therefore near Rawhide camp, to search for fossils in the auriferous gravels. At one point, close to the high bluff of basalt capping, a recent wash had swept away all talus and exposed the underlying compact, hard, auriferous gravel beds, which were beyond all question in place. In examining this exposure for fossils he observed a fractured end of what appeared to be a cylindrical mass of stone. This mass he forced out of its place with considerable difficulty on account of the hardness of the gravel in which it was tightly wedged. It left behind a perfect cast of its shape in the matrix, and proved to be a part of a polished stone implement, no doubt a pestle. It seems to be made of a fine-grained diabase. This implement was presented to the Smithsonian Institution on January 20, 1870. It is shown in the accompanying cut (figure 1), a photo-engraving from a drawing by Mr. W. H. Holmes. Mr. King is perfectly sure that this implement was in place, and that it formed an original part of the gravels in which he found it.* It is difficult to imagine more satisfactory evidence than this of the occurrence of implements in the auriferous, preglacial, sub-basaltic gravels.

The Calaveras Skull.—As is well known, there is also evidence indicating the existence of human remains in the gravel beds, particularly that afforded by the famous Calaveras skull. This strange relic I shall not fully discuss on this occasion, but a few words concerning it will not be out of place. No one has doubted that Mr. Mattison found the skull in the auriferous gravels beneath the lava, 130 feet from the surface, and that he honestly supposed it to be in place; but it has been asserted that it was purposely concealed there by others. Now the chemical analysis of the bone shows that it is a fossil. It contains only a trace of organic matter, over 62 per cent. of calcium carbonate, and only about 34 per cent. of calcium phosphate. A rhinoceros jaw from the same horizon contained more than two and a half times as much phosphate as carbonate, and was thus much less completely fossilized than the human bone. Truly fossilized human bones are very great rarities, and to suppose that the miners were not only successful in "salting" the mine with human bones, but that they procured truly fossil bones to do it with, requires a painful stretch of the imagination. But, further, when the skull was found a mass of gravel indistinguishable from the surrounding material adhered firmly to it and remained thus attached until, long afterwards, Dr. Jeffries Wyman removed it in Cambridge, Massachusetts. Hence the miners must have found it, if at all, in a formation similar to or identical with the auriferous gravels. The supposed joke would therefore be quite without point.

It has also been suggested that the skull may have fallen from the surface through some crack in the rock at a time sufficiently remote to allow the fossilization and the induration of the surrounding mass to take place. There is no direct evidence in favor of this hypothesis, and it is highly improbable that an open cleft 130 feet deep could be formed by natural causes in a mass of gravel capped by only 40 feet of lava. The fact that part of the tibia of another human being, too small to have owned the skull, was found in the mass adhering to the larger bone makes the suggestion more difficult of

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* I have submitted this statement of his discovery to Mr. King, who pronounces it correct.

acceptance; and finally the traces of such a cleft would certainly have been detected by Professor Whitney, his three assistants and several personal friends, all of whom carefully examined the locality with the finder of the skull not long after its discovery became known. I find that many good judges are fully persuaded of the authenticity of the Calaveras skull, and Messrs. Clarence King, O. C. Marsh, F. W. Putnam and W. H. Dall have each assured me of his conviction that this bone was found in place in the gravel beneath the lava.* Dr. Alfred R. Wallace, too, who has seen at least some of the auriferous gravels and table mountains, in speaking both of the implements found and the Calaveras skull, stated that these remains "present all the characteristics of genuine discoveries." †

Conclusion as to Facts.—The new evidence brought forward in this paper seems to me a considerable contribution to the argument in favor of the authenticity of the skull and amply sufficient of itself to prove that man existed during the Auriferous gravel period in California.

As for the accompanying mammalian remains, I am not aware that their authenticity has ever been questioned, while the Tertiary facies of some of them is freely acknowledged. Since the relics of humanity occur down to the very bottom of the gravels, it seems to me altogether probable that the beasts were contemporaneous with the human beings, for the advent of the last great lava flows and the subsequent glaciation seem the only known events adequate to account for their extinction or expulsion. There is a possibility, however, that the great beasts were all dead before human occupation began, just as to-day implements or human bones might be mingled with the remains of animals already extinct, but still lying at or near the surface. Even on such an hypothesis the remains of *Homo sapiens* and other animals in the gravels must be referred to the same geological horizon.

Many naturalists like Mr. Wallace would be little surprised at the discovery of paleolithic implements in the Pliocene, for there is considerable evidence that men must have existed in some quarters of the globe thus early. It is the relatively high stage of development indicated by the character of the tools which inclines some students to discredit the discoveries. We seem to be on the horns of a dilemma; either man reached the neolithic stage in California much earlier than in other parts of the globe, or the paleontologists are wrong in their reference of certain of the mammals to the Pliocene fauna. I seem, however, to see a *tertium quid* worth suggesting, but to which I am not ready to commit myself finally. In order to explain my trial hypothesis I must make a short digression on the age of the glacial phenomena in California.

* This statement is made by permission.
† Nineteenth Century Magazine, Nov. 1887, p. 667. See also "Darwinism," 1889, p. 456.

Correlation of Lavas and Gravels with Eastern Deposits.

Recency of Glaciation in California.—It is usual to make the tacit assumption that the Sierra Nevada of California was glaciated contemporaneously with the northeastern portion of North America, and, when it is suggested that the glaciation in the two regions may be independent phenomena, the answer is that some great change in terrestrial or cosmical conditions would seem needful to restore the glacial epoch. So far as the Sierra is concerned, it seems to me that the history of the past twelve months sufficiently disproves this argument. The snowfall last winter in the Sierra was exceptionally large, about 2¼ times the average precipitation having fallen. Much of this snow remained unmelted through the season, and when I left the mountains, on October 1, there were still thousands of snow banks where in ordinary seasons none remains even far earlier in the season. Many of these banks were also of great depth, say 100 feet, more or less. It is clear, therefore, that were this and succeeding winters to be as wet as the last, the range would show glaciers in great numbers, much as the Alps now do; in short, the glacial period of the Sierra would recur in a moderate way. Now, no one doubts that there was some cause for the unusual snowfall of 1889–'90, but no one has any suspicion what it was. No sensible change in cosmical or terrestrial conditions has occurred, the weather of the world at large was not remarkable, and, excepting as to precipitation, the year was not extraordinary even in California. In short, some very minute change, seemingly local in character, modified very delicately balanced conditions sufficiently to produce results which if repeated would be of great geological importance.

I regard this as proof that the glaciation of the Sierra may possibly have been local, and that it will be reasonable to pronounce it local if good confirmatory evidence to that effect can be adduced.

No one who has examined the glaciated regions of the Sierra can doubt that the great mass of the ice disappeared at a very recent period. The immense areas of polished surfaces fully exposed to the severe climate of from say 7,000 to 12,000 feet altitude, the insensible erosion of streams running over glaciated rocks and the freshness of erratic bowlders are sufficient evidence of this. There is also evidence that the glaciation began at no very distant geological date. As Professor Whitney pointed out, glaciation is the last important geological phenomenon and succeeded the great lava flows. There is also much evidence that erosion has been trifling since the commencement of glaciation, excepting under peculiar circumstances. I have discussed the deepening of the cañons of the gold belt in another paper * and need say no more here than that I attribute it to somewhat narrowly restricted local

* This volume, *ante*, p. 64.

conditions. East of the range, however, for example at Virginia City, andesites, which there is every reason to suppose preglacial, have scarcely suffered at all from erosion, so that depressions down which water runs at every shower are not yet marked with water-courses, while older rocks, even of Tertiary age and close by, are deeply carved. The rainfall at Virginia City is, to be sure, only about 10 inches, so that rock would erode only say one-third as fast as on the California coast; but even when full allowance is made for this difference, it is clear that these andesites must be much younger than the commencement of glaciation in the northeastern portion of the continent as usually estimated. So, too, the andesites near Clear lake, in California, though beyond a doubt preglacial, have suffered little erosion, and one of the masses, Mount Konocti (or Uncle Sam), has nearly as characteristic a volcanic form as Mount Vesuvius.

Furthermore, it is certain that the great valley of California was formerly a shallow and therefore also a warm gulf. The existence of this sheet of water would unquestionably increase the precipitation on the Sierra and indeed by nearly the whole amount of the evaporation from the gulf. Such a body of water might surely influence the climate as much as the imperceptibly small change of conditions which led to last winter's great snowfall, or in other words it may reasonably be supposed to have caused glaciation.

Thus there is evidence that the glaciation of the Sierra began and ended at a late date relatively to the glaciation of the northeastern states, and there is an assignable and even probable local cause for glaciation.

Survival of Pliocene Animals in California.—The reasonable hypothesis of a local glaciation of the Sierra, confined to time limits later than those of what is known as the glacial epoch, may be made to account for the extraordinary association of neolithic implements with Pliocene bones in California. When glaciation began in northeastern America the preëxisting mammalian fauna no doubt died out in part, but it is not probable that all the beasts resigned themselves to death without effort. Many of them must have sought congenial climates in the south and southwest, and no one can doubt that their existence must have continued longest in the more genial portions of the country. The climate of California was then, as now, independent of the great storm-generating divide of the Rocky Mountains, for in the northern hemisphere the prevailing winds are westerly. In California the great expanse of the Pacific ocean must always have affected the climate somewhat as it does now. It thus seems reasonable to suppose that the waning species of vertebrates found a veritable sanitarium west of the Sierra, and that they continued to exist there long after their congeners of the east were extinct.

In short, then, it is not necessary to suppose that man reached the neolithic age in California earlier than in Europe, if one supposes that a remnant of Pliocene mammals survived on the Pacific coast long after the age which they characterized was past. For such an hypothesis there are certainly analogies. The Australian fauna (and its flora, too) represents a survival, at least, to a certain extent, and the fauna of this hemisphere is of an older type than that of Eurasia. So, too, the tapir of tropical South America nearly resembles the extinct tapir of California. Perhaps he escaped through Mexico when ice appeared on the Sierra. Barrande was driven to the theory of colonies to account for Paleozoic faunal distribution, and the theory is surely as legitimate on the border line between the Tertiary and the recent period as when a more equable distribution of climate gave less incentive to migration. Dr. C. A. White, too, has done much to show that great caution must be exercised in assuming the simultaneous extinction of species in different regions. Finally, Professor Joseph Leidy, to whom I communicated an abstract of this paper, writes to me from Philadelphia:

"In the Academy here are some bones of the *Megalonyx*, from a Tennessee cave, retaining portions of articular cartilage and tendinous attachment, and in one instance a nail, apparently indicating the perpetuation of the animal under favorable conditions to a period closely verging on that of the human era."

Conclusion.—As a trial hypothesis, then, the suggestion of a survival of Pliocene animals in California to relatively late Pleistocene times seems worthy of consideration; but it cannot be definitely adopted or rejected until the faunas of the auriferous gravels and allied horizons are more fully investigated. That human remains are really associated with an extinct fauna in these gravels seems to me thoroughly established.

WASHINGTON, D. C., *December*, 1890.

DISCUSSION.

Reverend G. Frederick Wright: In the early part of October last while in Sonora to make arrangements for driving to the Yosemite, I was introduced to Mr. C. McTarnahan, assistant county surveyor of Tuolumne county, as a gentleman who could furnish me information concerning Table mountain. On inquiring of him concerning the situation of the Valentine shaft, to which reference is made by Professor Whitney, he was able to tell me the exact locality, though he had never heard of any human relics having been found in it; but he at once said that he had himself recently found a mortar in his father's mine underneath Table mountain. On asking him where the mortar was, he said that it was in the possession of Mrs. M. J. Darwin, of Santa Rosa, who passed through Sonora soon after the discovery, and to whom he gave it.

On returning from the Yosemite, Mr. McTarnahan repeated to me the information more in detail. The discovery was made in October, 1887, in the Empire mine, which was owned in part by his father and in which work is still continued. This mine is on the western side of Table mountain, and was reported upon by E. F. Thomas in the volume published by the state in 1888. This mine lies nearly westward from Shaw's flat, and, from the opening, penetrates the rim underneath Table mountain a distance of 742 feet. Mr. McTarnahan himself found the mortar in the gravel, as work was proceeding, 500 feet from the outside of the rim, which, from the direction of the drift, would make it 200 feet from the apex of the rim under the surface of the basalt. He described the mortar as a granite bowlder about eight inches in diameter, and the hollow four inches in diameter at the surface and three inches deep. There was no possible motive for Mr. McTarnahan to distort the facts in any way, and the measurements and other facts, as above given, were stated by him instantaneously in connection with the introduction of the subject, and everything in connection with the account had the appearance of straightforward honesty.

On writing to Mrs. Darwin at Santa Rosa, requesting photographs of the mortar and giving the statement furnished me by Mr. McTarnahan, she sent me a photograph with the measurements on the back side; but she writes that she does not remember to have learned from Mr. McTarnahan that the mortar was found in the tunnel, as that was a circumstance which he did not impress upon her and she does not remember that he mentioned it.

Altogether, these circumstances seem strongly confirmatory of the genuineness of the object. Mrs. Darwin was a tourist on her way from the Yosemite, and evidently neither she nor Mr. McTarnahan had set any special importance upon the geological position in which the mortar was found. Mr. McTarnahan is a young man, about twenty-five, and had never heard of the discoveries reported by Dr. Snell in the Valentine shaft, and evidently had been totally unimpressed by the archæological discussions with reference to that region ; so that the evidence seems to me of a very high order.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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NOTES ON THE EARLY CRETACEOUS OF CALIFORNIA AND OREGON.

BY GEORGE F. BECKER.

(*Read before the Society December* 31, 1890.)

CONTENTS.

THE SHASTA GROUP.

Original Definition and Fauna of the Group.—Messrs. Gabb and Whitney described two groups of lower Cretaceous beds in California, the relations of which to one another they left doubtful. One of them is extensively represented in the Coast ranges of California, and is especially characterized by the presence of *Aucella* accompanied by a few other shells, which, as it happens, throws little light on the true horizon. The age suspected was Neocomian. The other set of beds occurs on Cottonwood creek, near Horsetown, in Shasta county. These do not contain *Aucella*, but carry *Ammonites batesii, A. traskii* and a considerable number of other fossils, which led Gabb to suggest that they belonged to the Gault. It was evidently his opinion that they were younger than the *Aucella*-bearing beds, but the two sets were provisionally classed together as the Shasta group.* Professor Jules Marcou recognized only the beds at Horsetown as Cretaceous. Professor J. F. Whiteaves also discussed these beds in connection with their supposed equivalents in British Columbia, referring the *Aucella*-bearing series to the Neo-

* Pal. Cal., vol. II, 1869, p. xiv.

comian and the Shasta county series to the Gault. * These strata were again studied in connection with an investigation of the quicksilver deposits of the coast by Dr. White and myself. The *Aucella*-bearing beds of the gold belt in the Sierra Nevada of California were identified with those of the Coast ranges, which we called the Knoxville group, and all of them were considered equivalent to the Alaskan *Aucella*-bearing strata, the paleontology of which Dr. White has studied, and they were referred to the Neocomian with a slight doubt whether they might not be the latest Jurassic rather than the earliest Cretaceous. Dr. White made it clear that *Aucella* is both a Jurassic and a Cretaceous fossil, and in his discussion of its occurrence he showed that its apparent age is younger toward the edges of its area of distribution.† We considered the Horsetown group as seemingly younger than the *Aucella* beds, and Dr. White agreed in its probable reference to the Gault; but, like Gabb and Whitney, we found no thoroughly satisfactory means of making a comparison. The Horsetown beds lie unconformably upon a mass of nearly vertical slates, as was stated with reservations by Whitney and confirmed without reservation by myself, and it seemed possible that this non-conformity also divided the Knoxville beds from those of Horsetown. It was also considered possible that the non-conformity represented a pre-Cretaceous upheaval, suspected on other grounds, but unproved. The tendency of our researches was thus rather to emphasize the supposed difference in age between the Knoxville and Horsetown groups, while no final conclusion was reached as to their relations. ‡

Contemporaneously with the publication of these views Mr. J. Lahusen issued a monograph on *Aucella* in which he also followed this genus from about the middle of the Jurassic (the Oxfordian) upward into the Cretaceous. § His views seem to me substantially the same as White's, excepting that he discriminates numerous species in the genus while White tends strongly to regard the many modifications of this mollusk as mere varieties of a single species. The last contribution to the subject is by Mr. Whiteaves, who, from a study of the lower Cretaceous fauna of British Columbia in comparison with that of the Queen Charlotte's islands, has reached the conclusion that all of the *Aucella*-bearing beds of that region are the homotaxial, though not necessarily the contemporaneous equivalents of the European Gault. || I was not aware of Whiteaves' latest views when I made the observations to be recorded in this paper.

Importance of the Subject.—The subject of the age of the members of the Shasta group is one of great importance to California geology. The Knoxville beds of the Coast ranges are those which are so extensively metamor-

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* Trans. Roy. Soc. of Canada, vol. I, § 4, 1882, p. 85.
† Mr. A. Pavlow had previously suggested that the Russian species of *Aucella* were derived from the north, as is mentioned by Dr. White.
‡ Geology of the Quicksilver Deposits of the Pacific Slope, 1888, chapter 5.
§ Ueber die Russischen Aucellen, St. Petersburg, 1888.
|| Contributions to Canadian Paleontology, part II, 1889, p. 153.

phosed to pseudodiabases, pseudodiorites, glaucophane schists, phthanites and serpentines, and in them occur most of the quicksilver deposits. The *Aucella* beds of the Sierra Nevada of California are intersected by numerous auriferous quartz veins. They were referred to the Jurassic by Meek at a time when *Aucella* was supposed to be exclusively Jurassic, and upon this determination Professor Whitney based his assignment of the age of a great upheaval. I showed that this upheaval followed the deposition of the *Aucella*-bearing beds of the Coast ranges as well as those of the gold belt, and called it the post-Neocomian upheaval. Any further change in the horizon to which *Aucella* is assigned will evidently modify correspondingly the designation of this great disturbance. The question whether the non-conformity at Horsetown represents this Cretaceous upheaval or an earlier one is also important.

Exposures at Riddles.—During the past field season additional information has been obtained with reference to the relations of the two series. The supplementary facts are furnished chiefly by a locality at Riddles, Douglas county, Oregon, detected by Mr. W. Q. Brown while superintendent of a nickel mine in the neighborhood. He was kind enough to send me numerous instructive specimens. In June I visited Riddles and, with Mr. Brown's assistance, made examinations of the stratigraphy and additional collections.

The fossiliferous rocks at Riddles bear a very strong resemblance to those of the Knoxville series in California. There is the same prevalence of sandstones with subordinate layers of shale and occasional conglomerates and limestones. The sandstone in both regions is usually very dense, thin-bedded and of a dull greenish color. The strata at Riddles stand at high angles; they show considerable faulting and some metamorphism. Stratification is often almost completely obliterated, but there is evidence of at least one sharp fold and reason to suspect several. A few miles further north, at Roseburg, the strata in a corresponding position are not fossiliferous, but they are entirely similar to the more metamorphic portions of the Knoxville group. While the general aspect of the rocks at Riddles is such as forcibly to remind one of the Knoxville series, there are also differences. Limestone is more abundant at Riddles than in any part of the early Cretaceous areas in California which I have studied, and the conglomerates are much more extensively developed. These seem to form the upper layer of the fossiliferous series in Oregon. They are very coarse, and at points in the neighborhood the mass is hundreds of feet in thickness. This conglomerate is evidently extensive. Mr. Brown informed me that he had traced it continuously for over 20 miles. It is noteworthy that the pebbles of the conglomerate are largely composed of highly metamorphic rock, indicating a period of dynamo-chemical action prior to the uplift of the fossil-bearing strata.

The stratigraphical as well as the lithological relations of the beds in southern Oregon resemble those of the Knoxville group. The gently undulating unmetamorphosed Miocene sandstones, which are abundant along the Willamette valley, unquestionably rest unconformably upon the plicated, highly disturbed and metamorphosed strata near Roseburg, and there is every reason to suppose these absolutely equivalent to the partially metamorphosed beds at Riddles. Just so, in California, the Miocene of the Coast ranges lies in broad, flowing curves upon the sharply folded or utterly crushed masses of the Knoxville series.

There is no indication of any lack of conformity within the fossiliferous series. On the contrary, the various exposures, taken together, appear to show that from the conglomerates to the limestones the layers of rock were laid down without intervening disturbance. This observation is borne out by the distribution of the fossils; for, while the entire list cannot be collected at a single point, a given locality will contain two or more species also found at a lower horizon, as well as others met with at a higher stratigraphical level. The entire area over which fossils occur, and in which there is no indication of a stratigraphical break, is about three miles wide and five miles long.

Fossils from Riddles.—In the collections made at Riddles by Mr. Brown and myself, Dr. White has determined a few very significant fossils. These are:

Aucella concentrica, Fischer;
Ammonites batesii, Trask;
" *traskii*, Gabb;
Pecten operculiformis, Gabb;
Pleuromya lævigata, Whiteaves;
Cardium (Protocardium) translucidum, Gabb;
Belemnites impressus, Gabb;
Arca breweriana, Gabb.

Of these fossils the *Aucella* is much the most plentiful, as it also is in the Knoxville beds of California and in the gold-bearing slates of Mariposa county. The two species of *Ammonites* are found in the Horsetown beds, and are regarded as particularly characteristic of that horizon. The *Pleuromya* and the *Cardium* have also been found rather abundantly at Horsetown by Messrs. Diller and White and by myself, and the *Belemnites*, which is, of course, a somewhat ill-defined fossil, occurs both in the Knoxville and in the Horsetown beds. The *Arca*, according to Gabb, occurs in the Horsetown, and he also describes the *Pecten* from the same horizon.* Evidently, then, the beds at Riddles contain a mixture of forms, and the most characteristic fossil of the Knoxville beds is associated with *Ammonites* of Horsetown age

*Gabb also mentions the *Arca* and the *Pecten* as collected from Chico or uppermost Cretaceous beds, and *Cardium translucidum* is reported in Pal. Cal. only from the Chico beds. There is some doubt as to the specific identity of specimens collected in the Chico and Shasta groups (see Pal. Cal., vol. II, 1869, p. xiv). That fossils from these two groups are in a few cases very closely allied is unquestionable.

and with other fossils which are common in the Horsetown, though not found exclusively in that group.

Besides these well determined fossils a considerable number of others were found which Dr. White cannot identify specifically with entire certainty. The impression derived from the genera and from the specific analogies of these specimens is to confirm the inference made from the determinable shells. They are *Eriphyla*, possibly *unbonata*, Gabb; *Tessarolax distorta*, Gabb, too imperfect for positive identification; *Pholadomya*, probably an undescribed species; *Opis*, similar in external aspect to *O. vancouverensis*, Whiteaves; *Rhynchonella*, probably undescribed: a curious, remarkably flat *Ammonite*, seemingly undescribed; and a cast of a *Trigonia*.

Inferences from the Relations at Riddles.—The discovery of this fauna at the moderate distance of about 200 miles from the California localities evidently makes it possible to regard the Horsetown and Knoxville beds as contemporaneous. It does not follow immediately or of necessity that these groups were coëval, for since *Aucella* is a shell of wide time-range its occurrence alone does not prove that the Knoxville may not be middle Jurassic although the Horsetown is Gault. But the California *Aucella* localities are the most southerly of those known in the northern hemisphere, and as the genus undoubtedly migrated southward they probably represent the latest or nearly the latest period at which the form existed; so that the Knoxville locality might be regarded as of later date than the Riddles locality rather than earlier. Even were there no such guide to a probable conclusion, there would be in the present state of knowledge no ground justifying the separation of the Horsetown beds from the Knoxville group because, as has been shown, the two faunas were contemporaneous in southern Oregon.

Confirmatory Evidence from Canada.—Further confirmation of this view is obtained by a study of Professor Whiteaves' and Dr. G. M. Dawson's papers.* Dr. Dawson studied the stratigraphy of Queen Charlotte's islands and found in the Cretaceous, coarse conglomerates underlain successively by coal-bearing shales and sandstones, then agglomerates, and then again sandstones. These are respectively his subdivisions, *B*, *C*, *D*, *E*. In the conglomerates he found only *Belemnites*. In the conglomerates at Riddles, *Belemnites* also occurs, and Mr. Brown found one specimen of *Aucella* in this position.† In the subdivision *C*, which is of nearly the same lithological character as the rocks at Riddles, Dr. Dawson found *Ammonites batesii*, *A. traskii*, *Aucella*, and *Pleuromya lævigata*, all of which occur at Riddles and all excepting *Aucella* also at Horsetown. He also found *Ammonites stoliczkanus*, Gabb, and *Ancyloceras rêmondi*, Gabb, which belong to the Horsetown series.

* Mesozoic Fossils, by J. F. Whiteaves, part III, 1884.

† If, as I suspect, the conglomerates at Riddles are the equivalents of those in the Queen Charlotte's islands, the latter are also Gault and not Dakota, as has been inferred on stratigraphical grounds.

More recent collections in British Columbia show that five of the species found in the *Aucella*-bearing beds there are common to these deposits and to the subdivision *C* of Queen Charlotte's islands.

Conclusions on the Shasta Group.—The conditions and associations on the British Pacific coast thus appear to correspond completely with those in the United States so far as the *Aucella* beds are concerned, and the present indications are that all of them are to be regarded as equivalent to the Gault. Of course this reference is liable to fresh emendation as researches are further prosecuted, but in the meantime Gabb's name, the Shasta group, is the proper designation of the series.

The post-Jurassic upheaval of Professor Whitney, which became post-Neocomian in my former papers, now becomes post-Gault.

The Post-Triassic Upheaval.

The non-conformity at Horsetown preceded the earliest known Cretaceous of the Pacific slope. The corresponding disturbance was certainly later than the Carboniferous. There is also evidence that it was later than the Trias. At the head of Kaweah river, in the Mineral King district, about two miles from the summit of the western branch of the Sierra, a large mass of slate is included in the eruptive granite. The slates are vertical and very much metamorphosed, but at one point they show casts of shells. I brought in a considerable quantity of these remains, which have been examined by Dr. White and Mr. C. D. Walcott. They were unable to identify the fauna with any other yet discovered, but they pronounce it distinctly Triassic.

The main mass of the granite of the Sierra is earlier than the *Aucella* beds and in part at least later than these Triassic beds. It is very probable that a granitic extrusion accompanied the disturbance which led to the non-conformity at Horsetown. In British Columbia Dr. Dawson has traced a post-Triassic upheaval which was accompanied by granites.* This seems to add one more to the many indications that the Pacific coast throughout North America, if not throughout the two Americas, has had a very similar history.

Washington, D. C., *December*, 1890.

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* Trans. Roy. Soc. Can., Vol. 8, part IV, 1890, p. 6.

DISCUSSION.

Dr. G. M. DAWSON: Further evidence of the great north-and-south range of the earlier Cretaceous beds has been brought forward by Mr. R. G. McConnell, who recently discovered *Aucella*-bearing beds as far north as Porcupine river, within the arctic circle. There are some grounds for preferring the term early (or earlier) Cretaceous for the beds in question to the term lower Cretaceous. The strata appear to represent in at least a general way the middle Cretaceous of Europe; and it scarcely admits of doubt that fossils referable to still lower stages will eventually be found on the Pacific coast in the great mass of Cretaceous rocks as yet only partially examined.

Mr. J. S. DILLER: In Tehama county, California, where the contact between the Knoxville and Horsetown beds is well exposed, their relation, hitherto based wholly upon paleontologic evidence, can be studied to great advantage. The region is just north of the 40th parallel, extending from Tehama into Shasta county, and lies between the localities of California and Oregon referred to by Mr. Becker. On Elder creek, at the eastern base of the Coast range, the unaltered fossiliferous Cretaceous strata have an apparent thickness of nearly 30,000 feet.* The whole series, including both the Chico and Shasta groups, dips eastward away from the Coast range with remarkable uniformity and appears to be one continuous series of sediments, from top to bottom, without evident physical break. In the lower 19,900 feet, the only fossil found is *Aucella*. The sedimentary rocks are limited below by serpentines, resulting from the alteration of peridotitic eruptives, such as form a considerable portion of the Coast range. In the upper 3,900 feet, Chico fossils occur abundantly; while in the intermediate 6,100 feet, Horsetown forms have been found. They are best exposed in the Bald hills, between Paskenta and Lowrey's, where *Aucella* occurs abundantly in the basal portion, associated with *Ammonites batesii*, Trask; *A. ramosus*, Meek; *A. traskii* (?), Gabb; *Ancyloceras percostatus*, Gabb; *Rhynchonella*, sp. nov.; *Siliqua*, sp. (?) These strata have been traced northward about 40 miles to the original Horsetown beds on the North fork of Cottonwood creek, where the first four fossils named have been found either by myself or other observers.† It is especially noteworthy that *Aucella*, although diligently sought for, has not been found in that region north of Elder creek.‡

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*Am. Journ. Sci., 3d series, vol. XL, 1890, p. 476. During the field season of 1888-'89, Cretaceous fossils were collected in that region from 79 localities, of which 24 yielded forms belonging to the Shasta group. They were all identified by Dr. C. A. White and T. W. Stanton.

†Cf. Geol. Survey of Cal., Palaeontology, vol. II, 1869, pp. 210, 211, 213.

‡While the *Aucella* beds form, with the Horsetown beds, a continuous vertical series they are of very unequal horizontal distribution. The Horsetown beds lap far over to the northward upon the older metamorphic rocks beyond the *Aucella* beds, in much the same way as the Horsetown beds are themselves overlapped by those of the Chico group. North of Riddles, in Oregon, on the South fork of the Umqua, about two miles below the mouth of Cow creek, a great thickness of strata in which *Aucella* only has been found are well exposed. Downward they pass apparently by

Dr. C. A. WHITE: The paleontological discoveries which Dr. Becker has made in southern Oregon prove conclusively, what had before been rendered probable by the labors of Dr. Dawson and Mr. Whiteaves in British Columbia, that there is really a commingling of the fossil faunas of the Knoxville and Horsetown divisions of the great series of strata to which the term "Shasta group" has been applied in California, and that those strata all belong to one great paleontological horizon. Dr. Becker's well-known contributions to our knowledge of the geological history of the Pacific Border region are of prime importance, even if the assumed geological age of the formations to which he has referred should not prove to be demonstrable. Upon this latter point I have now much doubt, although his quotations of my views, at the time I expressed them, are in the main correct. For example, I do not now think that we are warranted in even approximately correlating any of the Cretaceous deposits of the Pacific border region with any one of the subdivisions of the European Cretaceous. We certainly are not yet able to satisfactorily correlate any of them with any of the formations of the interior and eastern portions of this continent. Again, while I have never published any opinion concerning the reputed Triassic fossils obtained from the Mineral King district, I am not now disposed to deny that the strata from which they came may represent a part of the European Triassic. At the time I examined them at Dr. Becker's request I believed he would be warranted in regarding them of Triassic age. They consisted of a number of molluscan generic forms such as in part characterize the European Triassic, and among them was one Paleozoic form, namely, a *Spirifer*. I did not then realize fully as I now do the importance of extreme caution in pronouncing upon such questions as that collection presented. I had not then made the discovery of Mesozoic forms in the Permian of Texas, the results of which are soon to be published; Gemmellaro had not then published the remarkable commingling of both molluscan and crustacean Mesozoic types which he has discovered in Sicily; and Karpinsky had not published his important similar discoveries in Russia. It is true that I knew of a part of Waagen's related discoveries in India, but I was then more disposed than now to follow the general custom of regarding such a state of things as exceptional rather than as one to be looked for in any part of the world, especially upon the confines of geological systems. Still, all this does not impair the value and correctness of Dr. Becker's conclusions as to the time of the great upheaval to which he alludes with reference to that of the deposition of the latest formation directly involved in it.

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gradual transition into metamorphic rocks, and upward they are succeeded, just as in California, by seemingly conformable shales and sandstones containing Horsetown fossils intermingled with *Aucella*. Mr. Will. Q Brown, who has given much attention to the geology of Douglas county, discovered *Aucella* in that region and called my attention to it in 1888, when we first examined the region together. The limestone in which the discovery was made may be of nearly the same horizon as the one three miles west of Paskenta, where *Aucella* occurs in abundance.

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THE RELATION OF SECULAR ROCK-DISINTEGRATION TO CERTAIN TRANSITIONAL CRYSTALLINE SCHISTS.

BY RAPHAEL PUMPELLY.

(*Read before the Society December* 30, 1891.)

CONTENTS.

RÉSUMÉ OF FORMER STUDIES.

Geology had its rise and most of its growth in the glaciated regions of Europe and America. To this circumstance is due the fact that comparatively little attention has been given to the part played by secular rock-disintegration in various geological processes.

In a former paper* I attempted to show, in some of its bearings, the important part performed by the action of this process through the ages. The central idea expressed was that a land surface exposed during a long period to the influence of a moist climate, and protected by vegetation, would be subjected to disintegration and decomposition of its rocks. The waters circulating in depth, charged with oxygen and carbonic acid, and bearing acids derived from vegetable decay, would set in motion a destroying action which

*The Relation of Secular Rock-Disintegration to Loess, Glacial Drift and Rock Basins; Amer. Journ. Sci., 3d ser., vol. XVII, 1879, p. 133.

begins with disintegration and ends with the reduction of the rock to the most insoluble products, such as quartz, clay and ferric oxide. The depth of this decay, other things being equal, is determined by lapse of time, by the permeability of the rock, and by the solubility of its constituents, rather than by its hardness. In tropical countries, and in our southern mountains, this depth is to-day measurable in places by hundreds of feet. I showed that when, by change of climate, the protecting vegetation was destroyed and the disintegrated region became arid, this great decayed mantle became the prey of the winds, and thus furnished the material for the wind-blown loess. Where, on the other hand, such a region became the seat of a continental glacier, this decayed mantle supplied, in its finer material and in its cores of semi-disintegrated blocks, the source of the greater part of the glacial débris.

Since the limit of the decay in depth is due to the character of the rock areas, the removal of the mantle by wind or ice would leave a topography different from that formed by stream erosion, and one in which rock basins would be frequent.

Finally, the rapidity with which this material, after accumulating by wind or ice, is removable by erosion, or by progressive ocean breaching, rendering turbid the waters of formerly clear parts of the sea, suggests the cause for the extinction of life and change of coast faunas.

The views expressed in the paper referred to were accepted in their entirety by von Richthofen* and, as bearing on glacial débris, rock basins and the topography of Scandinavia, by Nathorst.†

Evidence of secular Disintegration in ancient Rocks.

Derivation of Cambrian basal Conglomerates.—Our work in the Green mountains, and recent studies of the mountains of western North Carolina, have given me proof that the recognition of the importance of secular disintegration is essential to a proper interpretation of some of the most difficult points in the study of the crystalline schists. Throughout the Green mountains and the Appalachians, the Cambrian conglomerates and quartzites, resting on an older crystalline complex, contain large quantities of detrital feldspar in fragments or pebbles, up to three-quarters of an inch and more in diameter, together with grains and pebbles of blue quartz, all clearly derived from the destruction of the older granitic rocks. These feldspars are the same as those in the older rocks, and show their own detrital character. They often show partial kaolinization around or adjoining an unaltered nucleus. And in some cases these fragments, as my assistant, Dr. Wolff, finds, have been

* China, Vol. II, 1882, p. 758.

† "Pumpelly's teori om hetgdelsen af herzartemas sekulära förwittring för uppkomsten af Sjöar m. m."—Geol. Föreningens i Stockholm Förhandl, 1879, No. 52, Bd. IV, No. 10.

enlarged by the growth of a new feldspar, possibly albite, which, with the mica and independent albitic feldspar grains, some secondary quartz and magnetite, are all products of metamorphism, formed in place in the clastic rock. It seems quite clear that the kaolinization preceded the deposition of the conglomerate.

Now whence came these detrital feldspars? Surely not from attrition of pebble on pebble. I can imagine no other source than the débris of the deeply decayed mantle.

In these basal conglomerates occur pebbles of granite and schists, and, in rare instances, of limestone. The relative rarity of rock-pebbles as compared with those of quartz is due, doubtless, to the fact that, in a disintegration-mantle, cores with unaltered centers are comparatively rare as regards most rocks. Some crystalline rocks are reduced *in situ* almost wholly to kaolin and quartz in the upper part and to a fine gruess (or decomposition-residuum) in the lower zone.

The transgression which, in this case, ushered in the Cambrian, found the dry land deeply disintegrated. The breaching waves and currents removed to a distance the kaolin and other fine materials. The lower zone of semi-kaolinized material, and the still lower one in which the feldspar crystals were loosened by the alteration of the micaceous and hornblendic constituents, furnished the fragments of feldspar and the less altered cores of blocks for the conglomerate beds.

Before applying this hypothesis to the explanation of facts in the Green mountains, I shall give the evidence we have that they were dry land before the Cambrian.

Evidence of the Stamford Dike.—Clarksburg mountain, a spur of the Green mountain anticlinal near Williamstown, Massachusetts, is an oval mass of granitoid gneiss, mantled around its three sides with the Cambrian quartzite in which Mr. Walcott found Cambrian trilobites. On the eastern flank of the mountain, Mr. Wolff found a dike of basic rock in the granitoid gneiss, and this dike stopped short at the contact of the gneiss with the quartzite.

In digging to expose the contact relations, Mr. Whittle and myself found that the dike had been decayed and washed out before the quartzite was deposited, leaving an open fissure several feet deep and wide, for the beds of quartzite thicken and sag into the fissure, and contain, at the bottom, material contributed by the decayed dike (figures 1 and 2, page 212).

We have, in this, evidence of unconformity by erosion and of dry land, as well as of previous rock-decay.

Evidence from the Green Mountains.—One of the chief difficulties we met with, in studying the rocks of the Green mountains, was the sudden change from true quartzites overlain by the lower Silurian limestone in the valley, to white gneisses overlain by schists on the main ridge east of the valley.

President Edward Hitchcock had shown long ago the anticlinal structure of this central ridge.

In that part of this central ridge called Hoosac mountain, we find a central mass of the old granitoid gneiss, a very coarsely crystalline rock with one-inch to two-inch crystals of microcline, and blue quartz. This is overlain by the white gneisses and still younger schists, the whole forming a low, broad anticlinal, whose axis pitches about ten degrees northerly; while immediately west of this arch, the whole series is pushed over toward the west

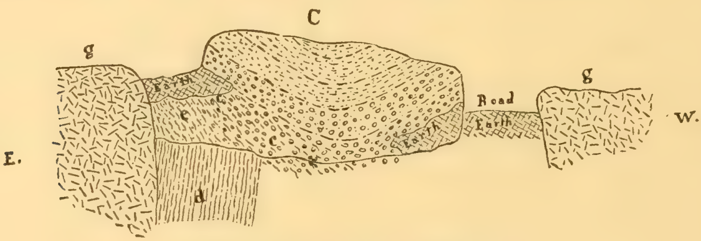

FIGURE 1—*Section through Stamford Dike.*

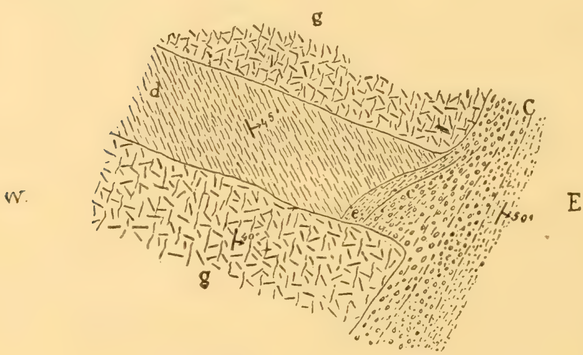

FIGURE 2—*Plan of Stamford Dike.*

Cambrian conglomerate deposited in the washed-out fissure of a metamorphosed diabase dike in granitoid gneiss. Near Stamford, Vermont. *C* = Cambrian (*Olenellus*) conglomerate deposited in the fissure; *c* = Lower layers of conglomerate, rendered schistose through admixture of the altered dike material; *d* = Diabase of the dike, showing schistose metamorphism; *e* = altered dike material; *g* = Granitoid gneiss (pre-Cambrian).

to make an overturned flat fold at the summit, and then to descend the western flank in a series of crumple-folds which are also overturned to the west. The axes of all these folds pitch about ten degrees to the north.

Toward the southern end, this lateral fold makes a remarkable turn to the east, so that it is here pushed over to the south; and in this overturn are enfolded both the white gneisses and the schist.

We have studied the mountain in detail, and find that the rocks surrounding the old granitoid gneisses, and included between it and the schist, are a stratigraphical unit, though varying in habit. *B*, *Ba*, *Bb*, *Bc*, in figure 3, represent the variations in habit of this formation.

Where this formation mantles over the low arch at the northern end, it is a well-defined conglomerate, *Ba*, containing pebbles of blue and white quartz and of feldspar, as well as blocks of the granitoid gneiss, up to ten inches in length, in a cement of finer quartz and feldspar grains and mica, showing all the marks of a clastic rock which has undergone some metamorphism. This conglomerate rests here, without any transition phases, directly upon the granitoid gneiss.

Along the eastern side of the anticlinal, it is a gneiss with parallel foliation in straight lines, marked by biotite and muscovite, *Bb*. On the western

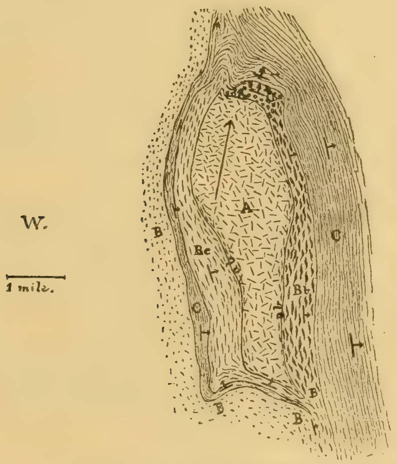

FIGURE 3—*Plan of Hoosac Mountain.*

C = Hoosac schists; *B* = Quartzite; *Ba* = Conglomerate; *Bb* = Coarsely foliated gneiss (dynamic product of the conglomerate); *Bc* = White gneiss (dynamic product of the conglomerate); *A* = Granitoid gneiss (pre-Cambrian). The arrow indicates the axis of the fold, pitching north.

side, *Bc*, along the overturned fold, it is a more massive, fine-grained, white gneiss, with relatively little mica and a more obscure foliation. These gneisses on the east and west seem to pass through coarse gneisses downward into the granitoid gneiss. We were able at several points to trace the lateral transition of the Lower Cambrian quartzite of the valley into these white gneisses, definitely settling the Cambrian age of this conglomerate-gneiss formation. But it seemed impossible to explain the sudden change from plain quartzite to highly feldspathic gneisses, which in one limb of the same arched strata are coarse, and in the opposite limb are finer with less foliation, while the arch itself is conglomerate, and which, on the eastern and western sides, pass by transitional beds, *a*, *b*, downward into the granitoid gneiss that we had proved elsewhere to be separated from them by a time-break.

At many points there is complete *structural* conformity between the pre-Cambrian granitoid gneiss and the overlying Cambrian. This is so as regards the relation of the granitoid gneiss and overlying white gneiss and conglomerate on Hoosac mountain. And it is even more marked on Clarksburg mountain. Here the quartzite, in describing a broadly-circling quaquaversal mantle around the end of the spur of granitoid gneiss, is crinkled into minute fan-like plications, and the granitoid gneiss shows in fine lamination the same plications in perfect parallelism, in horizontal section to those of the quartzite, while there is equal parallelism between the axes of the little crinkles in both rocks. This fine lamination disappears as we recede from the contact a short distance into the granitoid gneiss area. It is evident that this structure in the older rock was formed at the same time and by the same pressure as that in the younger.

This structural conformity, extending downward from clastics through apparently transitional rocks into apparently much older crystalline rocks, is a difficulty which is repeatedly encountered in the study of the areas of crystalline schists.

But I think the hypothesis of a pre-Cambrian decay of the granitoid gneiss gives the key to the problem in the Green mountains. The Cambrian transgression found the granitoid gneiss deeply disintegrated. As the breaching line of the sea advanced landward, during the positive movement, the upper zone of finer and wholly kaolinized material was removed to a distance, while coarser material of the deeper zone of semi-kaolinization was deposited nearer at hand, forming beds consisting chiefly of the little-altered feldspar and quartz, with larger pebbles from the veins of quartz and of harder granites, as well as from occasional cores of partly disintegrated blocks. Beneath these lay a zone in which the cohesion of the granite had been weakened by the first stages of disintegration—the alteration of the mica or hornblendic constituent lying between the other minerals. When the lateral thrust which produced the folding took place, its effect was different in three positions on Hoosac mountain: on the eastern side, on the top of the arch, and in the enfolded troughs on the western side. Along the monocline on the east, the pressure found relief in a slipping movement, resulting in the production of a laminated gneiss. On the western side, the material, resting on a base of rigid gneiss, was thrown into minor folds and, being caught in the enfolding, underwent a crushing action. On the other hand, at the top of the arch, as suggested to me by Mr. Bailey Willis, being the point toward which the movement of particles was directed, the material underwent only a crinkling of its layers through the pressure acting toward the arch under the mass of overlying rock.

On the dump of the central shaft of Hoosac tunnel lies material excavated from the eastern side of the granitoid gneiss core, and from the overlying Cambrian conglomerate, 1,200 feet below the surface. The granitoid gneiss in these large fragments is highly foliated, though coarse. Its large crystals of microcline are still present as elongated augen, many of which show cores one-half to three-quarters of an inch across, of continuous but wavy cleavage, while the rest of the individual is broken up into a mosaic by granulation and traversed by the greenish mica and epidote of the foliation. In other individuals, the granulation is almost complete. The blue quartz is also largely broken up by granulation, and the whole rock tends towards an augen-gneiss habit.

We find great blocks of undoubted conglomerate, which simulate so closely this foliated granitoid gneiss that, except for the pebbles of blue quartz and occasional rock pebbles, it would be difficult to distinguish between them. In these the large detrital feldspars are almost wholly granulated. Large numbers of other blocks of the conglomerate are composed mainly of pebbles of the granitoid gneiss and detrital microcline and blue quartz with the same secondary mica that marks the foliation of the granitoid gneiss in the blocks described above.

I imagine that we have here, in the highly foliated granitoid gneiss, the lower portion of the semi-disintegrated zone; and that those blocks of conglomerate which simulate it so closely are from the immediately overlying part of the Cambrian clastic beds, and made up largely of the gruess and cores derived from the more disintegrated granitoid gneiss. The foliation in both rocks is marked by roughly parallel courses of the micaceous constituent, which is a secondary formation in the planes of the slipping movement.

I think I have thus explained the puzzling variation in character of the lower Cambrian quartzite-conglomerate, white gneiss, and coarse gneiss formation of the Green mountain range. The transitional beds on Hoosac mountain, under the Cambrian gneiss on the eastern and western flanks of the arch, represent, I think, not only the beds formed from coarse feldspar gruess and pebbles from the granitoid gneiss, but also the semi-disintegrated zone of the granitoid gneiss which had escaped abrasion by the waves and which, by the weakening of its cohesion, mentioned above, acted under the lateral thrust to a great extent like the sediments above it. This unabraded zone of crystalline rock, which had had its rigidity weakened by beginning disintegration, would, under folding, pressure and metamorphism, show on the one hand a perfect and true transition into the parent crystalline rock, and on the other hand pass into the much younger beds through the similarity of constituents derived from it; and an apparent conformity would be forced upon the whole series, and the time-break would be masked by the foliation induced by the shearing action due to slipping movement.

The actual plane of separation between the sedimentary clastics and the purely cataclastic rocks is more difficult of definition, in the field, on the monocline of the forceward side, because there the tendency both of the shearing action of the slipping movement and of the action of granulation upon the coarse feldspars is not only to obliterate the outlines of pebbles, but to produce a uniform parallel foliation in which the dividing plane is lost.

The instance mentioned on the southern bend of Clarksburg mountain corresponds to the top of the arch, where the pebbles of the conglomerate, though squeezed, are still distinct, and the plane dividing the two rocks is not lost. Here I can imagine no other explanation for the fine lamination in the granitoid gneiss (existing only near the contact with the quartzite and crinkled in exact conformity with the quartzite lamination) than a superficial weakening of the gneiss by partial disintegration. The fan-like crinkling belongs to the region of squeezing on the inner side of a fold.

The transitions, such as I have described, from crystalline schists of clearly clastic origin into others which are in structural conformity but must be separated by a time-break, and which themselves pass downward into massive granitoid rocks, may be thought to admit of two explanations. These masked transitions occur along lines of great folding action, and are due to the action of the folding force upon both the massive rock and the clastic beds derived from its constituents. The alternatives are these:

1. Either the granitic rock was massive and unaltered at the beginning of the folding, and has undergone a shearing or squeezing action which produced a schistose structure, only near the surface of the rock, without affecting it in depth; or

2. The affected zone of the granite was already in such a condition of weakness as caused it to act like the overlying clastic beds; such a condition, in fact, as exists in the lowest zone of disintegration where only the strength of the micaceous constituent is affected.

The validity of this second alternative is strongly indicated by the fact that, in the transitions of this nature described above, the younger beds are composed of detrital feldspar and blue quartz and rock pebbles, all derived from the underlying granite and pointing toward a preëxisting and deep disintegration.

Corroborative Evidence from the Southern Appalachians.—It seemed to me doubtful whether, at the depth which then concealed the now exposed cores of the Green mountain folds, the folding force was sufficient to overcome the rigidity of the unaltered granite, except through the compensation of faulting. In a visit, last spring, to the superb Doe river section in eastern Tennessee, with Professor Van Hise, under the guidance of Mr. Bailey Willis, we saw the Cambrian quartzite several thousand feet in thickness (its lower beds abounding in coarse detrital feldspar and other fragmental minerals recognizable as coming from the underlying granite) resting on the granite, with the contact plane dipping 65° northwestward under the quartzite. To the west of the contact the whole immense thickness of the quartzite is visibly folded back upon itself. That the granite took no part in all this folding is evident, as pointed out by Mr. Willis, from the fact that numerous basic dikes which traverse it, without cutting the quartzite, have retained their shape in unwarped planes. Any compensating movements that affected this granite during the folding of the quartzite must have been of the nature of faultings.

Influence of antecedent Disintegration on Rock Formation.

Formation of basal Beds.—I am disposed to regard all the basal conglomerates and sandstones or quartzites that mark the beginnings of geological periods, as having been produced during positive movements by the breaching action of the ocean advancing over previously deeply disintegrated land surfaces. But, in the absence of more extended study of the facts in the field, I have confined my conclusions wholly to inferences drawn from those clastics in which detrital feldspars, with or without rock pebbles, play an important part. It would be wrong to assert that all of the detrital materials forming such basal clastic beds were derived only from a disintegrated mantle; for any geologist who has observed the breaching action of the ocean on a cliff-bound coast, will recognize the importance ascribed, particularly by von Richthofen,* to this greatest of all abrading forces.

Undoubtedly, under certain relations between minimum rapidity of the positive movement and maximum steepness of the seaward slope of the land, minimum hardness of the rock and minimum depth of disintegration, the breaching action would work to a greater or less depth into the solid rock, establishing in places its resulting surface (Ramsay's "plane of marine denudation;" von Richthofen's "plane of abrasion") below the region of secular disintegration.

But these conditions do not appear to have been general in the Appalachians during the Cambrian transgression. This is shown on Clarksburg mountain by the fact that the breaching did not extend so deep as the decay in the Stamford dike. It is shown still more clearly, I think, by the abundance of coarse detrital feldspar in the basal beds of the Cambrian. It seems to me that the same evidence is furnished by the blue quartz conglomerate; for the pebbles of this mineral are derived from the quartz of the coarse granite and gneiss.

Formation of detrital Rocks.—The breaking down of cliffs of solid granite or gneiss would produce blocks which would grind down to fine flour of at-

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*China, vol. II, 1882, p. 767.

trition and a very fine angular sand;* a conglomerate resulting from this process would have granite pebbles, not pebbles of pure quartz. But, in a mantle of disintegrated granite, the quartz is loose and ready to wear down by attrition to the smallest size that the local conditions of velocity will admit of; and the process is facilitated by fracture along the planes that separate the individuals of the quartz aggregates, as suggested by Daubrée.

The evidence of successive periods of ancient secular disintegration is necessary to support an hypothesis which presupposes their existence in explaining the apparently conformable transition between schists of widely different ages.

For early pre-Cambrian or pre-Algonkian time we have this evidence very clearly in the conglomerate forming the base of the graphitic limestone along the eastern edge of the Adirondacks. This limestone was found by Mr. Walcott, at Fort Ann, to carry fragments of older crystalline rocks. Going from this point to Westport, New York, Mr. Walcott, Professor Van Hise and myself found the bottom of this limestone everywhere charged with pebbles and bowlders of the older rocks and with great quantities of large fragments of the triclinic feldspar of the underlying hypersthene-granite. The appearances are that the limestone ushered in the period to which it belonged, and without any violent breaching action of the water. There is little evidence of attrition in the fragments, which appear to be cores, some only partially divested of their concentric altered layers. In some cases, these old cores are surrounded by what appears to have been a disintegrated shell, between which and the core, calcite has crystallized and new minerals have formed. This limestone is covered by a great thickness of garnetiferous gneiss, over which the fossiliferous Potsdam sandstone lies unconformably, as was pointed out by Mr. Walcott.

In the central ridge of the Green mountains we have one or more limestones, which have been assigned to the "Azoic" by President Hitchcock, lying below a series of highly crystalline gneisses, which, like the limestone, are represented in the pebbles of the basal conglomerate of the Cambrian.

These limestones, like that of the Adirondacks, rest generally on coarsely crystalline granitic or gneissoid rocks, without any intervening clastic sediments. But the underlying rock has almost everywhere the appearance of having been originally a coarse granite which has undergone a crushing action. The feldspar grades from large, one-inch crystals with wavy cleavage, into coarse and fine granulated aggregates; the quartz also is granulated. Moreover, some of the large crystals of feldspar, which have the

*This is clearly shown by the experiments of Daubrée ("Etudes Synthetique," 1879, p. 253). Daubrée also states that the ordinary sand of sandstones cannot be a product of attrition under torrents or wave action, and that some other source for them must be sought. The two sources that occur to him are glacial grinding, which produces coarse and fine grains, and disintegration under weathering.

wavy cleavage, are penetrated by the mica which, in blotches, marks the foliation of the rock. This rock presents, in the wavy cleavage of its feldspar, in the granulation of the feldspar and quartz, and in the foliation apparently contemporaneous with the crushing, the characteristics which should result from the action of a folding force upon the lowest zone of disintegration; the zone in which the integrity of the granite is weakened.

Of course we are dealing here with a period of much greater age than the Cambrian; and the conditions of depth and pressure may have presented very different relations to the rigidity of the granite from those ruling during the folding of the Cambrian sediments. But, with the evidence of a previous disintegration presented by the detritus in the Adirondack limestone mentioned above, I am disposed to ascribe the crushing and foliation of the granite underlying the old limestone to the action of the folding force, probably in pre-Cambrian time, upon a rock which had lost its integrity before the formation of the limestone.

Accumulation of Ores.—If the reader wishes to see a convincing illustration of a deep-reaching disintegration in pre-Silurian time, in a region which has not been folded, I know of no better instance than that now offered at Iron mountain, Missouri. Before the beginning of mining operations, Iron mountain was a hill covered, to an irregular depth, with blocks of magnetic ore altered to martite. In earlier geological times, it was a mountain of non-quartziferous porphyry, traversed by several large masses of magnetite, from which veins and veinlets of the same ore ramified in every direction through the porphyry. As the rock decomposed and was washed away, the ore remained to form a mantle of residuary fragments. In 1873,* I called attention to this, as an instance of ancient disintegration, and stated that beds of stratified ore-conglomerates occurring at the base of the mountain were probably of Silurian age, and that they indicated a pre-Silurian disintegration of the mountain mass.

During the present summer I revisited the locality, with Professor Van Hise, and found a startling confirmation of the former statement.

Professor W. B. Potter, reasoning from the premise of a pre-Silurian disintegration, instituted a series of borings through the Silurian strata which, in a flat position, surround the base of the mountain. These explorations resulted in the discovery of extensive areas of residuary ore-fragments lying on the pre-Silurian surface, and in the development of mining operations for their recovery.

On the western flank of the mountain (figure 4) the original surface of decomposed porphyry, grading downward into less altered rock, slopes downward at an angle of 28°, under strata of lower Silurian or upper Cambrian

* Geological Survey of Missouri, Iron Ores and Coal Fields, 1873, part I, p. 12.

limestone and sandstone, which incline at a lower angle (15° to 20°) away from the mountain mass.

Resting immediately on the altered porphyry is a bed, 10 to 15 feet thick, of angular fragments of ore, with the interstices filled with detritus of decomposed porphyry, which, showing no signs of stratification, follows the contact in depth. In places the limestone itself contains rounded pebbles of ore, but more of decomposed porphyry, forming in some beds a conglomerate. The residuary ore of the fragmental mantle-bed is evidently derived chiefly from a 30-foot vein of solid ore, which comes to the surface on the western flank and runs nearly parallel to the strike of the bed of fragmental ore. This bed is part of the pre-Silurian mantle of disintegration, and is not a Silurian sedimentary deposit. This is clear from the facts that it not only shows no stratification, but that the material filling the interstices between the ore fragments is wholly decomposed porphyry, without sand or limestone; whereas,

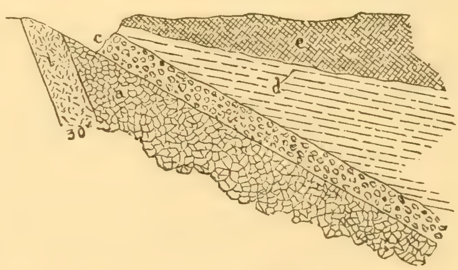

FIGURE 4.—*Section exposed by Mining on western Flank of Iron Mountain, Missouri, showing Mantle of pre-Silurian residuary Ore under Silurian Limestone.*

a = Decomposed porphyry; *b* = Vein of ore; *c* = Pre-Silurian mantle of residuary ore, 10 to 15 feet thick; *d* = Silurian limestone; *e* = Earth.

if it had been moved by breaching action, a separation would have taken place, resulting in the removal of the porphyry detritus and its replacement by sand and calcareous matter.

On the eastern flank, Professor Potter's explorations revealed a pre-Silurian valley, in which a large amount of detrital ore is accumulated, beneath the limestone. The mining has followed this valley for 1,500 feet or more, down its gentle slope, under the Silurian limestones and sandstones. Here also, while the overlying limestone carries more or less débris from the mountain, the ore-bed is unstratified and has its interstices filled with a wash of decomposed porphyry. The bed is in places 40 feet thick and 300 feet wide, growing narrower toward the lower end of the valley, and thinning out toward the sides, where the limestone rests directly on the porphyry. Toward the lower end of this ancient valley, the ore-blocks are larger and rather more rounded than those further up-stream. I imagine that these lower bowlders are the older ones and started from their source when the parent hill was much higher than when the up-stream part of the bed obtained its present slope. The greater height and steeper declivity would allow the blocks to roll further and more rapidly, while, as the height of the hill and the slope of the valley diminished, the ore débris was finally deposited nearer its source. The valley bottom is exposed in the mine and shows all the markings of torrent erosion.

Any attempt to state the amount of diminution in height that Iron mountain has suffered by disintegration, can, of course, be only a very rough estimate. But, considering the relation between the size of the known ore bodies and the volume of ore débris, so far as known, the lowering of the height of the mountain cannot well be placed at less than 150 feet since the Silurian transgression, and probably as large an amount before that time, or a minimum of 300 feet.

At Pilot knob, we have, apparently, evidence not only of a similar pre-Silurian mantle of ore débris around the base, but also of a much older disintegration in Algonkian time, in the occurrence of a conglomerate of porphyry and quartz pebbles with a cement of specular ore, forming the top of the mountain.

Formation of Transition Beds.—Professor Van Hise, knowing that I was at work on this subject, and being himself engaged in reviewing the literature of the pre-Cambrian rocks of America, kindly noted and called my attention to the following instances illustrative of the theory here advanced:

Newton * described the Potsdam sandstone exposed in the cañon of French creek, in the Black hills, as lying horizontally on—

> "Coarse, red, feldspathic granite, at top very much decomposed and changed into a soft clay, almost like a fluccan."

Professor Van Hise adds:

> "One can readily imagine that, folded and metamorphosed, there would be a gradual transition from the thoroughly crystalline rock to that which was originally a sediment."

Peale,† describing a section on the South Platte in Colorado, says:

> "Resting immediately upon the granite we have a very coarse sandstone * * *. Close to the granite the sandstone is coarsest and contains pieces of unchanged granite. In other places the sandstone appears to pass by gradation into granite."

Stevenson ‡ describes at several localities on the Gunnison and Grand rivers and elsewhere a peculiar regular laminated gneiss, dark brown or black, and resembling a micaceous sandstone. He adds:

* Geology of the Black Hills, 1880, p. 90.
† 7th Ann. Rep. Geol. and Geogr. Surv., 1874, p. 194.
‡ Geol. Surveys West of the 100th Mer., vol. III, 1879, pp. 344, 345.

"It always occurs directly under the sedimentary rocks, and no similar formation occurs lower down. It is clearly unconformable to the great mass of the schist and gneiss, though precisely like them in its changes. In consideration of all the circumstances, one cannot resist the temptation to regard it as belonging to a later period."

Endlich* describes contacts between the Potsdam quartzite and crystalline granitic rocks, in the Wind river country, where he finds it often difficult to draw the line between the two. "In certain instances the quartzites and granites blend into each other."

St. John† finds, in the Gros Ventres, the quartzite in the following relation:

"It is in contact with the unconformable Archean schists, from which it is separated by a handsome, rose-colored, finely-laminated gneissose lamina, which may be the metamorphosed inferior layer of the quartzite."

Loew‡ mentions the following:

"Occasionally, as for instance between Martin's ranch and Cajon pass, the granite gave rise to the formation of beds of arkose, a rock in which granite débris has been recemented, forming a sort of granitic sandstone resembling to some extent a granite."

These instances all point to a pre-Cambrian disintegration. The quartzite was formed from the residuary quartz of the disintegrated rock and the feldspar contributed by the feldspar-gruess.

Reference is made by N. H. Winchell§ to the occurrence in various places about Fort Ridgely, Minnesota, of a substance which is found under the Cretaceous beds "where they overlie the granite," and which passes by "slow changes into the granite," and "seems to be the result of a change in the granite itself." It has some of the characters of steatite and some of kaolin. Professor Winchell adds:

"It prevails in the Cretaceous areas, and is always present, so far as known, whenever the Cretaceous deposits have preserved it from disruption by the glacial period * * *."

Upham‖ describes the decomposition of the gneiss and granite to a depth of 20 or 30 feet in places, in Brown and Redwood counties, Minnesota, and to at least 10 feet in Renville county. These examples point to a pre-glacial disintegration extending through Mesozoic and Tertiary time which, over the glaciated areas, furnished ready-loosened material for the glacial débris.

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*11th Ann. Rep. Geol. and Geogr. Surv., 1879, pp. 68, 70, 71.
†Ibid., p. 411.
‡Geol. and Geogr. Surveys West of the 100th Mer., 1876, Part 3, p. 394.
§Second Ann. Rep. Geol. and Nat. Hist. Survey of Minnesota, 1874, p. 163.
‖Final Reports of Geol. Survey of Minnesota, vol. 1, 1884, pp. 570–572; vol. 2, 1888, pp. 196–197.

Bearing of Results on Time-Scale.

I imagine that the transgressions which ushered in the great periods from the Algonkian onward, were preceded by a deep-reaching disintegration of the land. This vast amount of loose material was removed with ease and rapidity by the breaching action of the advancing sea line. If we substitute this process in each period for the accepted one of slow erosion and breaching of hard rock, we shall, I think, have to materially reconsider our time-scales in so far as they depend upon the rate of accumulation of detrital materials.

DISCUSSION.

Dr. George H. Williams: I had the pleasure, last summer, of visiting most of the localities described by Professor Pumpelly, under his own guidance; and I then, as now, welcomed his theory of secular disintegration as a possible explanation of some of the difficulties encountered in my work on the crystalline and semi-crystalline areas of Maryland. In my paper on the Piedmont plateau in Maryland* I have stated the evidence that these two areas are separated by a time-break, which, however, does not seem to accord with the transition observable between them. It seems as though Professor Pumpelly's suggestion would go far toward removing this difficulty, if it be taken in connection with the interchange of material which must take place during the gradual metamorphism of rocks, thus obliterating any sharp line of contact which may have once existed between them.

Professor B. K. Emerson: Professor Pumpelly's theory of secular disintegration is applicable to the Triassic conglomerates of the Connecticut valley, in this to some extent anticipating my paper on that subject.* This paper is based on precisely the same suggestion in reference to the beds of the Connecticut valley, in Massachusetts, where arkose deposits have been penetrated 3,000 feet by artesian well borings. The degree of rounding of the conglomeratic materials is in proportion to the absence of feldspars and the sharpness of contact. Crossing Massachusetts, no Archean outcrop is met with until we reach the Douglas area, southeast of Worcester, where there is an almost exact duplicate of the Hoosac mountain section, with basal conglomerate and quartzite surrounding a central mass of Archean rocks.

Mr. G. K. Gilbert: I desire to call attention in this connection to a process of conglomerate formation to which allusion is rarely made, but

*Printed elsewhere in this volume.

which is nevertheless of importance. In the range of my observation it is the most important of conglomerate-producing processes. In the arid interior of our continent a large district is set with mountain ranges due to uplift along fault lines, while the intervening valleys are due to downthrow; and there is a continual transfer of material from the mountains to the valleys. This material is detached from the mountain masses by processes chiefly mechanical, and involving little rock decay. In the valleys it is assorted by running water, and the coarser part is accumulated as gravel in alluvial cones along the mountain bases, where it needs only cementation to become conglomerate.

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THE GEOTECTONIC AND PHYSIOGRAPHIC GEOLOGY OF WESTERN ARKANSAS.*

BY ARTHUR WINSLOW.

(*Read before the Society August* 19, 1890.)

CONTENTS.

INTRODUCTION.

The Area discussed.—The following pages refer chiefly to what is known as the coal region of Arkansas. This is in an area situated in the western part of the state, tributary to the Arkansas river. It extends from the Boston mountains on the north to beyond the Poteau and Petit Jean mountains on the south, thus covering an area about 100 miles long in an east-and-west direction by 50 miles broad in a north-and-south direction.

* Published with the approval of Dr. John C. Branner, State Geologist of Arkansas.

Historical Sketch.—The geotectonic geology of western Arkansas received little or no attention prior to the inauguration of the geological survey of the state now in progress. Shumard, in the report of Marcy's Red river expedition, made in 1854, makes no reference to the subject. In a paper, published in 1854, by Professor J. A. Warder, of Cincinnati, on a Geological Reconnoissance of the Arkansas River, an attempt is made to locate axes of flexure; and some of the conclusions have been confirmed by recent work of the state survey. Marcou touches upon the subject in the report of the Thirty-fifth Parallel survey. One of the most noticeable points in Marcou's interpretation of the geology of western Arkansas is the separation of the contorted slates about Little Rock, which he terms "metamorphic slates," from the overlying sandstones near that place, which he classes as Carboniferous, and which latter, he states, lie horizontally and unconformably upon the former. Beyond this to the westward, all of the various sandstones and shales exposed in the Ozark mountains and the Petit Jean mountains, as well as in the bluffs at Ozark and Van Buren, are included by him in the Carboniferous. This distinction between "metamorphic slates" and Carboniferous shales and sandstones led to some confusion in fixing the age of the uplifts. The horizontal position of the sandstones at Little Rock seemed to Marcou to preclude the idea that the force necessary for the metamorphosis and upheaval of the underlying "slates" could have been exerted posterior to the deposition of the sandstones, while at other localities rocks recognized as Carboniferous had evidently been subjected to such upthrow. He thus adopted an hypothesis of two distinct periods of disturbance, one anterior and the other posterior to the formation of the Carboniferous rocks. Thus the hills at Little Rock, at Hot Springs and at Sulphur Springs are stated to be dislocations anterior to the Carboniferous.

In the reports of the first geological survey of Arkansas, which was prosecuted between the years 1857 and 1860, no attempt is made to delineate geologic structure, and the positions of the anticlines and synclines is referred to only in the most disconnected and incidental manner along with the general descriptions of counties. Failure to consider these features led to most faulty conclusions in the attempt to correlate the rocks of this region with each other, as well as with those of other states.

Inception of the present Work.—When, therefore, in the autumn of the year 1887, I entered the coal region of Arkansas, preparatory to its study, it was with very vague anticipations; yet these anticipations were not sufficiently vague to preclude surprise, and, as my journey proceeded from point to point, surprise succeeded surprise. The thickness of the rock column which developed itself exceeded all expectations, as did also the number of the beds constituting this column. Instead of horizontal or gently dipping strata such as I expected to find, steep dips seemed to predominate, and the directions of these dips varied rapidly. While slowly meandering through the country on horseback, with only an occasional extended view from some peak, each topographic feature presented itself separately, and the differences in size, in outline, in profile and in trend, within comparatively small areas, added to the confusion of conception. It soon became evident that the problems which this country presented could be solved only through detailed work in which delineation of the topography must play an important part. Thus we came to the construction of the detailed topographic maps which are now being engraved, and which will appear in a forthcoming report of report of the Arkansas geological survey.

The small topographic map accompanying this paper, plate 8, is condensed from these detailed maps. It expresses only faintly, however, much that is shown to be of geological significance on the large sheets. As the construction of these sheets progressed, order began to develop itself; the relations of disconnected parts gradually became apparent; until now, as completed, the maps themselves stand as the solutions of various problems for the solving of which they were originally intended to be only one of the mean. To some of the results of this work I now wish to call attention.

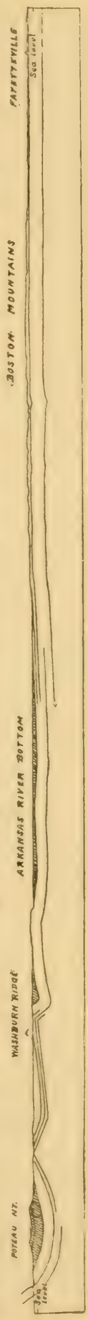


Figure 1—*Generalized Cross-Section from Poteau Mountains to Fayetteville.*
Scale, horizontal and vertical, 12 miles = 1 inch. Looking westward. Showing structure and thickness of the rocks exposed.

Age of the Rocks of Western Arkansas.

From the time of Owen's work, preceding the year 1860, the belief has been prevalent that the coal beds and associated rocks of western Arkansas are of sub-conglomerate or lower Carboniferous age. Without analyzing the reasons for this conclusion here, it suffices to say that our present knowledge of the flora of these coal beds, as well as the results of independent stratigraphic studies, lead to the conclusion that the coal beds of the Arkansas river and the associated rocks belong well up in the Carboniferous system. The complete display of the evidence leading to this conclusion is reserved for a future publication, since this question is not properly an essential part of this paper; but in general terms the line of argument is as follows: In northwestern Arkansas, in the vicinity of Fayetteville, *Archimedes* limestones and other rocks of probable lower Carboniferous age are well developed. Thence southward, across the Boston mountains, several cross-sections have been constructed with the results of proving the existence of barren strata over 1,000 feet in thickness intervening between these limestones and the coals of the valley of Arkansas river. The results of one of these sections are embodied in the generalized section, figure 1, and the total thickness of the formations exposed within the area described is there approximately shown. Further, a study,, by Mr. G. D. Harris, of the flora of certain coal beds on the Arkansas river, in the vicinity of Russellville, led to the conclusion that they represent horizons above the conglomerate. On stratigraphic grounds these latter beds are placed many hundreds of feet beneath the uppermost beds represented farther west in the state: hence we have reason for assigning to these latter beds a position well up in the Coal Measures.

The Geotectonic Geology.

Character and Distribution of the Flexures.—In illustration of the character of the flexures of this area, figures 1, 2, 3, 4, 5 and 6 are presented. Figure 1 is a generalized cross-section through the Boston mountains and

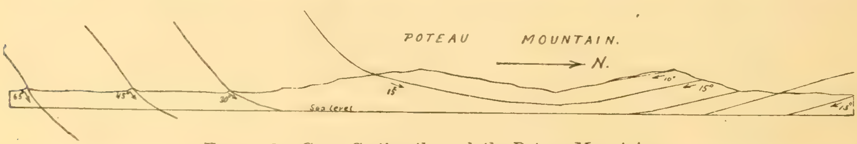


Figure 2.—*Cross-Section through the Poteau Mountains.*

Scale, horizontal and vertical, 1.6 miles = 1 inch. Looking westward. Showing the steeper dips northward.

the Arkansas river valley. It illustrates the diminution in intensity of flexing from south to north. This section is constructed along a line running in a direction nearly due north and south, at right angles to the axes of flexures, which are invariably east and west lines, exact or closely approximate. From the Poteau mountains northward the flexures are seen first to be intense, and then to diminish until they terminate in the grand monocline of the Boston mountains.

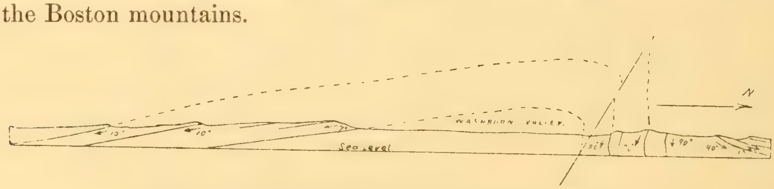


Figure 3.—*Cross-Section through the Washburn Anticline.*

Scale, horizontal and vertical, 1.25 mile = 1 inch. Looking westward. Showing overturned fold and fault, indicating lateral movement from the south.

Figure 2 is a section constructed on equal horizontal and vertical scales across the Poteau mountains. It illustrates not only the excessive dips of the south, but also the general fact of the greater inclination of northward dips over southward dips.

The last condition is also illustrated by figures 3 and 4: the former represents a section across the great Washburn anticline and the interesting series of ridges southeast of Greenwood; the latter a similar section across Backbone anticline, an analogous flexure and series of ridges west of Greenwood. The overturn of the fold is well marked in both of these cases; in fact, the flexure has passed to the extreme condition of a fault with an upthrow on the southern side, which toward the termini of the anticline diminishes to nothing. The character of these flexures and faults is typical of that attributed to lateral compression.

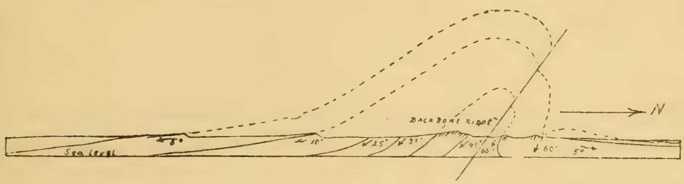


FIGURE 4.—*Cross-Section through the Backbone Anticline.*

Scale, horizontal and vertical, 1.25 miles = 1 inch. Looking westward. Showing overturned fold and fault, indicating lateral movement from the south.

Finally, figures 5 and 6 are sections across the southern base of the Boston mountains, illustrating the general synclinal plunge of the strata before they rise in a monoclinal arch to form the Boston uplift. It is probable that along with the production of the monocline some faulting took place, evidence of which is presented by abrupt rock-faces, with smooth surfaces, found along the foot of the mountains in the line of the flexure, sometimes

FIGURE 5.—*Cross-Section into the Boston Mountains.*

FIGURE 6.—*Cross-Section into the Boston Mountains.*

Scale, horizontal and vertical, 1.15 miles = 1 inch. Looking westward. Showing monoclinal flexure along the southern base.

accompanied by chalybeate springs; but the throw was probably slight and the horizontal extent short. Thence northward the strata dip gently southward or lie flat almost uninterruptedly, as shown in figure 1.

A study of these sections leads, therefore, to the conclusion that there was lateral movement and that this movement was from the south. A consideration of the horizontal extent of the flexures and of their distribution develops also many suggestive facts. The axes of the flexures are located on the topographic map accompanying this paper, and their topographic relations can be well studied there. Perhaps the most striking feature is the great number of distinct flexures represented in so small an area; but the lack of persistency in the plications, some of which are of great intensity, also demands attention. Thus, the anticlinal arch north of the Poteau mountains, termed the Coops anticline, which, opposite the middle point of its axis, is characterized by dips ranging from 10° to 20°, disappears eastward within a distance of about five miles and is immediately followed, in the prolongation of its axis, by the Magazine syncline, the plication being transferred to the Belva anticline on the south, the axis of which runs parallel to that of the Magazine syncline. The Washburn anticline illustrates this feature in a still greater degree. Here, within a distance of five miles from a section of 80° dips, the flexure disappears entirely, and in the prolongation of its axis westward there is a plateau in which the rocks are in a nearly horizontal position. The Backbone anticline, which is also characterized by excessive northerly dips, together with some faulting, terminates similarly toward the east at Greenwood, and in the position of its prolonged axis the rocks dip uniformly southward at angles of only a few degrees. The Biswell anticline, northeast of Greenwood, dies out westward and eastward within a distance of four miles from its center, and the Potato hill syncline is exactly in the line of the eastward prolongation of its axis. Along the southern foot of the Boston mountains, the synclinal flexure already mentioned and illustrated is seen to be composed of a series of short flexures which, in places, overlap each other.

Thus, in general terms, an interlocking system of flexures is produced. Invariably, where one of prominence begins to die out another of the same character begins to assert itself, either toward the north or toward the south, and generally a flexure of opposite character is developed in the prolongation of the axis of the expiring one. The plications thus seem to be, to a certain extent, compensatory; the relief from strain afforded by the flexing along one axis being supplied by the folding along a contiguous axis, while the first disappears.

From the last consideration it seems probable that developed cross-sections of the same bed across this area would have approximately the same length; though, even if this were so, such a result depends upon too many indefinite factors to be of much value. But, however exact such cross-sections might be, their mere development would not replace the strata of this flexed area in their original positions and relations. A restoration by stereogram of the flexures here involved, even according to the most conservative interpretations, would produce a surface on which the features of relief would be elongated ellipsoidal domes—it would be a typical warped surface, and, like other warped surfaces, could not be developed into a plane.

Dates of Elevation and Folding.—From the age assigned these rocks, it follows that the date of their elevation must have been post-Carboniferous. Further, the evidence is strong that this elevation was pre-Mesozoic; for, firstly, no Triassic or Jurassic rocks are found overlying these Carboniferous beds conformably; and, secondly, Cretaceous beds rest unconformably upon and in contact with the upturned edges of the Paleozoic beds along their southern border, the Cretaceous beds showing little or no evidence of disturbance; which latter fact demonstrates also that the folding, or at least such portion of the folding as was wide-spread in its effects, antedated that period. But the question whether the elevation and the folding were exactly simultaneous or whether the latter succeeded the former is a detail concerning which we have not complete evidence to present here. The existence of a disturbance in post-Cretaceous times is well established through the study of the eruptive rocks of the state, which are of post-Cretaceous age; but its effect in flexing the Coal Measure rocks seems to have been insignificant. According to Branner: *

> "The Cretaceous rocks have not been much disturbed or altered, even where the eruptives come up through them. Neither can it be positively stated that the eruptives greatly disturbed the Paleozoic rocks through which they pass, for the folding, crushing, and metamorphosis seem to be just as marked away from the outbursts as in their immediate vicinity."

General considerations of the magnitude of the movements involved, and of the character and comparative values of the different mountain-making epochs in the history of this continent, incline one to the belief, however, that the folding as well as the elevation of these Carboniferous rocks of Arkansas was synchronous with the movement which gave birth to the Appalachians, and that the similarity between the structure of this area and that of the Carboniferous area in Pennsylvania is not a mere accident but is due to a trans-Mississippian extension of the same cause.

Cause of Elevation and Folding.—As above expressed, the flexing of the strata in the coal region of western Arkansas is essentially Appalachian; and, reasoning from resulting forms, any explanation good when applied to the Appalachians will be good when applied here. A study of the various flexures reveals many features which call for compression and lateral movement. The influence of secular contraction in this movement cannot be discussed exhaustively until the results of studies elsewhere in the state are available; but, in view of the questioned adequacy of this cause, an attempt

* Private communication.

is made here to harmonize the phenomena with the cause, advocated by Reade,* found in expansion of the lower layers by rise of the isogeotherms.

Immediately preceding the date of elevation there was, over what is now southeastern Missouri and northern Arkansas, a land area of pre-Carboniferous rocks, southward from which extended the seas in which the Carboniferous rocks were laid down. In Missouri the total thickness of the Paleozoic strata is estimated by Broadhead to be in the vicinity of 5,000 feet. In Arkansas the thickness must be many times this, that of the Carboniferous strata of the Arkansas river valley alone being about 10,000 feet. The rocks of these Arkansas strata, sandstones, and shales bear evidence in the form of ripple marks and mud cracks of having been chiefly shallow-water deposits; hence the subsidence was both profound and gradual. An elevation of great magnitude succeeded this subsidence. The Arkansas area thus yields another illustration of a frequently observed sequence of a great orographic movement following a period of long-continued and abundant deposition. The thickness of the strata which accumulated during this period must have been great enough to allow a decided increase of temperature of the lower members, and the explanation of the subsequent movements by expansion through this increase of temperature thus finds undoubted support in this particular.

The sections represented on preceding pages yield evidence that a movement from the south accompanied the plicating action. The explanation to be offered for this is, that the region of most energetic plicating action was south of the area here especially treated. Excessive dips and an incipient metamorphosis of the rocks characterize a belt of country running in an east-and-west direction some twenty-five miles south of this area. It was in this same belt that the post-Cretaceous disturbance already referred to was most active. This last disturbance was accompanied by the formation and intrusion of igneous rocks; but none such have been recognized as accompanying the general upheaval of post-Carboniferous date.

The facts point thus to the conclusion that this belt was characterized by disturbances from post-Carboniferous to post-Cretaceous times. According to the theory of expansion, this belt was the one along which great tension was first developed in the upper layers from the great elevatory movements caused by the expansion of the lower layers. Through continued action of these causes the upper layers were fractured or stretched and the highly plicated lower layers, which were subjected to pressure, were protruded. The intrusion of molten rock in post-Cretaceous times was but the culmination of this action. On this interpretation we can understand how lateral movements of the rocks have been produced northward from this axis of disturbance; how the development of strong plications here gave relief to the

* "The Origin of Mountain Ranges;" by T. Mellard Reade, 1886.

strain in the lower layers; and how the intensity of the flexing diminishes away from this line northward to the Boston Mountains, as illustrated by figure 1.

But, in addition to presenting evidence of lateral movement, the warped character of the structure of the Arkansas valley, described on page 230, suggests the action of other causes. To produce such a warped surface, a considerable vertical and upward component in the force acting is necessary. The shells of successive strata constituting these quaquaversal arches must have been stretched or elongated. Gilbert has explained how this was produced by laccolite intrusion in the formation of the Henry mountains.* Here we have no reason to suspect the proximity of such masses of igneous rock. Conditions can be conceived by which lateral compression from two directions might alone produce this; but equally well, if not better, can we attribute this warping to expansion of the lower strata through an increase of temperature due to a rise of the isogeotherms with continuous sedimentation, as explained by Reade. A condition of tension in the upper layers would thus be produced; the topmost of these layers would be fractured and pulled asunder; the lower lying ones would be compressed and caused to flow and spread under the influence of great pressure. The amount of fracturing and the amount of spreading in any one case would be dependent upon the elasticity and the plasticity of the layer and upon the amount of pressure it is subjected to. The plications would thus represent the combined effects of two causes: Firstly, to the action of the general cause of expansion of the lower beds is due the production of the warped surface; secondly, to the superior activity of this first cause in the region to the south is due a lateral movement towards the north which, acting as a secondary cause, produced unsymmetrical folds and lateral compression of the rocks.

In connection with this question of the origin of quaquaversals, a suggestion is in place relating to the value of developed cross-sections constructed from observed dips. From such cross-sections the amount of linear compression in the plications of the Alps has been estimated at 72 miles, and in the case of the Appalachians at 88 miles. These figures have been criticised by geologists and thought to be excessive—more than the supposed causes were adequate to produce.

On the assumptions that the rocks are in a state of strain; that the upper layers of an arch are in a condition of tension; and that the bulging is produced by an effort of the compressed lower layers to protrude themselves, the top layers would undoubtedly be fractured. The forces of degradation would attack the arch vigorously along the lines of such fractures, would gradually remove the dome-like cover, and would then proceed to cut further down into the core. Such cutting means, however, removal of material,

*Geology of the Henry Mountains, 1877, p. 76.

and this means gradual relief from pressure of the underlying rocks; hence a constantly diminishing load opposes the forces tending to cause protrusion of the lower layers. Thus it is conceivable that expansion or protrusion may take place coincidently in a general way with the removal of the load. An immediate effect of such protrusion would be to increase the dip of the rocks adjacent to it, as is illustrated by figures 7, 8 and 9, which are ideal sections across such an arch. They show the successive changes of dip with the progress of degradation. The effect of such an interpretation of the origin of dips upon the represented length of a flexed stratum will be at

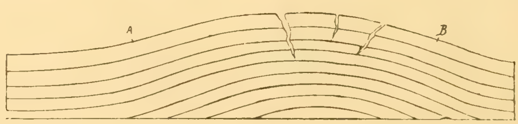


FIGURE 7.—*Ideal Section of Arching Strata. First Stage.*

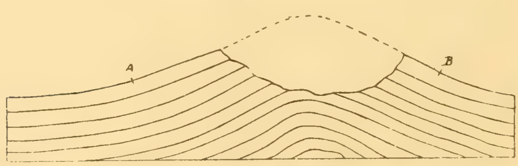


FIGURE 8.—*Ideal Section of Arching Strata. Second Stage.*

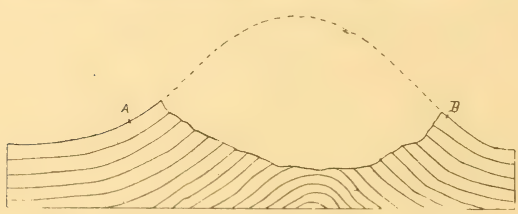


FIGURE 9.—*Ideal Section of Arching Strata. Third Stage.*
Ideal sections illustrating the progressive increase of dips with progressing degradation.

once appreciated. In figures 7, 8 and 9 the relative lengths of the lines connecting the points *A* and *B* are respectively 23, 25 and 30. May not the apparently excessive estimates of linear compression in many instances have been due to such a cause?

THE PHYSIOGRAPHIC GEOLOGY.

The general Surface.—The surface features of western Arkansas are typically those of stratified non-metamorphosed rocks, and their mode of production has been such as usually characterizes such rocks. The stage of topographic development here may be classed as mature, in that it includes great variety of form, from the cascade condition of the mountains to the broad base-level condition of the river bottom.

The ranges of level are not very great. From Fort Smith eastward the Arkansas river falls at a rate of about a foot to the mile, the altitudes being, at Fort Smith, about 430 feet; at Dardanelle, about 320 feet; at Little Rock, about 260 feet. The highest summit is that of Magazine mountain, which reaches an altitude of 2,850 feet.

Mountains.—The mountains vary in profile and plan according to the position and character of the strata composing them. The Boston mountain area on the north may be classed as an elevated plateau cut by deeply corraded channels. The general altitude is between 1,000 and 2,000 feet. The surface is undulating and, at a number of points, rises to summits several hundred feet above the surrounding country. The component rocks are grits, sandstones and shales; and in the northern portion limestones appear near the base. These rocks lie generally in a horizontal or slightly inclined attitude. Towards the south the mountain mass in places slopes gradually to the level of the river, but elsewhere it rises abruptly from the valley, presenting bold escarpments of massive sandstone along several benches; the mountain front is notched by ravines and hollows setting back into the plateau.

The mountains immediately south of the Arkansas river include the Sugar Loaf mountain, Poteau mountain and White Oak mountain. These are members of a system which extends westward into Indian Territory, and eastward, with somewhat irregular grouping, to the Arkansas river at and below Dardanelle, including such ranges as the Petit Jean and the Magazine, and such outlying masses as Mount Nebo and the Short mountains. The trend is approximately east-and-west in all cases. These mountains are of horizontal or flat synclinal structure, and are made up of alternating beds of sandstones and shales. They are, in many cases, typical illustrations of mountains of circumdenudation, notably Sugar Loaf mountain, Magazine mountain, Spring mountain and Mount Nebo. The elevation of the summits varies from about 1,000 feet to 2,850 feet above tide. They have generally very steep slopes, though these are frequently broken by benches formed by resisting layers of hard sandstone, which often stand out from the mountain side in abrupt escarpments. The crest is often a flat table-land, and this, as well as the benches on the sides, are frequently cultivated. Timber extends to the very summits of these mountains, though at the higher altitudes it is small and stunted.

Further southward, as the region of greater disturbance is approached, the mountains consist of steep-dipping strata, more or less metamorphosed; such mountains are those of the Rich Fork, Black Fork and Fourche ranges.

Ridges and Mesas.—The mountains are the more prominent, the grander features of the topography; but the ridges and mesas of this area far exceed the former in geologic interest. In height these hills vary from low mounds, 20 or 50 feet high, to diminutive mountains, 400 or 500 feet above the surrounding country. As a rule, however, the height does not exceed 200 feet, and the average ridge is in the neighborhood of 150 feet high.

The distinction between ridge and mesa implied by the above heading is based upon a difference in cross-section which admits of this division of the minor elevations into two classes. The first class, or that of ridges, includes those long, sharp-crested monoclinal backbones with no summit areas and whose sides slope immediately away from the crest in both directions. Sometimes both slopes are steep, but generally one is precipitous and rocky while the other is gentle and adapted to cultivation. The second class, or that of mesas, refers more particularly to flat-topped or gently sloping and undulating elevations of horizontal structure, approaching the character of plateaus, with steep sides partially or wholly surrounding the broad summit. This distinction, based upon structural differences, is by no means a rigid one, and the two classes are found to merge by insensible gradations.

The distribution of these ridges and hills, though obedient to the laws of geologic structure, is subject to so many modifications through influence of stratigraphy and erosion that, without careful study, all seems chaos. By reference to the map it will be seen, however, that what are distinguished as ridges can be generally grouped into a system, the members of which run in long parallel lines with intervening narrow valleys. These members are frequently broken by gaps, vary considerably in height and prominence, are squeezed together, appear to die out, curve around in loops, and coalesce to form one flat-topped, canoe-shaped end. Throughout these changes, however, each ridge can be recognized in all its different phases, and the idea of order is traceable throughout; while with the plateau-shaped hills the distribution is as irregular as the outline is varied, and the characteristics of form might almost be called accidental.

Another type of hills, commonly known as "potato hills," may properly be termed *cones*. They are of conical shape, slope steeply on all sides, and are generally made up of shale with, perhaps, a sandstone cap. They properly represent the last stage of erosion of the mesa.

Immediately north of the Poteau mountains there is a system of monoclinal ridges, composed of sandstone strata dipping toward the mountains; near the mountains, and especially along the larger drainage channels, they are sometimes well-nigh obliterated by the combined effects of torrential flows and the accumulations of mountain débris. Outside of such areas, however, they are easily traced, and their topographic persistence is often remarkable.

Coops ridge, a few miles north of the Poteau mountains, is especially worthy of notice on account of its isolated position and the peculiarity of its structure. It is evidently the remains of a quaquaversal arch of elliptical outline, of which arch the dome has been eroded and the underlying shales eaten out, so that now only a monoclinal rim is left. The height of the ridge varies, and the crest line is broken in places into a succession of small peaks; the greatest altitudes are at the termini of the anticlinal curve.

The system of ridges immediately north of Coops ridge is particularly well-marked; the rocks here dip northward at an angle of about 20°, but eastward this dip flattens and the ridges terminate in typical canoe-shaped points.

Jennings hill and the ridges which surround it in concentric ellipses are beautiful developments from a synclinal structure. These ridges are all monoclinal, and are composed of sandstones, underlain by shales dipping 5° to 10° convergently toward the common center line of the series of ellipses.

Of chief prominence among the ridges are those which flank the Washburn valley, on each side of the anticlinal axis. The inverted canoe-shaped connection of the two systems at the western end is boldly brought out both by the elevation of the ridges at this point and by their sharply defined outlines. Toward the east, some of the ridges of marked prominence die out or become relatively insignificant, an undoubted indication of a concomitant thinning of the hard layers, to which these ridges owe their prominence elsewhere.

A similar system of ridges is that of which the eastern termination is at Greenwood. It follows in the same way a strong anticlinal flexure; but on account of the faulting which accompanied this flexing (see figure 4, page 229) the ridges north of the axis are not always of prominence.

Many other instances of similar ridges might be cited and their local characteristics referred to, but such detail would be out of place here. Enough has been said to direct attention to the existence and character of these features of relief; their distribution and special characters can be studied on the map.

North of the Arkansas, between it and the Boston mountains, the character of much of the topography is essentially different from that last described, and from that south of the river generally: the hills are closely crowded, their outlines are very irregular, they have no uniformity in trend, and the slopes are gentle or steep, according to the meanderings of a capricious drainage system. The shales and sandstones, so common elsewhere, make up these hills, and they are generally capped by beds of the latter. As may be inferred, no pronounced and persistent dip of the strata characterizes this region. The angle of dip seldom exceeds 5°, and the direction is fluctuating. In short, the topography here is typically such as results from erosion in heterogeneous strata which lie in a horizontal position. The region north of the river has been one of repose, and erosion dominates stratigraphy; that south of the river has been one of disturbance, and stratigraphy asserts itself in the topography.

Valleys: General Character.—The greater part of the area treated in this paper may, in a broad sense, be considered part of one great valley—that is, as constituting part of a single drainage basin, bounded on the north and south by mountain ranges. It is here intended, however, to treat of valleys in a more restricted sense, as those depressions which intervene between and are complementary to all the individual mountains, ridges, and other minor elevations which have already been described. With reference to the geologic structure these valleys may be classed as follows: 1. Monoclinal valleys; 2. Anticlinal valleys; 3. Synclinal valleys; 4. Valleys in horizontal strata. With reference to surface detail, to soil, to vegetation, each and all of these various classes may be, in whole or in part, either rugged, undulating, or flat; may be wet alluvial bottoms, or dry loamy or rocky uplands; may be densely covered with forest growth, or may be prairies.

Valleys of the first three classes preëminently characterize areas of regular flexing of heterogeneous, non-metamorphosed strata. In regions of great contortion and rock crumpling, stratigraphic divisions have a too intricate distribution to control corrasion; in homogeneous strata, degradation is general and uniform, and there are no guiding planes to direct the forces of erosion along the lines of least resistance; and metamorphosed strata, even when not contorted, possess in a great degree the attribute of homogeneity and offer approximately equal resistance in all directions to degradation. The predominant rocks of western Arkansas are sandstones and shales. We have seen that sandstone is the distinctive ridge-forming material. Similarly the fissile, easily eroded shales underlie the valleys almost without exception.

Monoclinal Valleys.—These are the depressions between parallel monoclinal ridges, and agree with them in trend. Examples of such valleys are to be seen between the parallel ridges north of the Poteau mountains. Where such coalesce at the point of an anticlinal they broaden correspondingly and are bounded by steep walls of converging ridges, giving the valleys slipper-shaped outlines. At the terminus of a syncline a broadening takes place by a similar coalescence, but the valley here differs from the last in being bounded by converging ridges which present their gentle slopes towards the intervening depression.

By far the best development of monoclinal valleys, however, is between the members of those prominent systems of ridges which lie immediately north and south of Washburn valley. On the south side, near the eastern end of the area mapped, these depressions are neither deep nor broad, by reason of the thinning of the ridge-forming sandstone; while at the western end, the several valleys of the southern system sweep around in beautiful parallel curves and, by reason of the compression and verticality of the strata at this point, coalesce with a single valley of the northern system.

Anticlinal Valleys.—These, like monoclinal valleys, are depressions, generally between monoclinal ridges; but unlike those, both bounding slopes are across the stratification. In a region of great rock flexures the larger valleys are generally of this type. This area is no exception to the rule. The Hartford valley, in Sebastian county, is a remnant of a grand anticlinal valley; the Poteau mountain range forms its southern boundary, but of the northern border ridge only a fragment is left in Sugar Loaf mountain. The valley north of Sugar Loaf mountain is a similar remnant. Such valleys as these, however, are what may be called primary valleys, their surfaces being broken by ridge lines, between which lie secondary valleys of monoclinal or anticlinal form. The terminal anticlinal valleys resulting from the fusion of two such secondary monoclinal depressions have already been referred to. Examples of purely anticlinal shape are Coops prairie, surrounded by Coops ridge; and Washburn valley, occupying the center of the anticlinal arch of the same name. Such valleys are, however, rare here, and, as compared with the number of monoclinal valleys, the same may be said of all regions, including even those where numerous folds of the strata are developed; for each such fold can exhibit only one anticlinal valley which will be centrally located along the axis of flexure, whereas each distinct and persistent stratum of hard material affected by such flexure will be developed by erosion into a dividing ridge between two monoclinal valleys.

Synclinal Valleys.—These are both topographic and stratigraphic basins, formed, generally, by convergently dipping strata of monoclinal ridges. Complete and unbroken valleys of this type are exceedingly rare. The valley in the eastern extension of Sugar Loaf mountain is of this type, as is also that which extends from Greenwood westward. Other illustrations are the Potato hill prairie, the Philpott coal basin, and the Ouita coal basin.

Valleys in horizontal Strata.—These valleys differ from each of the three classes heretofore described in the extreme irregularity of their outline. No normal plan for such depressions exists. The typical cross-section is that of a flat plane bounded on both sides by abrupt escarpments, *i. e.*, is similar to the cross-section of an anticlinal valley. When of oblong shape they follow no prevalent trend; their directions are adventitious. Laterally, resistance to erosion is equal in all directions, and hence their growth is in all directions at a rate dependent entirely upon external conditions. The cañon, the narrow gorge, is the rudimentary form of a valley in horizontal strata. The intense corrasive energies of degradation are first spent before the slower processes of erosion and sapping show their effects in lateral degradation.

A gorge of this type is that of James' fork, south of Hackett City. Massard prairie, south of Fort Smith, may be considered an example of a valley eroded out of horizontal strata. Slight undulations in the rocks exist here, but are not sufficient to lend form to the valley. The characteristic irregularity of outline, as defined by the bounding ridges on the north and south, will be particularly noticed. It is an old valley; corrasion is no longer dominant, and lateral erosion has advanced far. The valley in which Russellville is situated may also be included in this class.

The Prairies of Western Arkansas.—Prairies are generally subordinate valley features, and are properly mentioned here. They are not the broad level tracts of country which are generally implied by the term prairie, and of which the prairies of Kansas are familiar examples. They cover comparatively small areas. Their surfaces may be flat or undulating, or may be diversified by knolls and small ridges. The absence or scarcity of trees is the essential distinguishing characteristic. The prevalent underlying rock of these prairies is always dark shale, which becomes exceedingly fissile and soft on weathering. Thin strata of sandstone occur with this shale, and these generally explain the existence and distribution of the various elevations. The characteristically rounded contour of a soft shale country rock is, however, dominant in the topography. A clayey soil exists frequently to a depth of several feet, and this is apparently derived directly from the shales by decomposition *in situ.* In places, however, the bare shales are exposed immediately at the surface. The vegetation is chiefly a coarse grass, which is high and luxuriant when not not cropped short and trodden down by cattle. Clumps of small sassafras trees and haw bushes are also often seen and, along the streams, willows, oaks, and other trees attain full size.

The maintenance of these prairies, and probably also their origin, may be explained as due to a combination of causes; namely, the alternation from an extremely cold, wet soil during the rainy season, to a dry hard soil in the dry season, and further the periodic recurrence of prairie fires which shrivel such young tree growths as overcome the obstacles inherent in the soils. In support of this hypothesis is the fact of the occurrence of small bunches of trees over the small prairie knolls, which, being raised somewhat above the surface, have never so cold and water-soaked a soil as the surrounding ground; also the growth of trees along the drainage channels, where there is more moisture in the dry season and where the conditions are generally more uniform. Once started, however, a growth of trees continues to flourish despite all the adverse conditions; for with the commencement of tree-growth the adverse conditions disappear. Hence it is that areas are found which show evidence of having once been prairies but are now timbered lands. Further, these prairies are now great open ranges for cattle, the grass is kept short, and there are no longer such fierce periodic conflagrations; consequently, in places, the growth of trees spreads rapidly over the surface.

A peculiarity of surface detail which often excites notice is the existence of numerous small, low mounds which occur over these prairies, sometimes in great profusion. In diameter they are generally under 50 feet, and in height less than 4 feet above the general level, with a profile approximately of turtle-back shape. In distribution they are most abundant over the lower-lying and more level areas. They are generally not arranged in any special order, but lie scattered promiscuously at varying intervals. At times, however, they are seen in rows, which arrangement makes them much more conspicuous and heightens the artificiality of their appearance. The material of these mounds seems uniform throughout and is essentially the same as the surrounding soil, though of somewhat superior fertility. It is opener, lighter and apparently richer in organic matter. Here the grass grows most luxuriantly and clumps of bushes or small trees are often found. Neither in the arrangement of the material nor in the contents of these mounds is there evidence of the agency of man in explanation of their origin. The mere fact of their great number would preclude this. They stand simply as products of a gentle erosive action in soft homogeneous material. Their surfaces represent a former general level. Their material is the old top soil. The intervening depressions are caused by the slow soaking and solvent action of rain accompanied by a gentle flow.

Prairies are scattered over nearly the entire area illustrated on the map, and an enumeration of them all would be impracticable here. Notable instances are: French prairie, at the western terminus of the Washburn anticline; Long prairie, north of the Backbone anticline; Massard prairie, south of Fort Smith; Potato hill prairie, south of Charleston; Grand prairie, north of Charleston; and the prairies east of Russellville.

The River System.—The river system of this area is a theme worthy of a separate chapter. Its evolution and the adjustment of the courses of the different streams will not be discussed here, as this would expand the paper beyond reasonable limits. A few points of interest in this connection may, however, be referred to.

As already stated, this region may be considered as having attained the stage of topographic maturity. The Arkansas river has about reached its base-level; the flow is even and not swift; there are no falls nor bars nor rapids over rocky bottoms, and a layer of sand or silt generally intervenes between the water and the underlying rock; corrasion has about ceased and the stream is extending its alluvial plains laterally. Of a previous stage of base-leveling there is more than a suggestion in the approximate uniformity in height of the majority of those elevations which we have termed ridges and mesas. To fully realize this, however, a careful study of the detailed topographic sheets is necessary.

The rocky gorge through which the Arkansas flows, gives it, in places, the character of an antecedent channel. This is especially noticeable at a point about thirty miles below Fort Smith, where the bluffs on either side for a distance of nearly ten miles come down to the water's edge almost continuously.

A valley of shales a few miles south of this offers opportunity for a shortening of the channel through easily corraded material; yet the river cannot escape from its inherited bondage between mountain walls. Another instance is just above Dardanelle. The gorge here is only a few miles long, but is particularly interesting in that it cuts straight across the point of a sharp syncline; a feature of flow of a decidedly antecedent character.

Of monoclinal shifting of channels, there is abundant evidence in the evenness in slope of the sides of many monoclinal ridges. In some cases this slope conforms exactly with the dip of the underlying sandstone, and in places this sandstone is almost as bare as when left by the stream as the channel gradually shifted down the slope of the rock.

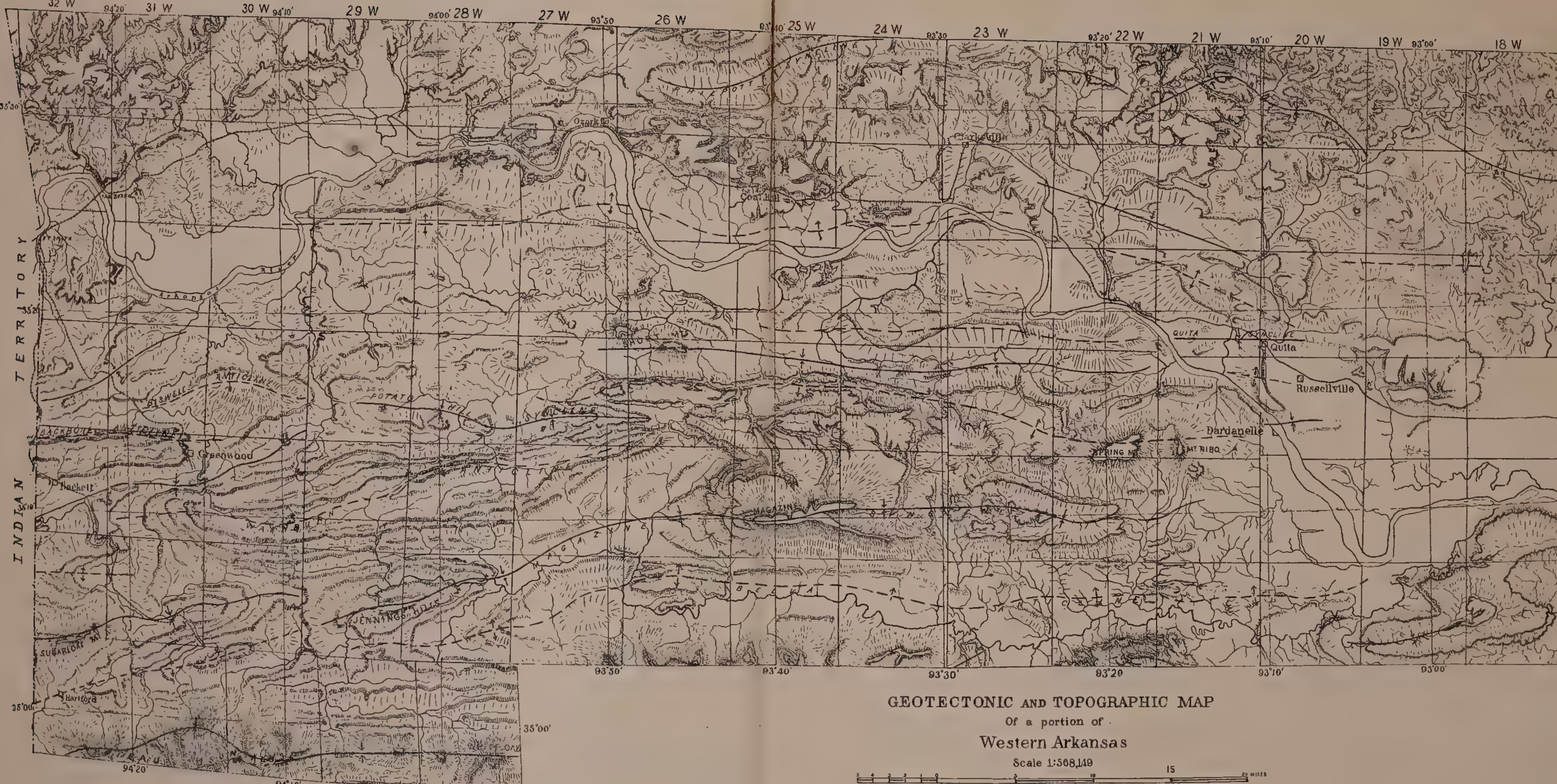
The courses of the stream across the ridge systems are always nearly at right angles, while they run lengthwise in the longitudinal valleys, thus illustrating the tendency of waterways to escape from hard strata and to abide in soft, as indicated by Gilbert.

Of backward headwater erosion most of the anticlines seem to furnish evidence. The valley enclosed by Coops ridge seems indisputably a result of this action.

An interesting case of the reädjustment of channels is presented by Petit Jean creek along the Jennings hill syncline. The stream at one time evidently followed the axis of the syncline, as is indicated by the succession of notches along the line through the encircling ridges. From this central channel it has evidently been diverted to the one it now occupies, north of the monoclinal ridge, by the tapping action of a stream which flowed originally as a tributary in this valley of soft rock.


32 W
94°20'
31 W
30 W
94°10'
29 W
94°00'
28 W
27 W
93°50'
26 W
35°30'
Ozark
Van Buren
Ft. Smith
Arkansas River
35°20'
INDIAN TERRITORY
BISWELL ANTICLINE
POTATO HILL SYNCLINE
BACKBONE ANTICLINE
Greenwood
Hackett
35°10'
MAGAZINE
JENNINGS HILLS
SUGARLOAF MT.
Hartford
35°00'
35°00'
93°50'
94°20'
94°10'
94°00'

GEOTECTONIC AND TOPOGRAPHIC MAP
Of a portion of
Western Arkansas
Scale 1:568,149



GEOTECTONIC AND TOPOGRAPHIC MAP

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GLACIAL LAKES IN CANADA.

BY WARREN UPHAM.

(*Read before the Society December* 31, 1890.)

CONTENTS.

INTRODUCTION.

Definition.—A glacial lake, according to my use of the term in this paper and elsewhere, is a body of water bounded in part by a barrier of land-ice. The lake may be hemmed in by a glacier, as the Merjelen see, or by a continental ice-sheet, as Lake Agassiz. And the same name is also applicable to the lakelets, wholly bounded by ice, which are occasionally formed, attaining a considerable depth and extent and continuing through several years, on the surface of glaciers, as in the Himalayan range, or on an ice-sheet, as observed by Nordenskiöld in Greenland.

Extent and numbers.—The abundant and extensive development of glacial lakes here to be considered attended the recession of the ice-sheet of the second or last Glacial epoch in Canada, being due to the temporary damming of the waters of glacial melting and of rains on areas where the land has a northward descent. While the ice-sheet was melting away from south to north on such a slope, free drainage was prevented, and a lake was formed, overflowing across the lowest point of what is now the southern water-shed of the basin. Many of these lakes were of small extent and short duration, being soon, by the continued retreat of the ice, merged into larger glacial lakes, or permitted to flow away where basins sloping northward are tributary to main river-courses draining southward. President Chamberlin has well written of these lakes fringing the ice-sheet:

"They vary in areal extent from trivial valleys blocked by ice to the broad expanses of the great basins. If an attempt were made to enumerate all instances, great and small, and all stages, earlier and later, the list of localities and deposits would swell, not by scores and hundreds, but by thousands."*

Evidences of Glacial Lakes.

Five principal evidences of the former existence of glacial lakes are found, namely, (1) their channels of outlet over the present water-sheds; (2) cliffs eroded along some portions of the shores by the lake waves; (3) beach ridges of gravel and sand, often on the larger glacial lakes extending continuously through long distances; (4) delta deposits, mostly gravel and sand, formed by inflowing streams; and (5) fine sediments spread widely over the lacustrine area. A few words of general description may be given to each of these before proceeding to note their special features for some of the more important Canadian glacial lakes.

Outlets.—Among the evidences of glacial lakes, the one most invariably recognizable and most definite in its testimony is the outlet showing distinct stream erosion across the rim dividing adjacent river basins, which now in many instances send their waters respectively to the Gulf of Mexico and to Hudson's bay or the Gulf of St. Lawrence. Obviously, water-courses could only exist in these positions as the outlets of lakes which were pent up by some barrier that is now removed. Shore lines traceable northward from these deserted channels must therefore belong to a lake, and cannot be regarded as the record of any marine submergence.

Closely associated with such channels crossing water-sheds, and at the same level, are the three following classes of proof cited, namely, eroded cliffs, beach ridges, and deltas; and below these shore records are the fine lacustrine sediments. These are found in hydrographic basins which are now drained by a continuous descent northward, presenting no indication that any land barrier ever existed across their lower portions to form these lakes, being afterward removed by erosion or by depression. The shore lines,

* Proc. A. A. A. S., vol. XXXV, for 1886, p. 208.

as shown thus by wave-cut cliffs, wave-built beaches, and deltas brought by inflowing rivers, extend far along both sides of the present hydrographic basin, often rising slightly and regularly northward, instead of sinking in that direction, as they would do if there had been a depression of the land at the north. When traced carefully with levelling, they are found, sometimes after an extent of hundreds of miles, as on the glacial Lake Agassiz and about the great lakes tributary to the St. Lawrence, to terminate abruptly where the basin attains its greatest width. Hence it is manifest that the barrier of these lakes could not have been land formerly raised higher than now, but was the receding ice-sheet, against which the land shores terminated.

On slopes descending in parallelism with the retiring ice-border, drainage from it in many places flowed in channels from which the streams became turned into new and more northerly courses as the ice retreated. Several glacial river-courses of this kind I have observed between the Côteau des Prairies and the Minnesota river.* Others have been noted by G. M. Dawson,† McConnell,‡ and Tyrrell,§ in various parts of Alberta and Assiniboia. But these seldom were outlets of glacial lakes of large size. It was only when extensive hydrographic basins were inclined toward the ice-sheet, that broad glacial lakes, as those named Lake Saskatchewan, Lake Souris, and Lake Agassiz, and the greatly enlarged Laurentian lakes from Superior to Ontario, were held between the northwardly sloping land and the waning ice-sheet, with long continued outflow across the present main water-sheds of the continent.

The depth of erosion of these outlets varies from 50 feet or less to 150 feet or more. So far as known to me, they are cut through the easily eroded drift deposits, and sometimes beneath these, on the extension of the great plains in the Canadian northwest, through Cretaceous shales or clays and soft, unconsolidated sandstones, which could be easily worn away. Nowhere is it found that a glacial river has channelled deeply into the harder rock formations. The time required for the work observed was brief.

Eroded Cliffs.—This type of shore lines, denominated sea cliffs by Gilbert, is developed where a glacial lake has formed a terrace, usually in the unmodified glacial drift or till, with no definite beach deposit. Waves and currents at these places have been efficient to erode, by undercutting at the base of the terrace, and to carry away, rather than to accumulate. Only a small portion of the shores of Lake Agassiz examined by me consists of these steep, wave-cut slopes of till; and they nowhere form conspicuous topographic features, their range in height being from five or ten to thirty feet. This is

* Geological and Natural History Survey of Minnesota, Final Report, vol. I, 1884, pp. 508-9, 606.
† Report on the Geology and Resources of the Region in the vicinity of the Forty-ninth Parallel, 1875, pp. 263-5; Geological Survey of Canada, Report of Progress for 1882-83-84, p. 150 C.
‡ Geological Survey of Canada, Annual Report, new series, vol. I, for 1885, pp. 21 C and 74 C.
§ Ibid., Annual Report, new series, vol. II, for 1886, pp. 43 E, 45 E, and 145 E, 146 E.

indeed a very slight elevation in comparison with the cliffs of till of similar origin on some parts of the shores of Lake Michigan and others of the Laurentian lakes, where erosion has been in progress from the time of the glacial recession to the present day. Scarboro' heights on Lake Ontario, near Toronto, extending nine miles with a height of 170 to 290 feet, consisting of till and interglacial beds, are cliffs thus produced by postglacial lake erosion. The duration of the glacial lake appears to have been much shorter than the postglacial epoch.

It is important, however, to note here that cliffs of preglacial erosion, which remained as prominent escarpments through the vicissitudes of the ice age, became in some places the shores of glacial lakes. Of this class are the bold highlands of Pembina, Riding, and Duck mountains, which rise steeply 100 to 1,000 feet from the highest western shore line of Lake Agassiz, to form the margin of a plateau that stretches with a moderately undulating surface westward. Even where this lake washed the bases of the cliffs, it doubtless eroded them only to a slight extent. The horizontal Cretaceous beds of this great escarpment originally extended eastward a considerable distance, as believed by Hind and Dawson, probably so far as to cover the areas now occupied by Lake Winnipeg and the Lake of the Woods; and we must attribute the erosion of their eastern portion, leaving this steep line of highlands, to river action during the Tertiary era, not in any important degree to glaciation, and least of all to shore-cutting by the glacial lake.

Beaches.—The course of the shore of a large glacial lake is usually marked by a deposit of beach gravel and sand, forming a continuous, smoothly rounded ridge, such as is found along the shores of the ocean or of our great lakes wherever the land sinks in a gently descending slope beneath the water-level. The beach ridges of Lake Agassiz, and of the glacial representatives of the Laurentian lakes, commonly rise three to ten feet above the adjoining land on the side that was away from the glacial lake, and ten to twenty feet above the adjoining land on the side where the lake lay. In breadth, these ridges vary from ten to twenty-five or thirty rods. The beach deposit takes thus the form of a broad wave-like swell, with a smooth gracefully rounded surface. Like the shore accumulations of present lakes and of the sea coast, these glacial lake beaches vary considerably in size, having in any distance of five miles some portions five or ten feet higher than others, due to the unequal power of waves and currents at these parts of the shore. Moderate slopes bordering the greater glacial lakes were favorable for the formation of beach ridges, and such ground frequently displays many beaches at successive levels, which marked pauses in the gradual elevation of the land when it was relieved of its ice-burden, and in the subsidence of the lake as its outlet became eroded deeper or as the glacial retreat uncovered new and lower avenues of discharge.

Waves driven toward the shore by storms gathered the beach gravel and sand from the deposit of till or other drift which was the lake bed; and corresponding deposits of stratified clay, derived from the same erosion of the till, sank in the deeper part of the lake. But these sediments were evidently of small amount and are not commonly noticeable on the sheet of till which forms the greater part of the lacustrine areas. Where the beaches cross delta deposits, especially the fine silt and clay that lie in front of the delta gravel and sand, they are indistinctly developed or fail entirely. On the other hand, the most massive and typical beach ridges, often continuous several miles with remarkable uniformity of size, are found on areas of till that rise with a gentle slope of ten or fifteen feet per mile. Under the influence of irregular contours of the shore, however, the beach deposits assume the form of bars, spits, hooks, loops, and terraces, of which Gilbert has given a careful classification, with analysis of the interactions of waves and currents by which they were made.*

Deltas.—A broad expanse of water exposed along a distance of many miles to strong winds is required for the formation of sufficiently large and powerful waves to erode cliffs or accumulate well defined beach ridges; but the area of any glacial lake, small or large, may be partly occupied by deltas brought into its margin by tributary streams. These deposits at the mouths of small brooks are often only a few rods wide; while the deltas of rivers, especially those supplied with much englacial drift from the melting ice-sheet, sometimes extend many miles in a flat or moderately undulating plain of gravel and sand, lying at the level which the surface of the lake held during the accumulation of the delta, or within a few feet above or below that level. But at the mouth of the river forming the delta, it was frequently built up in a fan-shaped mass to a considerable height, the head of the alluvial slope being in some instances 50 feet or more above the lake. The delta plain is generally bounded on its lakeward side by a somewhat steep descent, partly due to the ordinary conditions of delta formation, but often made more conspicuous by erosion of the outer portion of its original area by waves and shore currents when the lake fell to lower levels.

Winds in many places have channelled and heaped the surface of the more extensive deltas, acting most efficiently as soon as they became uncovered from the lake, and before they could be overspread by vegetation; and many of the resulting sand dunes, which frequently range from 25 to 100 feet in height, though mainly covered by grass, bushes, and trees, are still undergoing slight changes of their form by wind erosion. All the dunes on the areas of the glacial lakes Agassiz, Dakota, Souris, and Saskatchewan, occur on delta deposits; but the great tracts of dunes about the south end of Lake Michigan belong wholly to beach accumulations, being sand derived

* "The Topographic Features of Lake Shores:" Fifth Annual Report of the U. S. Geol. Survey, 1885, pp. 75–123; "Lake Bonneville:" Monographs of the U. S. Geol. Survey, vol. I, 1890, chapter II.

from erosion of the eastern and western shores of the lake, whence it has been borne southward by shore currents, especially during northern gales. None of the beaches of our glacial lakes are large enough to make dunes like those on Lake Michigan, though the size and depth of Lake Agassiz, its great extent from south to north, and the character of its shores, seem equally favorable for their accumulation. It is thus again indicated that the time occupied by the recession of the ice-sheet was comparatively brief.

Lacustrine Sediments.—In front of the delta plains of gravel and sand, the finer silt and clay brought into the glacial lake by the same tributaries were spread over the lake-bottom, covering the till on large tracts adjacent to the great deltas. Only small contributions of fine sediment, usually inappreciable, as before stated, on the greater part of the lake basin, were supplied from the shore and sublittoral erosion of till, which yielded the gravel and sand of the beaches; but some of these areas of wave erosion, reaching a quarter of a mile off shore, are plentifully strewn with the residual bowlders.

Because of their relation to the receding ice-sheet, the glacial lakes might be expected to receive noticeable deposits, including bowlders, from floating bergs and from floes of the ice-foot which would be formed in winter along their northern barrier. It is certain, however, that no deposits which can be referred to such origin are spread generally over the lake basins. Bowlders are absent or exceedingly rare in the beaches, deltas, and finer lacustrine sediments. In a few places, however, I have observed bowlders in considerable numbers on osar ridges of gravel and sand, where they were evidently brought and stranded by floating ice-masses from the melting ice-border, whose distance could not have exceeded a few miles at the farthest and indeed probably was not so much as one mile while the bowlders were being stranded.

Where terminal moraines cross a glacial lake, their knolly and hilly contour, as deposited on land, is changed to a smoothed, slightly undulating surface, and their proportion of bowlders exposed to view is diminished. The lake levelled the till that would otherwise have formed knobs and hills, in which process many of its bowlders were covered.

After the drainage of the glacial lakes by the complete departure of the ice-sheet, the lower portions of their basins, in depressions and along the present river-courses, have become filled to a considerable extent by fluvial beds of fine silt. These are similar in material with the lacustrine sediments bordering the deltas, from which they are distinguishable by their containing in some places shells like those now living in the shallow lakes and streams of the region, remains of rushes and sedges and peaty deposits, and occasional branches and logs of wood, such as are floated down by streams in their stages of flood. In the valley of the Red river of the North these recent fluvial deposits have commonly greater thickness and extent than the underlying silt of the glacial Lake Agassiz, which however in some portions, as near the deltas of the Sheyenne and the Assiniboine, occupies large areas.

Principal Glacial Lakes of Canada.

British Columbia, Athabasca, and the Northwest Territory.—Light-colored silt deposits, distinctly stratified and of considerable thickness, which seem to me referable in some districts to glacial lakes and in others to river-floods supplied from the melting ice-sheet, are reported by Dr. G. M. Dawson in many basins of the British Cordilleran region. His interpretation of their origin, however, is by a marine submergence since tha latest glaciation of the region. No fossils, either of the sea or of fresh water, are found, though they are abundant in postglacial marine beds of the St. Lawrence valley, on the southwestern side of Hudson's bay, and in Greenland and Grinnell land; but lakes of only moderate size temporarily bordering the ice-sheet during its departure would probably be destitute of life, and this would certainly be true of rivers produced by the glacial melting. These deposits occur, up to heights 2,300 to 2,700 feet above the sea, in the basin of the Kootanie and upper Columbia, on the interior plateau of British Columbia, on the northward extension of the great plains crossed by the Peace river, and in the upper valleys of the Stikine, Liard, and Yukon rivers.*

On the last named river and the Lewes, tributary to it, Russell refers the formation of silt beds fully 200 feet thick, and of higher terraces, to a glacial lake, named by him Lake Yukon, 150 miles long from north to south, with a maximum width of about ten miles and depth of between 500 and 600 feet; and he suggests that this lake was probably caused by a depression of the upper part of the Yukon basin by the weight of the ice-sheet. The mouth of Lake Yukon, at its northern end, was near the northwestern boundary of the ice-sheet at its maximum extension, the whole lake being within the area that was ice-covered, as is known by the limits of glacial drift and striæ, which are first found in ascending the Yukon near the Rink rapids, approximately in latitude 62° 20′ north and longitude 136° 15′ west, about 160 miles east of the line between British America and Alaska.†

No other portion of the Dominion of Canada presents a more interesting or more difficult problem in Quaternary geology than these "White silts," as they are denominated by Dawson; and much further field-work and study will be needed to demonstrate the conditions of their deposition in each of the numerous basins in which they are found. But I believe that ulti-

*Reports of the Geological and Natural History Survey of Canada; Trans. Royal Society of Canada, vol. VIII, sec. iv, 1890, pp. 3-74, with five maps; American Geologist, vol. VI, Sept. 1890, pp. 153-162; Nature, vol. XLII, Oct. 30, 1890, pp. 650-653.

† Bull. Geol. Soc. Am., vol. 1, pp. 140, 146-8, 544.

mately they will be shown to be everywhere attributable either to fluvial deposition attendant on the recession of the ice-sheet or to deposition as deltas in glacial lakes, which owed their existence to ice-dams or to depressions where the land had sunk beneath the ice-weight and has since been reëlevated. For example, the Kootanie basin may well have been filled by a glacial lake obstructed in the present course of drainage by the retreating ice-sheet and outflowing by the way of Pack river and Lake Pend d'Oreille, which President Chamberlin finds to have been covered by the maximum advance of the ice, while gravel-bearing floods from the glacial melting poured thence to the south and west.* Again, the silts on the Peace river east of the Rocky mountains seem referable, as will be stated more fully on a later page, to a glacial lake held by the barrier of the departing ice-sheet on the north and northeast, with outflow southeastward into Lake Agassiz.

Alberta, Assiniboia, and Saskatchewan.—During the recession of the ice-sheet from Alberta, small glacial lakes doubtless existed in the basins of the Bow and Belly rivers, outflowing from the former successively by the Little Bow river and the Snake valley, and from the latter successively by the Verdigris, Etsi-kom, and Chin coulées, which Dr. Dawson describes as remarkable abandoned river-courses now carrying little or no water. The glacial drainage from the present sources of the South Saskatchewan, and probably also of the North Saskatchewan and Athabasca, was thus carried southeastward, in parallelism both with the main Rocky Mountain range and with the retiring ice-border, to the Milk river west and south of the Cypress hills. The whole area of Alberta, partly land sloping northeastward and partly ice sloping southwestward, with glacial lakes here and there along the ice-margin, seems then to have been tributary to the Missouri and the Gulf of Mexico.†

From Lake Pakowki, through which this glacial drainage for a long time flowed southward to the Milk river, the ice-front must have been withdrawn more than two hundred miles to the east, past the Cypress hills and Wood mountain, before a lower outlet from the Saskatchewan country north of these highlands would be obtained by Twelve Mile lake and over the present continental water-shed to Big Muddy creek, which flows through the northeastern corner of Montana to the Missouri. But only a slight further retreat of the ice was sufficient to give still lower avenues of drainage. As soon as the Missouri coteau was uncovered, a glacial lake occupying the valley of the South Saskatchewan in the vicinity of its elbow outflowed by the way of Moose Jaw creek, and through a glacial lake in the upper Souris or Mouse river basin, to the Missouri near Fort Stevenson. Later the outflow from the Lake Saskatchewan may have passed to the Lake Souris by way of the Wascana river, after flowing through a glacial lake which

* U. S. Geol. Survey, Bulletin No. 40, p. 8.
† Compare with Mr. J. B. Tyrrell's paper in Bull. Geol. Soc. Am., vol. 1, pp. 401, 403.

probably extended from Regina sixty miles to the westward in the upper Qu'Appelle basin.

Through the whole period of the existence of the Lake Souris, which at first outflowed to the Missouri and afterward to Lake Agassiz, the glacial lake in the basin of the South Saskatchewan, doubtless also at last including the North Saskatchewan, was tributary to it, and the outlet of this Lake Saskatchewan was transferred to lower courses as the border of the ice-sheet receded from southwest to northeast. When the upper part of the Qu'Appelle became uncovered, but its lower portion remained enveloped by the ice, the Saskatchewan outflow probably passed to Lake Souris successively by the Moose Jaw creek and the upper Souris, by the Wascana and the Moose Mountain creek, and by the Summerberry and Pipestone creeks. Finally the whole length of the Qu'Appelle was uncovered, and the great glacial river from Lake Saskatchewan flowed along the course of this valley. At first this river crossed the divide between the River that Turns and the head of the Qu'Appelle, where it eroded a trough-like channel; but later it probably found a lower outlet farther north, flowing southward to the Qu'Appelle through the valley of Long or Last Mountain lake.

A noteworthy feature of many of the old water-courses which were outlets of glacial lakes, then carrying a much greater volume of water than now, is the occurrence of long and narrow lakes in such valleys, of which Long lake in Assiniboia, lying on the west side of a high remnant of the eroded Cretaceous strata called Last mountain, is a conspicuous example. This lake is about fifty miles long from south to north and one to two miles wide. Its southern end is separated from the Qu'Appelle river by alluvial deposits only a few feet above Long lake, which have been brought into the valley since its great glacial river ceased. Similarly the Qu'Appelle valley has been partly refilled by the postglacial deposits of its tributaries, and the present stream in its course through the Fishing lakes flows at a level about sixty feet above the bed of the outlet from the glacial Lake Saskatchewan. The table on page 252, compiled from Hind's Report of the Assiniboine and Saskatchewan Exploring Expedition, brings into view the remarkable topographic features of this valley, and shows the lengths and maximum depths of the lakes through which the river flows. Its elevations are referred to sea level, approximately, by comparison with the Canadian Pacific railway.

Other rivers which thus flow through lakes produced by postglacial alluvium in the beds of the outlets of glacial lakes, are the James river, formerly the outlet of Lake Souris; the Pembina river, which, with Lang's valley, afforded a later outlet from Lake Souris, now marked by Pelican, Rock, and Swan lakes, besides several other lakes of small size; the Minnesota river, with Brown's valley, by which Lake Agassiz outflowed where now lie lakes Traverse and Big Stone and Lac qui Parle; the St. Croix river and Lake

St. Croix, formerly the course of drainage from the west part of Lake Superior, when that lake was held 500 feet higher than now by the barrier of the receding ice-sheet; and the Illinois river, the outlet of the glacial Lake Michigan, flowing through Lake Peoria.

Elevations along the Qu'Appelle Valley (Outlet of Lake Saskatchewan).

Locality.	Miles from Elbow of the South Saskatchewan.	Feet above the sea.	Maximum depths of lakes in feet.	Height of bluffs in feet.
Elbow of the South Saskatchewan	0	1619		140
Ponds on the River that Turns	7–8	1686	about 10	110
Height of land	12	1704		110–140
Sand Hill or Eyebrow lake	24–28	1685	about 20	115–150
Buffalo lake	58–74	1635	about 20	190
Lake	83–84	1624	about 15	185
Fourth Fishing lake	135–144	1504	54	270
Third Fishing lake	144–149	1503	57	270
Second Fishing lake	150–153	1501	48	275
First Fishing lake	154–160	1500	66	300–350
Crooked lake	198–203	1389	36	300–320
Round lake	218–223	1364	30	310
Mouth of the Qu'Appelle	268	1264		220

Manitoba and Keewatin.—Lake Agassiz, the largest of all the glacial lakes of North America, occupying the basin of the Red river of the North and Lake Winnipeg, covered the greater part of Manitoba and a considerable area of eastern Saskatchewan and southwestern Keewatin. The length of Lake Agassiz from south to north extends across nine degrees of latitude, from its mouth at Lake Traverse on the western line of Minnesota, below latitude 46°, to an undetermined northern limit on the Nelson river probably north of latitude 55°. On the east Lake Agassiz covered the present sites of Rainy lake and Lake of the Woods, and on the west it washed the bases of Pembina, Riding and Duck mountains and the Porcupine and Pasquia hills, reaching on the Assiniboine to Brandon, and on the Saskatchewan to the vicinity of Prince Albert, some forty miles west of the junction of the North Saskatchewan and South Saskatchewan rivers. Its area was about 110,000 square miles, or more than the combined areas of the five great lakes which outflow by the St. Lawrence. At the time of the formation of its highest beach, the depth of Lake Agassiz above Fargo and Moorhead was nearly 200 feet; above Grand Forks and Crookston, a little more than 300 feet; above Pembina, Saint Vincent, and Emerson, on the international boundary, about 450 feet; above Winnipeg, about 550 feet; and above the central part of Lake Winnipeg and the north end of Lake Manitoba, respectively about 750 and 650 feet.

The highest shore of Lake Agassiz, very distinctly marked by beach ridges and rarely by low eroded cliffs, I have traced with levelling along an extent of about 600 miles in Minnesota, North Dakota, and southern Manitoba; and Mr. J. B. Tyrrell, of the Canadian Geological Survey, has extended this examination a hundred miles farther northward, along the escarpments of Riding and Duck mountains. The mouth of Lake Agassiz at its highest stage was 1,055 feet above the present sea level, and the highest observed portion of its shore line, reported by Tyrrell near latitude 52° on the northern part of Duck mountain, has an elevation of about 1,460 feet. Along the distance of 400 miles from the southern end and mouth of Lake Agassiz to the north end of Duck mountain, its highest shore thus ascends 400 feet; and the rate of ascent is somewhat uniformly about one foot per mile through the entire distance. This glacial lake has an outlet 125 to 150 feet deep and about one and a half miles wide, called Brown's valley, crossing the continental water-shed where lakes Traverse and Big Stone now outflow respectively to the north and south; and the glacial river which discharged the overflow of Lake Agassiz along this channel and the present course of the Minnesota river has been named the River Warren, in honor of Gen. G. K. Warren, who carefully surveyed the whole extent of the valley and rightly explained its origin. The very extensive delta deposits of gravel and sand brought into Lake Agassiz by the Sheyenne, Pembina, Assiniboine, and other rivers, and the associated lacustrine sediments of fine silt spread farther over the lake bed, will be noticed in a later part of this paper, which relates to the departure of the ice-sheet and its contributions of englacial drift to these deltas.*

The glacial Lake Souris, occupying the basin of the Souris or Mouse river from the most southern portion of this river's loop in North Dakota to its elbow in Manitoba, where it turns sharply northward and passes through the Tiger hills, outflowed in its earliest stage, as already noted, by the James river to the Missouri; and later to Lake Agassiz by successively lower outlets, first along the Sheyenne, and last of all by the way of Lang's valley and the Pembina river. North of the Souris basin, an arm of Lake Souris extended along the Assiniboine from Griswold and Oak Lake to some distance above the mouth of the Qu'Appelle; and the main body of the lake was deeply indented on the east by the high oval area of Turtle mountain, an outlier of the lignite-bearing Laramie formation, which is well developed on

* Detailed reports on Lake Agassiz are published by the Geological and Natural History Survey of Minnesota, Eighth and Eleventh annual reports, and Final report, vols. I and II; by the U. S. Geological Survey, Bulletin No. 39; and by the Geological and Natural History Survey of Canada, Annual report, new series, vol. IV, part E. More full descriptions and discussion of this glacial lake, now in preparation, will form a monograph of the U. S. Geol. Survey.

the upper part of the Souris river and forms, with overlying drift deposits, the massive terrace of the Coteau du Missouri on the west. The length of Lake Souris was about 170 miles, from latitude 48° to latitude 50° 35′ ; and its maximum width, north of Turtle mountain, was nearly 70 miles.

When the ice-sheet west of Lake Agassiz had receded so far as to uncover Turtle mountain, the outflow from Lake Souris passed north of this mountain by the Pembina, perhaps after taking for a brief time the course of the Clearwater river, Lac des Roches, and the Mauvaise coulée to Devil's lake and the Sheyenne. The channel of outlet by the Pembina, extending about 110 miles from the elbow of the Souris to the Pembina delta of Lake Agassiz, is eroded 100 to 300 feet in depth, probably averaging 175 feet, along the greater part of its course; but it is from 300 to 450 feet deep, probably averaging 350 feet, along its last twenty-five miles. Its average width in each of these portions is about one mile. It is cut through the plateau of Fort Pierre shale that reaches westward from the Pembina mountain escarpment. Outside of this valley the shale is overlain by only a thin sheet of till, which varies generally from 10 to 30 or 40 feet in thickness; but the valley itself contains a considerably greater depth of till. From lakes Lorne and Louise to its delta the Pembina probably flows in its preglacial and interglacial course, where its old valley became wholly or partly filled with till in each of the glacial epochs. The topographic features of this valley will be more fully shown by the notes of approximate elevations referred to the sea level on page 255; those of the first column being in the bottom of the valley, and those of the second along the top of its bluffs at the general level of the adjoining country.

At the Mowbray bridge the bottom land is about an eighth of a mile wide and ten feet above the river. About forty feet higher is a narrow terrace of modified drift, an eighth to a fourth of a mile wide, reaching along the southern side of the river for one and a half miles to the east, and also well shown in many places on each side of the river for six miles or more both to the west and east; but along much of this distance one or both sides of the valley slope gradually from 100 or 75 feet above the river to the bottom land. The higher portions of the sides or bluffs of the valley have steep slopes, rarely interrupted by terraces. But a remarkably broad terrace or plateau, evidently formed during the preglacial or interglacial erosion of this valley, extends on its southern side three miles to the east from the Mowbray bridge and road, with a maximum width of about one and a half miles, and an elevation of 1,450 to 1,425 feet above the sea, or about 200 feet above the river. A lakelet half a mile long from east to west lies on the southern part of this plateau at the foot of the bluff that rises thence about 100 feet to the general level of the adjoining country. All the way for twenty-five miles from this bridge to the Pembina delta, especially in the vicinity of the fish trap, the

Elevations along the Pembina Valley (Outlet of Lake Souris).

Locality.	Distance in miles from the Elbow of the Souris.	Feet above the sea, for bottom of the valley, and surface of water in rivers and lakes.	Do., top of the bluffs enclosing the valley.
Elbow of the Souris, in a valley that has been eroded about 100 feet by the present river flowing to the Assiniboine, since the glacial Lake Souris ceased to outflow to the Pembina by Lang's valley	0	1265	1475
Divide in Lang's valley, near the line between sections 31 and 32, T. 5, R. 17, Manitoba, separating Lang's creek flowing west to the Souris and Dunlop's creek flowing east to the Pembina, determined by railway survey	4	1364	1475
Bone lake, three miles long and a half mile wide	5– 8	1357	1480
Grass lake	10–11	1355	1485
Pelican lake, ten miles long and about a mile wide, mostly 10 to 15 feet deep, but in its deepest portions about 20 feet, rising three feet between its lowest and highest stages	11–21	1355	1485–1510
Junction of outlet of Pelican lake with the Pembina	22½	1348	1510
Lake Lorne, area about one mile square, maximum depth about 8 feet	23–24	1346	1510
Lake Louise, of nearly the same area and maximum depth	25–26	1345	1510
Mouth of Badger creek	27	1343	1510
Rock lake, eight miles long and one half to one mile wide, maximum depth, 10 feet*	30–38	1335	1510–1550
Mouth of Clearwater river	40	1332	1525
At the Marringhurst bridge, on the north line of section 16, T. 3, R. 12, Manitoba	42	1330	1480
Swan lake, five miles long and one mile wide, maximum depth probably about 10 feet	50–55	1310	1500
At La Riviére, determined by railway survey	67	1287	1550
At crossing of the Boundary Commission road†	75	1265	1550
At crossing of the old Missouri trail	80	1250	1545
At the Mowbray bridge, on the line between sections 21 and 22, T. 1, R. 8, Manitoba	85	1235	1540
On the international boundary	100	1125	1540
At the fish trap, section 30, T. 163, R. 57, North Dakota, two miles west of the Pembina mountain escarpment and seven miles west of Walhalla	108	1050	1400–1500

* Glenora prairie, north of Rock lake, a slightly undulating expanse of modified drift, stratified gravel and sand, extending six miles from west to east and two to three miles wide, has an elevation of 1510 to 1500 feet, descending eastward with the valley.

† Dr. Dawson notes a wide terrace here, in some places thickly strown with bowlders, on the southwestern side of the river and about 200 feet above it; and he refers its origin to preglacial erosion of the valley.

river flows in a very picturesque valley, whose sides, rising steeply 300 to 450 feet, are roughly seamed and cleft by tributary ravines and gorges, with here and there hills and small plateaus that have been left isolated by the process of erosion. This valley has frequent exposures of the Fort Pierre shales, which also within a half mile to one mile back from the river form the high plateau through which the river has cut its way. The narrowness and depth of the partially drift-filled valley indicate that its area of drainage was no greater in preglacial time than now.

The mouth of Lake Souris where it first outflowed to Lake Agassiz by the Big coulée and the Sheyenne was approximately 1,600 to 1,500 feet above the present sea level, being gradually cut down about a hundred feet by the stream. But on account of subsequent changes which are known to have taken place in the relative elevation of the land and water surfaces in this district, the shore line of the northern part of the lake at the end of its time of outflow to the Sheyenne would now have an elevation of about 1,600 feet at Lang's valley. Therefore, when its channel of discharge was transferred to the new course by Pelican lake and along the Pembina, the Lake Souris was suddenly lowered about 125 feet to the level of the top of the bluffs of Lang's valley, and a further lowering of 110 feet was afterward effected by the gradual erosion of this valley. The lake was wholly drained by this outlet, for the general level of the land adjoining the Souris in the vicinity of the mouth of Plum creek, which is the lowest portion of the lake bed, is about twenty feet above the present divide in Lang's valley. Since the waters of the Souris ceased to flow along this course, the sediments of gravel and sand brought by tributaries have filled portions of the Pembina valley 10 to 20 feet, forming the barriers of its shallow lakes; and the divide in Lang's valley has been raised probably ten feet by the deposits of Dunlop's creek.

Seventeen shore lines of Lake Agassiz are recognized in descending order, which were formed while this great glacial lake outflowed southward by Lakes Traverse and Big Stone; and eleven lower shore lines record later pauses in the declining lake level, while it outflowed northeastward across the south part of Keewatin. Perhaps at first this northerly outflow was turned eastward and then southward, passing along the border of the receding ice-sheet which still covered the area of Hudson's bay, and eventually flowing through lakes Superior and Michigan to the Mississippi. When the ice upon Hudson's and James's bays and the adjoining country was so far melted as to admit the ocean there, it at first covered the land west of James's bay 350 to 500 feet above the present sea level. Lake Agassiz, and the numerous glacial lakes which had existed in the basins of the Moose, Albany, and other rivers tributary to James's bay, were then drained northward into this inland sea. An early northeastward outflow from Lake Agassiz probably crossed the water-shed between the Poplar and Severn; and later outlets were found along lower courses, including the canoe route by the Hill and Hayes rivers. Each of the successive outlets was probably eroded to a considerable depth, being occupied by the outflowing river during the time of formation of two or more beaches, until the retreat of the southeastern border of the portion of the ice-sheet remaining west of Hudson's bay finally permitted drainage to take the course of the Nelson, the ice-dammed Lake Agassiz being thus changed to Lake Winnipeg.

Within the time after the ice-sheet had retreated beyond the valley of the lower Saskatchewan, and before its melting upon Hudson's bay permitted Lake Agassiz to gain an outlet northeastward to the sea, it seems certain that the ice must have been melted upon a large region north of the Saskatchewan basin, where drainage now passes east by the Churchill and north by the Mackenzie, but was then pent up in lakes by the ice-barrier and caused to flow to the south. Lake Agassiz thus received the waters of the upper Churchill, and of the basins of the Athabasca and Peace rivers, the great head streams of the Mackenzie; and the Churchill, and probably also the upper Mackenzie basin, continued to be tributary to this lake through all its lower stages of outflow to Hudson's bay.

Extensive areas bordering the Peace river are described by Dr. Dawson as "covered superficially by fine silty deposits resembling those of the Red river valley, and doubtless indicating a former great lake or extension of the sea in the time immediately succeeding the glacial period."* The exploration of ancient shore-lines is very difficult in that generally forest-covered region, and it must be many years before the boundaries and outlets of former bodies of water in the basins of the Peace and Athabasca rivers can be mapped; but it may be predicted with reasonable confidence that these basins, now drained to the Mackenzie and the Arctic ocean, will some time be found to have contained glacial lakes outflowing southeastward to Lake Agassiz. Probably the earliest outlet from the glacial lake of the Peace river was across the water-sheds to Lesser Slave lake and to the North Saskatchewan at its eastward bend about fifty miles below Edmonton; and the latest outflow from the Athabasca glacial lake appears to have formed a channel across the continental divide near the famous Methy portage.

The water-course by which the Churchill, bringing the Athabasca outflow, passed into the Saskatchewan, tributary to Lake Agassiz, extends southeastward about a hundred miles by Lake of the Woods, Pelican, Heron and Birch lakes, Great and Ridge rivers, Beaver, Sturgeon and Pine Island lakes, to the Saskatchewan at Cumberland house. This was the route of Franklin and Richardson in 1820. The latter states that "by Beaver

* Descriptive Sketch of the Physical Geography and Geology of the Dominion of Canada, 1884, p. 32.

lake and its chain of waters, Nelson river receives supplies from the very banks of the Missinippi or Churchill river. Indeed, the Beaver lake chain, which lay in our route, originates within a hundred yards of the latter stream." Frog portage, at this locality, " is three hundred and eighty paces long. The path leads through a low swampy wood, and over a flat tract of gneiss rising only a few feet above the waters on each side." The further descriptions of their journey up the Churchill river, which " resembles a chain of lakes with many arms, more than a river," and by Isle à la Crosse lake, Deep river, Clear and Buffalo lakes, and Methy river and lake to Methy portage, indicate that this was at one time the avenue of outflow from a glacial lake in the Mackenzie basin.*

Ontario.—The province of Ontario, extending from the mouth of the Ottawa westward to Lake of the Woods and from the great Laurentian lakes northward to Albany river and James's bay, presents a most admirable field for the exploration of glacial lake shores, deltas, and channels across water-sheds. The recession of the ice-sheet was in general from the southwest and south toward the northeast and north. As soon as its border was withdrawn across the various parts of the water-shed south of the Laurentian lakes, each considerable stream valley and embayment between the height of land and the ice-front held a glacial lake. Doubtless hundreds of channels may be traced where these lakes outflowed. But the continuing glacial retreat merged these minor lakes into a few of large size, overflowing at the lowest passes. Portions of the Canadian shores of these glacial representatives of the present Laurentian lakes are recorded by eroded cliffs, beach ridges, deltas, and lacustrine sediments; but along other portions of their boundary, where they were held in by the receding ice-barrier on the northeast and north, the land shows no shore erosion nor beach deposits.

From the western part of the basin of Lake Superior a glacial lake outflowed to the Mississippi at the lowest point of the present water-shed between the Bois Brulé and Saint Croix rivers in northwestern Wisconsin. The bed of the old outlet is 1,070 feet above the sea, or 468 feet above Lake Superior; and it is bordered by bluffs about 75 feet high, showing that when the course of outflow began here the West Superior glacial lake was approximately 550 feet above the present lake level. Silts referable to this glacial lake are found near Superior and Duluth, and its delta deposits and shore lines are traceable here and there along the northwestern shore of Lake Superior in Minnesota, but it may well be doubted whether they extend into Canadian territory. Before the ice-sheet had retreated so far as to uncover the region about Port Arthur, its departure from Wisconsin and Michigan had probably permitted Lake Superior to become confluent with Lake Michigan over

* Narrative of a Journey to the shores of the Polar Sea, in the years 1819, '20, '21 and '22, by John Franklin, Captain R. N., F. R. S.; including an appendix of Geognostical Observations by John Richardson, M. D., Surgeon to the Expedition. Also, Sir John Richardson's Arctic Expedition in Search of Sir John Franklin.

the low divide of the Au Train and Whitefish rivers, the latter of which is tributary to Little bay de Noc. The series of beaches observed north of Lake Superior at a locality near the Petits Écrits, between Nipigon bay and the Slate islands, at heights in descending order 331, 267, 259, 224, 90, 40, and 30 feet above the lake,* are apparently referable, for the highest, to a time when Lake Superior was confluent with the adjacent great lakes, with outlet by Chicago to the Illinois river, and, for the lower levels, to later stages of separate existence of Lake Superior, with discharge by a river, probably at first crossing the Au Train water-shed, but afterward, during the formation of the three beaches at and below 90 feet, outflowing by the present mouth at the Sault Ste. Marie. Like the beaches of Lake Agassiz, this series seems to indicate that the departure of the ice was followed by a northward uplift of the land.

Beaches of sand and gravel occur on Owen Sound, at the southwestern side of Georgian bay, about 200, 150, and 120 feet above Lake Huron, or about 780, 730, and 700 feet above the sea.† These probably belong to a stage of the glacial retreat when a vast confluent glacial lake, which Spencer has named Lake Warren, stretched from the western end of the basin of Lake Ontario over the whole or the greater part of the four higher Laurentian lakes. During the glacial retreat from Lake Michigan and the western portion of Lake Erie, each of these areas had an outlet to the Mississippi; that of Lake Michigan crossing the height of land close west of Chicago, only twelve or fifteen feet above the lake and approximately 595 feet above the sea, while the outflow from Lake Erie passed over the lowest point of the water-shed between the Maumee and the Wabash, 770 feet above the present sea level. The departure of the ice from the southern peninsula of Michigan, however, gave to the glacial Lake Erie, with its extension northward over Lake St. Clair and the southern end of Lake Huron, a lower outlet across the water-shed of the Shiawassee and Grand rivers, allowing the glacial lake Erie-Huron to flow into the glacial Lake Michigan by a pass which is now 729 feet above the sea. Soon after this, and apparently previous to the dates of the Owen Sound beaches, Lake Erie-Huron was further lowered by the recession of the ice from the Strait of Mackinaw; and the fully extended Lake Warren, probably holding one level through connecting straits from lakes Ontario and Erie to Lake Superior, discharged its surplus waters by the Chicago outlet. If the correlations here indicated are true, the differential uplift of portions of the shores of Lake Warren, toward the north, northeast, and east-northeast, above its Chicago outlet, has been approximately 338 feet near the middle of the north side of Lake Superior, 185 feet on Owen Sound, and about 265 feet near the eastern end of Lake Erie, where

* Geological Survey of Canada, Report of Progress to 1863, p 913.
† Ibid., p. 912.

Gilbert finds a beach of this glacial lake 860 feet above the sea. Doubtless a distinct series of these beaches is traceable upon the southwestern part of Ontario from near Toronto and Hamilton westward and northward to Georgian bay, marking pauses in the uplifting of the country while the ice-barrier still occupied a large part of Lake Ontario and turned the glacial drainage of this whole district into the Mississippi.

The further stages of the glacial recession, uncovering an outlet from the Lake Ontario basin by Rome to the Mohawk and Hudson, and the history of the Niagara river and of the glacial Lake Ontario, have been ably discussed by Gilbert. On a different theory, not recognizing an ice-sheet and referring the high ancient beaches of this basin to marine submergence, the same field has also been elaborately and ably studied by Spencer. According to the glacial theory held by Gilbert, which seems to me the true one, while the retiring ice-sheet still rested against the Adirondack mountains and thence stretched across the St. Lawrence valley to the Laurentide highlands north of Montreal and Quebec, the glacial Lake Ontario, outflowing at Rome, formed a well marked beach which Gilbert has mapped, with determinations of its height by levelling, from the Niagara river east to Rome and north to the vicinity of Watertown. The Canadian portion of this beach, surrounding the western end of Lake Ontario and running along its northern side to the vicinity of Belleville, has been similarly traced by Spencer, who has given to the beach and lake the names "Iroquois beach" and "Lake Iroquois." The height of Lake Ontario is 247 feet; and that of the old outlet crossing the water-shed at Rome is 440 feet, above the sea level. Thence the beach in its course northward adjacent to the eastern end of Lake Ontario has a gradual ascent of about five feet per mile along a distance of 55 miles northward to the latitude of Watertown, where the highest beach is 730 feet above the sea, showing that a differential uplift of about 290 feet has taken place, in comparison with the Rome outlet. From Rome westward to Rochester, the beach has nearly the same height with the outlet; but farther westward it descends to 385 feet above the sea at Lewiston and 363 feet at Hamilton, at the western end of Lake Ontario. Continuing along the beach north of the lake, the same elevation with the Rome outlet is reached near Toronto, and thence east-northeastward an uplift is found, similar to that before noted east of the lake, its amount near Trenton and Belleville above Rome being about 240 feet.

Only two surfaces of former levels, which are supplied by the old shores of Lakes Warren and Iroquois, conduct us from Chicago to Watertown and the mouth of Lake Ontario. Between the level of Lake Warren at the eastern end of Lake Erie and the latest level and highest beach of Lake Iroquois at the western end of Lake Ontario, there is a vertical fall of approximately 500 feet; and from the latest in the series of several Iroquois beaches near Watertown, where they occupy a vertical range of about 80 feet, the lowest being the last formed, corresponding to the highest beach at Hamilton, there is a fall of about 400 feet to the St. Lawrence at its outflow from Lake Ontario through the Thousand Islands. These two levels, and the respective descents of 500 and 400 feet, bring us to the sea level of the Champlain epoch, or time of departure of the ice-sheet of the second Glacial epoch, which was the barrier of these glacial lakes; for fossiliferous marine beds overlying the till extend inland along the St. Lawrence valley to Ogdensburgh and Brockville, close below the Thousand Islands and at the same level, within a few feet, as Lake Ontario. From Lake Warren to the Champlain ocean we thus have an apparent descent of 900 feet. But the first and third of the levels which are thus brought into close geographic correlation, namely, Lake Warren, Lake Iroquois, and the sea, are separated chronologically by the time of the existence of the intermediate Lake Iroquois, and we must seek to eliminate the changes of levels which occurred within that time.

If the earliest beach of Lake Iroquois had been taken for this comparison there would have been 50 feet more of fall from the level of Lake Warren at the western end of Lake Ontario, and 80 feet more of fall from Lake Iroquois to the sea. The 130 feet thus found measures the differential rise of the area of Lake Ontario during the early part of the time between the dates of Lake Warren and of the sea at Ogdensburgh. But this differential uplifting meanwhile affected the whole lake region, extending westward over the area that had been occupied by the glacial Lake Warren; and it is probable, as shown by the beaches of Lake Agassiz, that the greater part, indeed nearly all, of the 265 feet of gradual change in levels between Chicago and the eastern end of Lake Erie took place during the time of the glacial Lake Iroquois, and previous to the time of the sea level in the St. Lawrence valley with which Chicago and Lake Warren are compared. There was also a small amount of differential rise of the Ontario basin during the latter part of the time of the glacial Lake Iroquois, between the formation of its latest beach with outflow by Rome to the Mohawk and the complete departure of the ice on the area crossed by the St. Lawrence to which the ocean was then extended. To carry back our comparison of Chicago and Lake Warren with the sea level to the stage of the glacial recession when the Niagara and the Mohawk were first uncovered from the ice, we have then to subtract from the 900 feet of apparent descent an undetermined amount, which is probably at least 250 feet and very likely may be fully 300 feet. The height of the Chicago outlet above the sea level at the time of greatest extension of Lake Warren is thus found to have been 650 or 600 feet, which differs only slightly from its present height of about 595 feet. Chicago having had nearly the same elevation as now, we learn from the shore lines of

Lake Warren that the country adjoining the eastern end of Lake Erie was at that time depressed more than 200 feet, while the vicinity of Owen Sound and the region north of Lake Superior were respectively about 180 feet and about 300 feet lower than now. The Rome outlet of Lake Iroquois was at first 50 or 100 feet above the sea level, and it was uplifted to about 300 feet above the sea while it continued to be the outlet, and to probably 350 feet, lacking less than 100 feet of its present height, by the time of the extension of the sea to Ogdensburgh and Brockville.

A similar comparison of the latest beaches of Lake Agassiz with the marine submergence of the country southwest of James's bay, where the land after the withdrawal of the ice-sheet stood 350 to 500 feet below its present height, suggests that the outlet of Lake Agassiz at lakes Traverse and Big Stone was slightly lower in relation to the sea level then than it is now, perhaps by a difference of 25 or 50 feet; but probably this difference was considerably greater, amounting to 100 or 200 feet, when the earliest and highest beaches of that glacial lake were formed. In this connection it may also be remarked that the studies of Chamberlin and Salisbury on the driftless area of Wisconsin indicate a greater depression on the western than on the eastern part of that area in the closing stage of the first Glacial epoch,* just as Chicago had its present height while western Minnesota was somewhat depressed at the time of recession of the later ice-sheet.

Before leaving the Laurentian lakes, we may glance rapidly over some of the explanations of their ancient elevated shore lines which have been offered by successive writers. Mr. Thomas Roy, a civil engineer of Toronto, in a paper communicated in 1837 by Lyell to the Geological Society of London, regarded the body of water that formed the terraces and beach ridges near Toronto as an immense lake, with surface at one time about 1,000 feet above the sea, held in on all sides by formerly higher barriers of land.† But Lyell during his travels in this country in 1841–42 examined these shore lines with Mr. Roy and pronounced them to be of marine origin.‡ In 1861 Professor E. J. Chapman attributed the deposition of drift in this lake region to a marine submergence exceeding 1,500 feet, but he was unable, like all subsequent observers, to find any marine fossils. The beach ridges he referred to a very extensive fresh-water lake formed in a later epoch when the land was uplifted, the lake being supposed to be held in by a greater elevation of the country between the Adirondacks and the Laurentide highlands.§ During the same year Mr. Sandford Fleming published a detailed description and map of the Davenport ridge and terrace, which are portions of the Iroquois shore line near Toronto, referring them to the action of Lake

* U. S. Geol. Survey, Sixth Annual Report, pp. 277, 304.
† Proceedings Geol. Soc. London, vol. II, pp. 537–8.
‡ Travels in North America, vol. II, chapter xx.
§ Canadian Journal, new series, vol. VI, pp. 221–229 and 497–8.

Ontario when it stood "about 170 feet above its present level."* The Geological Survey of Canada in its valuable Report of Progress to 1863 described these "ancient beaches, terraces, and ridges," on pages 910 to 915, but presented no theory of their origin. In 1877 Mr. George J. Hinde, in a paper on the glacial and interglacial strata of Scarboro' heights and other localities near Toronto, accounted for the drift by the agency of ice-sheets during two great epochs of glaciation, separated by a long interglacial epoch which had a climate nearly like that of the present time. The Laurentian lakes at the close of the Glacial period, according to this author, were much larger than now, as shown by the old shore lines; but he is not sure whether their barrier was the receding ice-sheet or "accumulations of glacial débris which have since been removed."† The southern high shore lines of these lakes, in the United States, have been regarded by Whittlesey, Newberry, Claypole, and Gilbert, as of fresh-water formation, the lakes having been held higher than now by the ice-sheet during its departure;‡ and Spencer is the only recent writer who has examined this region and believes the beaches to be sea shores.§

The water-shed which divides the upper St. Lawrence basin from the basin of James's bay, is covered by many channels of outflows from glacial lakes pent up between that water-shed and the departing ice-sheet on the north. Kenogami or Long lake, north of Lake Superior, having a length of about fifty-four miles from northeast to southwest and a width mostly between a half mile and two miles, forming the head of Kenogami river, tributary to the Albany, occupies the channel of outlet from a glacial lake in the Albany basin, passing southward by Trout lake and Black river to Lake Superior.‖ The elevation of Kenogami lake, according to the survey of the Canadian Pacific railway, is 1,032 feet above the sea. Dr. Robert Bell states in a letter that the summit crossed by the Height of Land portage close south of this lake, and leading from it to Black river, is about seventy feet higher, being therefore approximately 1,100 feet above the sea. This portage "is about a half mile long, and is over an accumulation of well-rounded bowlders with gravel and earth filling the interspaces in part; at other parts the bowlders are piled on each other quite naked. The valley between the rocky walls is about half a mile wide. The surface is somewhat level, and there is a subordinate valley or depression sweeping around on the west side between the

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*Canadian Journal, new series, vol. VI, pp. 247–253.

†Ibid., vol. XV, pp. 388–413.

‡C. Whittlesey, "On the Fresh-water Glacial Drift of the Northwestern States," 1864, pp. 17–22: in Smithsonian Contributions, vol. XV. J. S. Newberry, in Report of the Geological Survey of Ohio, vol. II, 1874, pp. 50–65, with three maps. E. W. Claypole, "The Lake Age in Ohio," pp. 42, with four maps, in Trans. of the Geol. Soc. of Edinburgh, 1887. G. K. Gilbert, "Changes of Level of the Great Lakes," in The Forum, vol. V, June, 1888, pp. 417–428; and "History of the Niagara River," in Sixth Annual Report of the Commissioners of the State Reservation at Niagara, for 1889, pp. 61–84, with three maps.

§J. W. Spencer, "The Iroquois Beach," in Trans. Royal Society of Canada, sec. iv, 1889, pp. 121–134, with map; and "The Deformation of Iroquois Beach and Birth of Lake Ontario," in Am. Jour. Sci., 3d ser., vol. XI, Dec., 1890, pp. 443–451.

‖Geol. Survey of Canada, Report of Progress, 1871–72, p. 336.

bulk of the accumulation of boulders and the rocky bluff on that side." The ancient water-course thus described west of the portage is probably only a few feet above Kenogami lake, having very nearly the same elevation as the divide between the Missinaibi and Michipicoten rivers, some 150 miles distant to the east. Both these low points of the water-shed were doubtless occupied by rivers outflowing from glacial lakes on the north during the recession of the ice-sheet.

Missinaibi lake, near the head of Missinaibi river, the western branch of the Moose river system, is about 1,020 feet above the sea. This lake "bears S. 48° W., is twenty-four miles long, nearly straight, and varies from a half to one and a half miles in width."* Close southwest of Missinaibi lake, in the continuation of this glacial river-course, is Crooked lake, at an elevation of about 1,038 feet. "It is eight and a half miles long, and averages less than a quarter of a mile in width." Near the head of Crooked lake and only a few feet above it is the Height of Land portage, approximately 1,042 feet above the sea; and thence descending toward Lake Superior the old channel contains Dog lake, having a height of about 1,026 feet, and Mattagaming or Mattawagaming lake, which according to the Canadian Pacific railway survey is 1,025 feet above sea level.

When the Kenogami, Missinaibi, and other glacial lakes of the James's bay region became merged in one of great extent, rivalling Lake Agassiz, the outlet of this confluent lake crossed the low water-shed south of the eastern end of Lake Abittibi, passing to Lac des Quinze and Ottawa river. The elevation of Lake Abittibi, according to observations of the Canadian Geological Survey, is about 857 feet above the sea, and the portage over the water-shed rises only about 100 feet higher. Its present altitude is thus nearly a hundred feet less than that of the Kenogami and Missinaibi outlets; and it is probable that when the land was first uncovered from the ice-sheet the Abittibi outlet was relatively lower than the others by a much greater difference, and that with reference to the sea level it was much less elevated than now.

The Ottawa then received not only the overflow of a vast glacial lake in the basin of James's and Hudson's bays, but also, as Gilbert has shown, the discharge of Lakes Superior, Michigan and Huron, through Georgian bay and by Lake Nipissing and the Mattawan river. Lake Nipissing is only 58 feet above Lake Huron, or 639 feet above the sea; a low water-shed of gravel and sand divides it from Trout lake, tributary to the Mattawan; and the junction of this river with the Ottawa, distant only 100 miles from Georgian bay, is about 50 feet below that bay and lakes Huron and Michigan. But on account of the northeastward depression of the upper St. Lawrence and Ottawa basins when the ice disappeared, the avenue of dis-

*Geol. Survey of Canada, Report of Progress, 1875-76, p. 330.

charge from the upper lakes by way of Lake Nipissing was then considerably lower than either their earlier Chicago outlet or their present outlet by Detroit and Lake Erie.

Quebec, the Eastern Provinces, the Northeast Territory, and Labrador.—Attending the retreat of the ice-sheet from New England, Quebec, and the eastern provinces, many glacial lakes of small size and short duration were formed on areas declining toward the north or northwest, as in the valley of the Contoocook river in New Hampshire;* on the western flanks of the Green Mountain range in Vermont, where Mr. C. L. Whittle informs me that delta deposits of such origin occur up to heights of fully 2,000 feet; on head streams of the River St. John in northern Maine; and in southern Quebec, between the Atlantic–St. Lawrence water-shed and the receding ice-front. Fewer and still smaller glacial lakes, usually leaving no well-marked records of their existence, doubtless also attended the glacial retreat in New Brunswick, Nova Scotia, Newfoundland, and Labrador. But soon the ocean-washed ice-border was melted back from the Gulf of St. Lawrence and along the broad St. Lawrence valley to Quebec and Montreal, admitting the sea to the area of Lake Champlain, which, with the Hudson valley, had been occupied during the recession of the ice by a long and narrow glacial lake, extending from near New York city to near Montreal, caused by the southward elevation and northward depression of the land.†

North of the St. Lawrence the receding ice opposed no barrier to drainage from large areas until it withdrew across the height of land dividing the St. Lawrence waters from those tributary to James's and Hudson's bays, when upon the country around Lake Mistassini and upon many other tracts glacial lakes of considerable size must have been formed. In the exploration of that region traces of these former lakes, especially of their channels crossing the water-shed, should be carefully looked for, as not the least important of our records of the ice age.

Extent and Thickness of the Ice-Sheet.

The relation of the glacial lakes to the ice-sheet leads us to inquire what were the extent and thickness of the ice, its centers of outflow, the manner of its final departure, and the areas probably occupied by its latest remnants. In connection with these inquiries, we learn much from the delta deposits of the glacial lakes, especially Lake Agassiz, concerning the outlines of the ice in its recession and the amount of its englacial drift, which was contained in the ice-sheet and was set free during its final melting.

The extreme southern limit of the glacial drift, and the division between

* Geology of New Hampshire, vol. III, 1878, pp. 103-120.
† Bull. Geol. Soc. Am., vol. 1, p. 566.

the earlier drift, belonging to the first Glacial epoch, and the later drift, belonging to the much later second Glacial epoch, have been delineated by President Chamberlin, combining the results obtained by the explorations of many observers during the past twenty-five years.* The southern margin of the drift is shown to lie wholly within the United States, excepting that it is indented at the eastern foot of the Rocky Mountain range by an angle which barely touches the 49th parallel. Dr. Dawson's more recent map of the extent of the drift in the western part of Canada, however, places the apex of this angle south of the international boundary, along which he has had exceptional opportunity for examination.† But the limit of the ice-sheet of the second Glacial epoch, to which our glacial lakes are referred, is found north of this boundary from the 104th to the 114th meridian, that is, across southern Assiniboia and Alberta, from the Coteau du Missouri to the Rocky Mountains. The abundance of lakelets held in hollows of the drift and the small amount of change in the drift contour since the departure of the ice-sheet indicate that the latest glaciation of these provinces reached south to the Wood mountain and Cypress hills and to Lake Pakowki and the upper portion of Milk river.

Including this Canadian part of the southern limit of the second ice-sheet, its course may be briefly noted as follows: From Nantucket, Martha's Vineyard, Block island, and Long island, it runs west-northwestward across northern New Jersey and northeastern Pennsylvania, to an angle near Salamanca, N. Y., about fifty miles south of Buffalo and the eastern end of Lake Erie; thence it passes southwestward into southern Ohio; thence west-northwestward and northward in numerous loops through Indiana, northeastern Illinois, and Wisconsin, to an angle less than seventy-five miles southeast of the western end of Lake Superior; thence southward to Des Moines, Iowa; thence north-northwestward to the head of the Coteau des Prairies; again southward to the Missouri river and northeastern edge of Nebraska; thence northwestward, very irregularly lobate, through South Dakota and North Dakota, to Wood mountain in the southern edge of Assiniboia; thence westward by the Cypress hills to the Rocky Mountains on the international boundary; and thence, in lobes determined by the mountainous character of the country, across northwestern Montana, the narrow northern extremity of Idaho, and the northeastern edge and the central and western parts of Washington, to the Pacific coast in the latitude of 48°, Puget sound and the Strait of Juan de Fuca being wholly inside the glaciated area.

Along the shores of British Columbia and southern Alaska the ice-sheet pushed through gaps of the Coast range and terminated in the sea from the

* U. S. Geological Survey, Seventh Annual Report, Plate VIII.
† Trans. Royal Society of Canada, vol. VIII, sec. iv, 1890, Plate II.

Strait of Juan de Fuca and Vancouver island northwestward to the vicinity of the Copper river and Prince William's sound.* But most of Alaska and a portion of the adjacent Northwest Territory of Canada had too little snowfall or were otherwise affected by climatic conditions unfavorable for glaciation. The northwestern limit of the continental ice-sheet, as determined by Russell,† McConnell,‡ and Dawson,§ passes northeastwardly from the Coast ranges about Mount St. Elias, to cross the Yukon and Pelly near the meridian 136° 15′, and thence extends nearly due north to the Arctic ocean close west of the mouth of the Mackenzie.

The scanty observations which have been gathered in the Arctic archipelago, concerning the transportation of drift from the Archean area of the Northwest Territory northward to Baring land, from the region of the Coppermine river northward to Prince of Wales strait, from North Somerset 100 miles or more toward the northwest and northeast, and from south to north in Smith sound,|| indicate that the greater part of this archipelago was enveloped by the continental ice-sheet, and that from Baffin land, North Devon, Ellesmere land, and Grinnell land, it was continuous eastward to the ice-sheet of Greenland.

On the Atlantic coast it filled Hudson strait with an eastward outflow, as determined by Dr. Robert Bell;¶ Labrador was wholly ice-covered excepting the upper portion of the mountain range south of Cape Chidley, which seventy miles from the cape attains an elevation of about 6,000 feet above the sea;** Newfoundland, enveloped by the farthest eastward portion of this ice-sheet, was glaciated radially outward into the ocean on the north, east, and south;†† and thence southwestward the border of the ice-sheet, passing beyond the shore-line of Nova Scotia, rested on the irregular submarine ridges and plateaus of the Fishing Banks, which consist of Tertiary strata more or less overspread with morainic drift deposits, extending from Newfoundland to Cape Cod and Nantucket.

The part of North America and outlying islands thus enclosed, amounting to more than 4,000,000 square miles, I believe to have been occupied by the ice-sheet of the second Glacial epoch at its time of maximum area. In the following discussion of the probable thickness of this ice-sheet, I shall endeavor to set forth my reasons for this belief, which differs from the opinions of Mr. J. B. Tyrrell, who thinks that a narrow driftless tract borders the

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*G. M. Dawson, in Quart. Jour. Geol. Soc., London, vol. XXXVII, 1881, p. 278; Trans., Roy. Soc. Can., vol. VIII, sec. IV, 1890, Plate II.

† Bull. Geol. Soc. Am., vol. I, pp. 140, 146–8.

‡ Ibid., p. 544.

§ Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, vol. III, for 1887–88, pp. 132 B and 149 B.

|| G. M. Dawson, Geol. and Nat. Hist. Survey of Canada, Annual Report, vol. II, for 1886, pp. 56-58 R.

¶ Geol. and Nat. Hist. Survey of Canada, Report of Progress, 1882-84, p. 36 DD; Annual Report, vol. IV, for 1888-89, p. 111 E.

** A. S. Packard, Memoirs of the Boston Society of Natural History, vol. I, 1866, pp. 219, 220.

†† John Milne, Quart. Jour. Geol. Soc., London, vol. XXX, 1874, pp. 725-8.

eastern base of the Rocky Mountain range in Canada,* and of Dr. G. M. Dawson, who doubts that an ice-sheet has ever existed on a much wider area stretching from the Rocky mountains far eastward across the Peace and Saskatchewan plain country nearly to Lake Athabasca and the lakes of Manitoba.† Without entering into a discussion of the methods of formation of the various drift deposits, it may make my views more readily understood to add that I agree perfectly with Mr. Tyrrell in referring all deposits of bowlder-clay or till directly to the agency of land-ice, without modification or aid by water; while Dr. Dawson, on the other hand, refers all these deposits of till to a glacio-natant origin, that is, to deposition from floating ice supplied from glaciers and borne over the till-covered areas during their submergence by lakes or the sea.

In a paper published last year,‡ I presented somewhat in detail the evidence that the ice-sheet of the second Glacial epoch covered the highest summits of the White mountains, the Green mountains, and the Adirondacks, flowing over them from the north and northwest. The thickness of this ice-sheet at the culmination of the latest glaciation of the northeastern part of our continent was about one mile over northern New England and northern New York; and Dana has shown, from the directions of striation and transportation of the drift, that over the Laurentide highlands between Montreal and Hudson's bay it had probably a thickness of fully two miles. On the east we are indebted to Professor C. H. Hitchcock for the proof that the ice-sheet overtopped Mt. Washington, 6,293 feet above the sea; and in British Columbia Dr. Dawson finds that it covered mountains 5,000 to 7,640 feet high, and he estimates that its highest central part upon that province "had an elevation of at least 7,000 feet above the mean elevation of the interior plateau, which would be equivalent to an elevation of about 10,000 feet above the present sea-level, or probably 11,000 feet above the sea-level of the time." § Between these eastern and western areas of great known thickness of the ice, as determined by the height of glacial drift and striæ on mountains, probably this ice-sheet across the the interior of Canada at one time attained a thickness of a mile or more on a central belt several hundreds of miles wide, reaching from the Rocky Mountains and the upper Mackenzie to Reindeer lake and Lake Winnipeg, the southwestern part of Hudson's bay, James's bay, the Laurentide highlands, southern Labrador, and the Gulf of St Lawrence. This proposition differs so widely from the views of the authors before cited, for the country adjoining the eastern base of the Rocky Mountains, that the evidences of its truth for that district must be definitely and particularly stated.

* Bull. Geol. Soc. Am., vol. 1, pp. 396, 400, 401.
† Trans. Roy. Soc. Canada, vol. VIII, sec. IV, pp. 54–74.
‡ Appalachia, vol. V, pp. 291–312; also in American Geologist, vol IV, 1889, pp. 165–174 and 205–216.
§ Trans. Roy. Soc. Canada, vol. VIII, sec. IV, p. 28.

The prevailing courses of glaciation and dispersal of the drift lead me to recognize, with Dr. Dawson, the existence of two central areas upon which the ice was accumulated in greater depth than elsewhere and from which consequently it flowed outward on all sides. One of these areas embraced the Laurentide highlands, James's bay, a portion of Hudson's bay, and the western part of the Archean region from lakes Superior and Winnipeg to Great Slave and Great Bear lakes. From this large northeastern or Laurentide center of outflow, the ice-sheet crept southward, eastward, and northward, to the limits of glaciation before noted. Westward the ice from this area outflowed, as I believe, to the limit of Archean boulders on or near the base of the Rocky Mountains, where I find, from Dr. Dawson's observations of the drift in Alberta and on the Peace river, that it abutted against and was confluent with ice outflowing eastward and southeastward from the Rocky Mountains. The other area whence currents of the ice-sheet flowed radially in every direction was the northern-central part of British Columbia; and the portions of the ice-sheet pouring outward respectively from these two centers have been named by Dawson the Laurentide and Cordilleran glaciers. Toward the south, west, and northwest, the Cordilleran outflow extended to the boundaries of our glaciated area; but eastward, pouring through passes of the Rocky Mountains, and in the Peace river region probably overtopping the highest summits, which there are only about 6,000 feet above the sea, the Cordilleran ice pushed across a narrow belt adjoining the mountains, to a maximum distance of nearly 100 miles, and there (on land about 2,500 feet above the sea) became confluent with the Laurentide ice, the two united currents thence passing in part to the southward and in part to the northward from the interior tract where the confluent ice was thickest.

Taking up the particular description of localites where the junction of the Laurentide and Cordilleran drift has been observed, we may begin at the international boundary and proceed northward. Laurentian erratics and drift are stated by Dawson to extend quite to the foot of the Rocky Mountains near the 49th parallel and to occur between the 49th and 50th parallels "stranded on the surface of moraines produced by the large local glaciers of the Rocky Mountains." *

In the neighborhood of Calgary, which is the western limit of Laurentian bowlders and till, Dawson reports somewhat farther westward a deposit resembling bowlder-clay, in which the stones "are entirely those of the mountains or sandstone blocks from the underlying beds." Accordingly he declares that the absence of Laurentian erratics west of Calgary is probably to be accounted for "by the existence of Rocky Mountain glaciers of sufficient size in this region to fend off the eastern glaciating agent." Again, he mentions, west of Calgary, "heavy glacial striation in a southward or southeastward

* Trans. Roy. Soc. Canada, vol. VIII, sec. IV, p. 57. American Geologist, vol. VI, Sept., 1890, p. 162.

direction * * * about thirteen miles east of the mountains, in a region of wide valleys and low foot-hills."*

On the Peace river in its course close east of the Rocky Mountains, and on its tributary, Pine river, Dawson reports drift containing a large proportion of "hard quartzite pebbles like the more resistant materials of the axial range of the Rocky Mountains. These are mingled with a preponderating number of fragments of the softer sandstones of the country, and imbedded in a whitish or cream-colored silty clay, not unlike the material representing the bowlder-clay over wide districts west of the Rocky Mountains. No Laurentian or other fragments of eastern origin were observed in this region." Continuing eastward, these drift deposits become more conspicuous, attaining in places a thickness of 150 feet. On reaching the D'Echafaud river, about 100 miles from the mountains, though "no change in the character of the drift deposits was noted, * * * Laurentian pebbles and bowlders were for the first time seen in considerable abundance * * *. East of this point * * * the surface is thickly covered with drift deposits, so much so that exposures of the underlying rocks are, as a rule, only found in the larger river valleys."† No better evidence could be desired by a glacialist, accounting for the formation of the bowlder-clay by the agency of land-ice, to demonstrate the confluence here of two currents of the ice, one flowing eastward from the Cordilleran area, and the other flowing westward from the Archean area, whose nearest portion is on Lake Athabasca, about 400 miles distant.

Near the divide between the Liard and Yukon river systems, Dawson found drift on the summit of an isolated mountain 4,300 feet above the sea and about 1,000 feet above this part of the Pacific-Arctic water-shed.‡ This, however, is on the west side of the Rocky Mountains proper, which, as defined by Dawson, constitute the northeastern marginal range of the broad mountainous Cordilleran belt. With this definition, the Rocky Mountains are intersected by the Mackenzie river south and west of Great Bear lake.

Farther northward, the Laurentide or eastern portion of the ice-sheet pushed northwestward to the extreme limit of the drift. "The till near the lower ramparts of the Mackenzie," according to Mr. R. G. McConnell, "is in approximately the same latitude as the northern boundary of the Archean area on the east, and the gneissic bowlders which it contains must have travelled either directly west or northwest in order to reach their present situation." He therefore infers that "the ice from the Archean gathering grounds to the east poured westward through the gaps and passes in the eastern flanking ranges of the Rocky Mountains until it reached the barrier

* Geol. and Nat. Hist. Survey of Canada, Report of Progress, 1882-84, pp. 146 C, 151 C; Annual Report, new series, vol. I, for 1885, p. 167 B.

† Geol. and Nat. Hist. Survey of Canada, Report of Progress, 1879-80, pp. 139, 140 B.

‡ Geol. and Nat. Hist. Survey of Canada, Annual Report, vol. III, 1887-88, p. 119 B.

formed by the main axial range, when, being unable to pass this, it was deflected northwestward in a stream from 1,500 to 2,000 feet deep down the valley of the Mackenzie and thence out to sea."*

A partial measure of the thickness of the ice-sheet on British Columbia is furnished by the elevation on the sides of mountains to which it has spread its deposits of till. These accumulations of glacial drift are noted in many places by Dr. Dawson, who however refers them to lacustrine or marine action. They reach upward to an approximately horizontal limit or terrace 1,000 to 2,500 feet or more above the general level of the country, and to heights from 3,500 feet to more than 5,000 feet above the sea. In some places their upper margin may form a true terminal moraine, marking the boundary of the ice at its maximum thickness or at some stage of pause or reädvance during its final melting. Elsewhere it is probably determined by the general upper limit to which englacial drift was carried in the ice in sufficient amount to produce by its deposition a well defined sheet of subglacial till or ground moraine. The material of the higher terraces, according to Dawson, is "identical in character with that of the general covering of bowlder-clay, or so closely alike as to be indistinguishable from it."†

During the departure of the ice-sheet, its melting was due to the influence of sunshine and rains, the latter being doubtless brought then as now by great storms sweeping across the continent in an eastward and northeastward course. In consequence the borders of the ice-sheet appear to have been pushed back generally in the same northeastward direction. Along the valley of the St. Lawrence, the glacial current, which had before passed southeastward transversely across it to the coast of New England, was during this recession of the border of the ice-sheet deflected toward the southwest, conforming to the law that the glacial motion near the edge of the ice turned perpendicularly toward its boundary.

In the latest stages of the waning ice-sheet it probably became divided into three remnants, one covering northern British Columbia and contiguous portions of the Northwest Territory and Alaska; another occupying the region west, northwest and north of Hudson's bay, stretching northward to the large islands of the Arctic ocean; and a third covering Labrador and the country north of the St. Lawrence. From the second of these areas, glacial currents moved south-southwestwardly across the Churchill river and Reindeer and Athabasca lakes, partly obliterating the earlier westward striæ, and southeastwardly across Marble island in the northwestern part of Hudson's bay. Possibly the recession and final melting of the continental ice-sheet caused it to extend over lands within the Arctic circle which had not been covered by the ice when it reached farthest south. From the melting of

* Bull. Geol. Soc. Am., vol. 1, p. 543.

† Geol. and Nat. Hist. Survey of Canada, Annual Report, vol. III, 1887-88, pp. 89, 91, 96, 119, 172 B; Trans. Roy. Soc. Canada, vol. VIII, sec. IV, p. 36.

its last remnants, moisture-laden winds doubtless carried portions of it across Baffin's bay and Davis strait to be deposited again in the ice-sheet that still covers the interior of Greenland.

Proportion of Englacial Drift supplied to the Deltas of Glacial Lakes.

Osars, kames, and terminal moraines, the comparatively loose upper part of the till, and the beds of gravel, sand and clay which form valley terraces and plains in drift-covered regions, appear to be derived from the englacial drift that had been gathered up into the ice-sheet from the surface over which it moved, especially from the sides of hills and mountains, being thence borne forward in the lower portion of the ice. My observations of the Côteau des Prairies at lakes Benton, Shaokatan, and Hendricks in southwestern Minnesota,* and of the osar at Bird's Hill, Manitoba,† indicate that the amount of englacial drift contained in certain favored portions of the ice-sheet, as near its border where conspicuous moraines were being formed, or on tracts to which glacial currents converged, was equal to a general drift sheet 30 to 40 feet thick. During the departure of the ice, its englacial drift became superficial by the melting of its upper part, until, when only a thickness of a few hundred feet or less of the ice remained, its surface was covered by the drift which it had held; and such a condition probably extended many miles back from the margin of the ice-sheet during its entire retreat from the glaciated area. The latest glacial melting and the attendant rains therefore caused much of the englacial and finally superficial drift to be washed away by streams and deposited as stratified or modified drift, some of the coarsest portions being laid down in ice-walled channels as osars and kames, but far the greater part being borne beyond the ice-margin to form flood-plains of rivers and deltas of lakes or of the sea.

The "White silts" of British Columbia were doubtless in large part derived directly from the englacial drift of the Cordilleran portion of the ice-sheet; and the relationship of the topography to the recession of the ice determined for the various districts where these silts are developed whether their deposition was fluvial or lacustrine. And the direction of glacial drainage across water-sheds affords reliable information of the course of retreat of the ice-border on the same areas. For example, the old river-bed described by Dawson as descending to the southward and westward between Dease lake, tributary by the Liard and Mackenzie to the Arctic ocean, and the Tanzilla river, tributary by the Stikine to the Pacific, proves that the ice-border there retreated northeastward.‡

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* Geology of Minnesota, vol. I, 1884, pp. 603-4.
† Geol. and Nat. Hist. Survey of Canada, Annual Report, vol. IV, 1888-89, pp. 38-40 E.
‡ Geol. and Nat. Hist. Survey of Canada, Annual Report, vol. III, 1887-88, p. 69 B.

The deltas of Lake Agassiz show that extensive contributions of silt were received in that lake from the englacial drift of the retreating ice both on the east and west; and these deposits agree with the terminal moraines of that region in indicating that against this great glacial lake the ice was melted back faster than on the adjoining land areas. On the eastern side of Lake Agassiz only the Buffalo and Sand Hill rivers brought in noteworthy deltas, but several other tributaries from the east are at the present time larger than these. No topographic or other now existing causes for this difference are discoverable; and we are left to the inference that, during the vicissitudes of the glacial recession, exceptionally large rivers poured down from the ice-surface, laden with its drift, to these deltas. Similar conditions seem also to have been largely efficient to produce the three great deltas which I have examined on the western side of Lake Agassiz, namely, the Sheyenne and Pembina deltas in North Dakota and that of the Assiniboine in Manitoba. Each of these demonstrably contains much tribute of modified drift, that is, of drift brought directly from the ice by the rivulets, brooks, and rivers formed in its melting. But this could not have taken place, if a considerable embayment in the ice-front had not been made by its more rapid melting where it was washed by the glacial lake. In like manner, the portions of the ice-border washed by the sea in the Gulf of St. Lawrence and in Hudson strait and Hudson's bay were undoubtedly melted back exceptionally fast during the departure of the ice-sheet. At the last, indeed, the ice probably became divided into Arctic and Labrador areas on opposite sides of Hudson's bay.

In closing this essay, we may profitably notice the Assiniboine delta of Lake Agassiz and attempt to estimate its proportion of modified drift as distinguished from the alluvium of ordinary river erosion. This remarkable delta of gravel and sand covers an area of about 2,000 square miles and has an estimated average depth of at least fifty feet. Its volume therefore is about twenty cubic miles, which exceeds the combined capacity of the Qu'Appelle valley, which was the outlet of the glacial Lake Saskatchewan, and the Assiniboine valley from the mouth of the Qu'Appelle to this delta. Each of these valleys has an average width of about one mile, and their depth probably averages 250 feet along their extent of about 350 miles, being eroded in drift and the underlying soft Fort Pierre shales. This was doubtless a preglacial and interglacial water-course, which became partly filled with drift in each of the principal epochs of glaciation. Much of the erosion of the upper Qu'Appelle valley during the departure of the last ice-sheet was effected by its glacial river while it emptied into the Lake Souris; and probably the lower valley and that of the Assiniboine were only filled on the average to the extent of a third or half of their depth by the drift of the last glacial epoch. The erosion of the valley therefore must have fallen far short of supplying the material of the Assiniboine delta, not to mention the fine silt and clay which were carried into the lake beyond the gravel and sand delta and may be of equal volume. Probably at least half of these lacustrine deposits were modified drift brought down by streams from the melting ice-sheet on the upper Assiniboine basin north of the mouth of the Qu'Appelle and swept forward by the strong current of the river until they could be deposited in Lake Agassiz.

DISCUSSION.

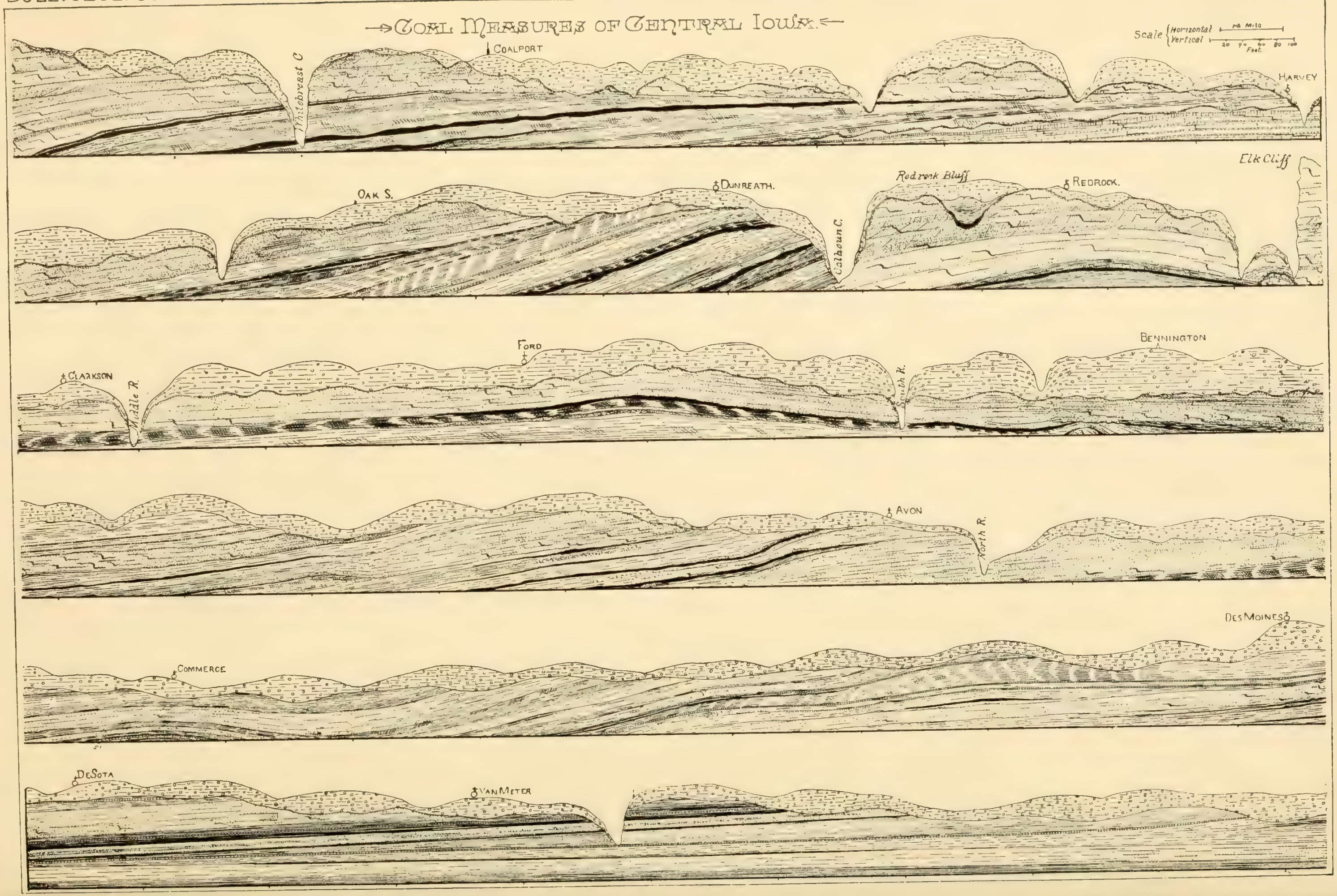
Dr. George M. Dawson: It is unfortunate that the time at Mr. Upham's disposal has been so short that he has been able to present to the Society only the outlines of his paper, but even these are sufficient to show that he has been as diligent and untiring in this as in his former publications in the collection and collation of facts. Since many of the observations quoted by him are those made by myself, it is particularly interesting to me to note how these may be reärranged under hypotheses which differ in part from those which I have suggested; and I may be permitted, even at this late period of the meeting, to refer to one or two of the points upon which he has touched.

I infer from Mr. Upham's remarks that he now believes the southern and western limit of the area of the Great Plains affected by the second maximum of glaciation to have been coëxtensive, or nearly so, with that of the first maximum. This, I am pleased to find, nearly agrees with the view which I have been led to favor and have lately advanced, viz., that the area affected by the second glaciation was even greater than that of the first in the region in question. As Mr. Upham further adopts my definition of the Laurentide and Cordilleran centers of glaciation, the most important outstanding difference in our views, in so far as the western half of the continent is concerned, is that connected with the mode of glaciation of the Canadian Great Plains. If the bowlder-clay is to be explained as the bottom-moraine of a great ice-sheet, he must be right in carrying this ice-sheet as far as the bowlder-clay extends, or, in other words, practically to the western and southern limits of the drift-covered region. My own view, based on extended opportunities of observation in the actual region, is that the bowlder-clay, like the other drift deposits of at least the greater part of the plains, is of glacio-natant origin. There is also, I think, much to show that even if the Laurentide glacier did extend across the plains to the western limit of the drift, it did not there become confluent with the Cordilleran glacier, but reached that limit at a time when the latter was comparatively reduced, and overlapped the deposits of an earlier and wider Cordilleran glaciation.

Those valleys of southern Alberta which are adopted by Mr. Upham as former channels of glacial lakes have been examined and in some cases surveyed by me, and I have elsewhere discussed their origin, mentioning the explanation advocated by the author as a possible one. It is doubtful whether our present stock of information is sufficient to enable perfectly definite or final conclusions to be reached respecting them, as they are susceptible of various explanations. Referring to Mr. Upham's allusion to the opinions expressed by Mr. Tyrrell, I believe I am right in stating that that gentleman has not advocated the existence of a driftless area along the base of the Rocky Mountains in Alberta, but rather that such eastern drift as occurs along a belt of country near the base of the mountains is to be explained as the deposit made in a lake or lakes held in there by the margin of a continental glacier.*

On the question of the meaning of the White silt formations of the British Columbian region, I need not, I think, say anything at the present time, as the general result of my examination of these deposits, with reference to the observations made over all parts of the area in which they are found, have lately been published. Nothing has since occurred to affect the general conclusions at that time provisionally arrived at, and I can scarcely accept Mr. Upham's strictly academic statement of his belief on the subject as weakening the force of such arguments as have grown up around the facts.

* Bull. Geol. Soc. Am., vol. 1, p. 401.


COAL MEASURES OF CENTRAL IOWA.
Scale {Horizontal
Vertical
Feet.
Whitebreast C
COALPORT
HARVEY
Elk Cliff
OAK S.
DUNREATH.
Calhoun C.
Red rock Bluff
REDROCK.
CLARKSON
Middle R.
FORD
South R.
BENNINGTON
AVON
North R.
DES MOINES
COMMERCE
DeSOTA
VAN METER

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STRATIGRAPHY OF THE CARBONIFEROUS IN CENTRAL IOWA.

BY CHARLES R. KEYES.

(*Read before the Society December* 31, 1890.)

CONTENTS.

INTRODUCTION.

The exposed stratified rocks of central Iowa are made up chiefly of Lower Coal Measure clays, shales, and sandstones. In the southeastern portion of the area the upper member (for Iowa) of the Sub-Carboniferous—the St. Louis limestone—is exposed along the Des Moines river. To the westward the so-called Middle Coal Measures and the Upper Coal Measures are represented. Hitherto it has been supposed that the three recognized divisions of the upper Carboniferous rocks in the state have each a maximum thickness of about two hundred feet. Lately, however, the Upper Coal Measures alone have been discovered to have at least double this estimate; and at a still later date the vertical extent of the other two formations has been found to differ very much from the limit usually assigned: the Middle Coal Measures being considerably thinner than was supposed, and the Lower Coal Measures very much thicker.

Very recently a detailed section (plate 9) was made from Harvey, in the southeastern part of Marion county, along the line of the Des Moines river to the capital city and thence up the Raccoon river to De Soto, in Dallas county, a distance of sixty-five miles. The circumstances for its construction have been made very favorable by the numerous excellent exposures afforded by railway lines that have been built nearly the entire distance on each side of the two streams. These railway cuts, taken together with the natural outcrops on the rivers, permit the stratigraphy of the district to be very satisfactorily traced in all the minor particulars.

Along the line just specified, more than two hundred exposures were examined and measured, the different beds being carefully correlated in the field by direct passage from point to point. Out of this number, ten of the most instructive and typical sections have been selected, and descriptive notes are appended, indicating the salient characters of the various strata. Each is marked on the accompanying general section, the base of which is the low-water limit in the Des Moines river. It is thought that the two methods of illustration will adequately present, in the briefest possible manner, the leading geological features of the region. The stratigraphical relations of the several beds will find further explanation beyond.

The Quaternary deposits have not yet been differentiated with sufficient care to warrant the separation, in a general section, of the drift sheets and the löss.

Description of Sections.

I. Harvey Exposure.—Quarry in S. W. qr. N. W. qr. Sec. 4, *T.* 75 *N., R.* 18 *W.*

3. Drift and löss (exposed)	10 feet.
2. Gray and ash-colored marl, with abundant fossils: *Spirifera keokuk*, Hall; *Pentremites koninckiana*, Hall; *Zaphrentis spinulifera*, Hall; *Athyris subquadrata*, Hall; *Productus marginocinctus*, Prout; and others	5 "
1. Blue limestone, weathering brown in places, thinly bedded above (exposed)	12 "

II. Coalport Section.—S. E. qr. S. W. qr. Sec. 4, *T.* 76 *N., R.* 19 *W.*

6. Heavily bedded sandstone, with lepidodendrids, sigillarids, filices and calamites below (exposed)	15 feet.
5. Dark-colored clays and shales, sandy in places	30 "
4. Coal (mined at this place)	5 "
3. Dark clays and bituminous shales	14 "
2. Coal, rather impure	2 to 3 "
1. Sandstone, very thinly bedded, and sandy shales (exposed to water's edge)	8 "

No. 6 of this section is not exposed on the river bluff at this place, but crops out in a ravine some distance inland.

III. Redrock Exposures (Plate 10).

12. Drift and löss, with characteristic fossils	20	feet.
11. Drab and yellow clayey shales	25	"
10. Coal (small basin only)	3 to 6	"
9. Fire-clay, enclosing rounded water-worn pebbles, up to one foot in diameter, of "Redrock" sandstone, most abundantly on the sloping sides of an ancient ravine	1	"
8. "Redrock" sandstone; a fine-grained, massive, yellow and red sandrock, concretionary in places, the upper surface more or less weathered and channeled; maximum thickness more than 150 feet (exposed)	55	"
7. Shale, laminated and highly bituminous	1½	"
6. Yellow sandstone, soft, fine-grained and thinly bedded	3	"
5. White sandrock, compact	1	"
4. Yellow sandstone (like number 6)	2	"
3. Highly bituminous shales, laminated and coaly above and becoming more and more coal-like westward	5	"
2. White sandstone, fine-grained, everywhere penetrated vertically by rootlets of lepidodendrids	2 to 4	"
1. Shales, ash-colored and yellow (exposed to water's edge)	20	"

Numbers 12 to 8 are shown in a quarry at Redrock bluff, in N. W. qr. N. E. qr. Sec. 35, T. 77 N., R. 20 W., and are represented in figure 1, plate 10. The rest of the section is exposed on the opposite side of the Des Moines river, in S. W. qr. Sec. 1, T. 76 N., R. 20 W.

IV. Dunreath Exposures.—N. E. qr. Sec. 28, *T.* 77 *N., R.* 20 *W.*

15. Quaternary deposits	20	feet.
14. Clayey and sandy shales (exposed)	25	"
13. Dark clayey slate, with abundant ferns at base	10	"
12. Coal	5	"
11. Fire-clay	1½	"
10. Clayey and sandy shales	45	"
9. Sandstone, massive and compact, in two layers, separated by a soft, sandy seam and a thin bituminous bed, with abundant calamites and a few lepidodendrids	5	"
8. Dark shales, clayey and sandy	6	"
7. Bituminous shales	6	"
6. Coal, impure in places	6	"
5. White fire-clay	4	"
4. Dark clayey shales	6	"
3. Thinly bedded clayey sandstone, with numerous lens-shaped septarial concretions up to four feet in diameter	7	"
2. Bituminous shales	3	"
1. Dark-colored sandy and clayey shales (exposed)	45	"

V. Bennington Section.—S. E. qr. N. W. qr. Sec. 9, T. 77 N., R. 21 W.

7. Löss and stratified drift	47 feet.
6. Yellow sandstone, thinly bedded	20 "
5. Blue sandstone, with a layer of white clay	1½ "
4. Bituminous shale, with a compact, nodular and highly ferruginous band	6 "
3. Coal	2 "
2. Drab fire-clay	3 "
1. Sandy shales (exposed)	5 "

VI. Ford Bluff.—N. E. qr. S. E. qr. Sec. 10, T. 77 N., R. 22 W.

9. Drift and löss	10 feet.
8. Light-yellow sandstone, soft, heavily bedded above, thinly bedded below, with much clay	35 "
7. Dark shale, highly bituminous in places, with hard concretionary layer	2 "
6. Fire-clay with sigillarid roots	¼ "
5. Drab shales, somewhat sandy above	12 "
4. White clay	3 "
3. Soft sandstone, buff, heavily bedded	4 "
2. White clay	4 "
1. Sandy and clayey shales (exposed to water level)	25 "

VII. Des Moines Section.—(Several Exposures in the City of Des Moines.)

17. Variegated clayey shales	15 feet.
16. Blue earthy limestone, nodular and weathering brown; contains *Productus muricatus*, N. and P.; *Chonetes verneuilianus*, N. and P.; and *Streptorhynchus crenistriatum*, Phillips	⅔ "
15. Variegated clayey shales	8 "
14. Bituminous shales, with concretionary masses below which contain *Productus muricatus*, N. and P.; *P. cora*, d'Orb.; etc. A thin coaly seam shown in some places	3 "
13. Light-colored shales, clayey, drab and yellow	7 "
12. Variegated clay-shales	4 "
11. Nodular limestone, earthy throughout, highly fossiliferous	½ "
10. Light-colored and variegated shales	5 "
9. Impure limestone, somewhat fossiliferous	1 "
8. Light-colored clays	5 "
7. Buff-colored micaceous sandstone, concretionary in places and passing into sandy shales elsewhere	15 to 25 "
6. Light-colored shales, sandy in places	4 "
5. Coal, impure	2 "
4. Light and dark sandy shales	20 "
3. Bituminous shales, highly fossiliferous	2 "
2. Coal, rather impure	2 "
1. Fire-clay (exposed to water level)	1 "

VIII. Commerce Exposure.—S. E. qr. N. W. qr. Sec. 29, T. 78 N., R. 25 W.

6.	Drift	25 feet.
5.	Clay-shales, passing into sandy shales	20 "
4.	Buff sandstone, soft, thinly bedded	15 "
3.	Variegated clays	10 "
2.	Blue limestone, in three layers separated by partings of marl	2½ "
1.	White shales (exposed to water level)	1 "

IX. Van Meter Bluff.—S. W. qr. N. E. qr. Sec. 26, T. 78 N., R. 27 W.

14.	Drift	10 feet.
13.	Light-colored shales, clayey	7 "
12.	Compact fossiliferous limestone	1½ "
11.	Fissile bituminous shales, coaly below	1½ "
10.	Light-colored clay-shales	4 "
9.	Brown sandstone, heavily bedded, and containing abundant roots of lepidodendrids and fronds of ferns	4 "
8.	Clayey shale, sandy above	6 "
7.	Coal	½ "
6.	Variegated clays and shales	20 "
5.	Bituminous shales	2 "
4.	Fragmentary limestone	5 "
3.	Blue and gray shales	6 "
2.	Bituminous shales, with concretionary layer above	2 "
1.	Blue clayey shales (exposed)	5 "

X. De Soto Section.—N. W. qr. S. W. qr. Sec. 30, T. 78 N., R. 27 W.

14.	Drift	15 feet.
13.	Gray limestone, fossiliferous	1 "
12.	Variegated clay-shales	8 "
11.	Buff sandstone, soft, thinly bedded and shaly	30 "
10.	Blue clayey shale	5 "
9.	Limestone, compact, fossiliferous	2 "
8.	Highly bituminous shales, coaly below, with several clay partings	4 "
7.	Shaly sandstone, with highly ferruginous band above	2½ "
6.	Sandstone, compact	3 "
5.	Shaly and clayey sandstone	6 "
4.	Coal	1½ "
3.	Fire-clay	4 "
2.	Fragmentary limestone, fossiliferous	2 "
1.	Light-colored clays (exposed)	1 "

Lithological Features of the Strata.

General Characters.—In lithological characters the Coal Measures of central Iowa contrast sharply with the other Paleozoic formations of the state. Not less striking is the relative thinness, as a rule, of the individual layers, or beds, which follow and replace one another, upwards and laterally, in rapid succession. Often within a vertical distance of a few inches or a few feet, layers of sand, clay or shale are succeeded by different strata; or else are changed both in color and chemical composition. Of the three general types of rocks recognized, the argillaceous are the most prominent and most widely distributed; arenaceous deposits are developed only in much less volume; while the calcareous rocks are exceedingly unimportant and are restricted to a few thin bands, seldom more than eight or ten inches in maximum thickness.

Argillaceous Materials.—The clay-shales make up by far the greater portion of the Lower Coal Measures in Iowa. On exposure to atmospheric agencies they quickly disintegrate into soft clays and are easily carried away by running water. For the most part they are ashen, drab, or black in color, though red, yellow, buff and blue shades are of not uncommon occurrence. In some localities the variegated shales—blue, drab, red, yellow and ashen indiscriminately mingled—predominate. It is in the latter shales that crystallized gypsum frequently occurs abundantly. At Des Moines and elsewhere, diamond-shaped crystals of selenite are the more plentiful, though not infrequently some of them are greatly elongated in the direction of the vertical axis, sometimes attaining a length of eight or ten inches. In the latter habit, twinning is quite common. Often the crystals are acicular and, radiating from a center, form little rosettes, which lie in great numbers on the exposed surfaces of clays.

The light-colored shales occasionally afford impressions of ferns and lepidodendron roots, but for the most part they are unfossiliferous. The dark-colored, bituminous varieties, on the other hand, are often highly charged with organic remains. From a single locality (Des Moines) nearly one hundred species of invertebrates have been recognized, besides a number of fossil fishes and plant remains. A partial list of these organisms, with full notes, has been given in another place,* and considerable additional information of the same sort will soon appear in a form for reference.

The light-colored shales, by the gradual addition of fine, sandy material, pass imperceptibly into sandy shales, and these again into shaly sandstones and finally into hard, compact sandrock. This gradual transition may take

* Proc. Acad. Nat. Sci., Phila., 1888, pp. 222-246.

place laterally in the same horizon, or vertically from one layer to another. By a constant increase of carbonaceous matter the dark-colored shales become highly bituminous and then coaly.

The economic aspects of the Carboniferous clays and shales in the area under consideration need not be dwelt upon here. They are of such great practical importance that they form the theme of a special investigation, the results of which will soon be announced.

Arenaceous Deposits.—Although a large amount of sandy material is present in the Coal Measures of the region under consideration, it is usually mixed with clay to such an extent as actually to form sandy shales. In some cases, however, the sand constitutes a sandrock which is sufficiently compact to afford material for ordinary rough masonry. The hard portions of the sandstones are for the most part very limited, being only two or three feet in thickness; or in the form of large spherical concretions in a softer matrix. These sometimes attain a diametric measurement of five or six feet. Within the limits of the area in question there is, however, one notable exception to the general character of the arenaceous deposits, *i. e.*, the "Redrock" sandstone. This is an enormous consolidated sand bed having a geographic extent of more than twenty miles in its longest direction and at least six or seven miles in width. It rises in high mural escarpments along the Des Moines river, chiefly in Marion county. For the most part it is a rather compact, massive, homogeneous sandrock, though in places it passes into a fine-grained ferruginous conglomerate. Occasionally large spherical concretions are met with. In the upper part it becomes thinly bedded, with a considerable amount of clay intermingled. The base is rich in plant remains: lepidodendrids, sigillarids, calamites and ferns of many species. The upper surface has been subjected to sub-aërial erosive agencies, as has been fully shown in another place.* This denudation took place during the Lower Coal Measure period, since an extended coal deposit, with its associated shales, is found laid down in the old gorges of the sandstone.

In regard to this remarkable sandrock formation, the following conclusions have been reached, as fully stated elsewhere: †

(1.) It is not the basal member of the Coal Measures, as it was considered by Worthen.

(2.) It is not the shore extension of the Kaskaskia limestone, as was at one time supposed.

(3.) Its geographic extent is not so limited as it has been regarded.

(4.) The most interesting consideration is the fact of its elevation above the surface of the sea and its subjection to atmospheric influences for a long period of time before submergence again took place. During that interval

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* Am. Journ. Sci., 3d series, vol. XLI, 1891 (in press).
† *Loc cit.*

the great thickness of sandstone was probably almost entirely removed in places.

While no other arenaceous bed, within the limits of the area under consideration, is so extensive as the "Redrock" sandstone, there are numerous sandy strata of considerable importance; yet they contain a large percentage of clayey material and are more or less distinctly laminated, thus partaking more of the character of sandy shales.

Passing westward, the sandrocks appear to gradually acquire more and more clay, becoming first shaly sandstone beds, and ultimately homogeneous clay-shales with no grit whatever. Another noticeable feature in this gradual transition from a compact massive sandstone to a clayey shale is that the bed becomes thinner as the proportion of clay increases, so that, when the stratum has changed its facies completely, the argillaceous layer is perhaps only one-third or one-fourth of the maximum thickness.

Calcareous Beds.—The limestones of the Coal Measures play an unimportant part in the lithological features of the region; they consist merely of a few thin bands in the upper portion of the general section, *i. e.*, above the Lower Coal Measures, as commonly designated in this part of the state. Though seldom exceeding ten or twelve inches in thickness, these calcareous bands are the most persistent and easily recognizable, over wide areas, of any of the horizons in central Iowa. They are fragmentary or nodular, very impure from a large admixture of clayey material, and more or less highly fossiliferous.

Coal.—From an economic standpoint, the coal of the region forms by far the most important deposit. The seams vary from a few inches to seven or even eight feet in thickness; the average of the veins at present worked being between four and five feet. These are disposed, not in two or three continuous layers over the entire area, but in numerous lenticular masses from a few hundred yards to several miles in diameter. A single horizon may thus contain several of these lens-shaped beds of greater or less extent. Along the line of the general section the coal-bearing horizons have been found to number more than a score; and the extension of the investigations beyond the limits of the particular area here considered has very greatly increased this figure. Recognizing this fact, the aggregate amount of coal is far in excess of what has been supposed hitherto. The peculiarities of its disposition and the consequent popular misunderstanding concerning the actual extent and distribution of the coal beds has led to a large but useless expenditure of capital. This phase of the question will receive further expansion in another place.

Stratigraphical Relations.

The General Section.—By reference to the general section of the Coal Measures in central Iowa as illustrated in plate 9, it will be noticed that the strata have a decided general dip toward the west, and that the inclinations are more marked at the eastern part of the section than at the western. The different inclinations of the various beds appear to be due largely to conditions imposed by the original shore contours of the great Carboniferous seas rather than to the subsequent operation of orographic forces. In support of this supposition it is worthy of note that the greatest variation in the inclination of the beds is in the immediate vicinity of unconformities, such as are shown at Elk cliff, Redrock bluff and Bennington.

The stratigraphical importance of the coal seams is not so great as has been generally supposed, since the bituminous beds are, with very few exceptions, quite limited. Only a single case is at present known in which the geographic extent of a coal stratum is more than four or five miles, and for the greater part of this distance the coal is but a few inches in thickness. It follows that the coal seams of the region are not nearly so extensive as commonly supposed, and that they possess little value in general correlations.

There is an opinion prevalent among the miners of the district that there are only three workable coal horizons. These are usually designated as the "first," "second," and "third" seams. Should any subordinate seams be encountered in the sinking of a shaft, they are not taken into consideration. As a matter of fact, the "three" veins are not continuous over areas of any great extent, and may have widely different stratigraphic values, even within very short distances; the "first," "second," and "third" seams of one shaft may be entirely distinct from the similarly called seams of another mine scarcely half a mile away. A noteworthy instance for citation in this connection is a boring made near the city of Des Moines. It was two hundred feet in depth. Twelve distinct coal horizons were met, giving a total thickness of coal of thirteen and one-half feet; yet none of the beds were thick enough for profitable working. Only one-third of a mile away was a mine removing coal from two seams, one of which was from four to five feet in thickness.

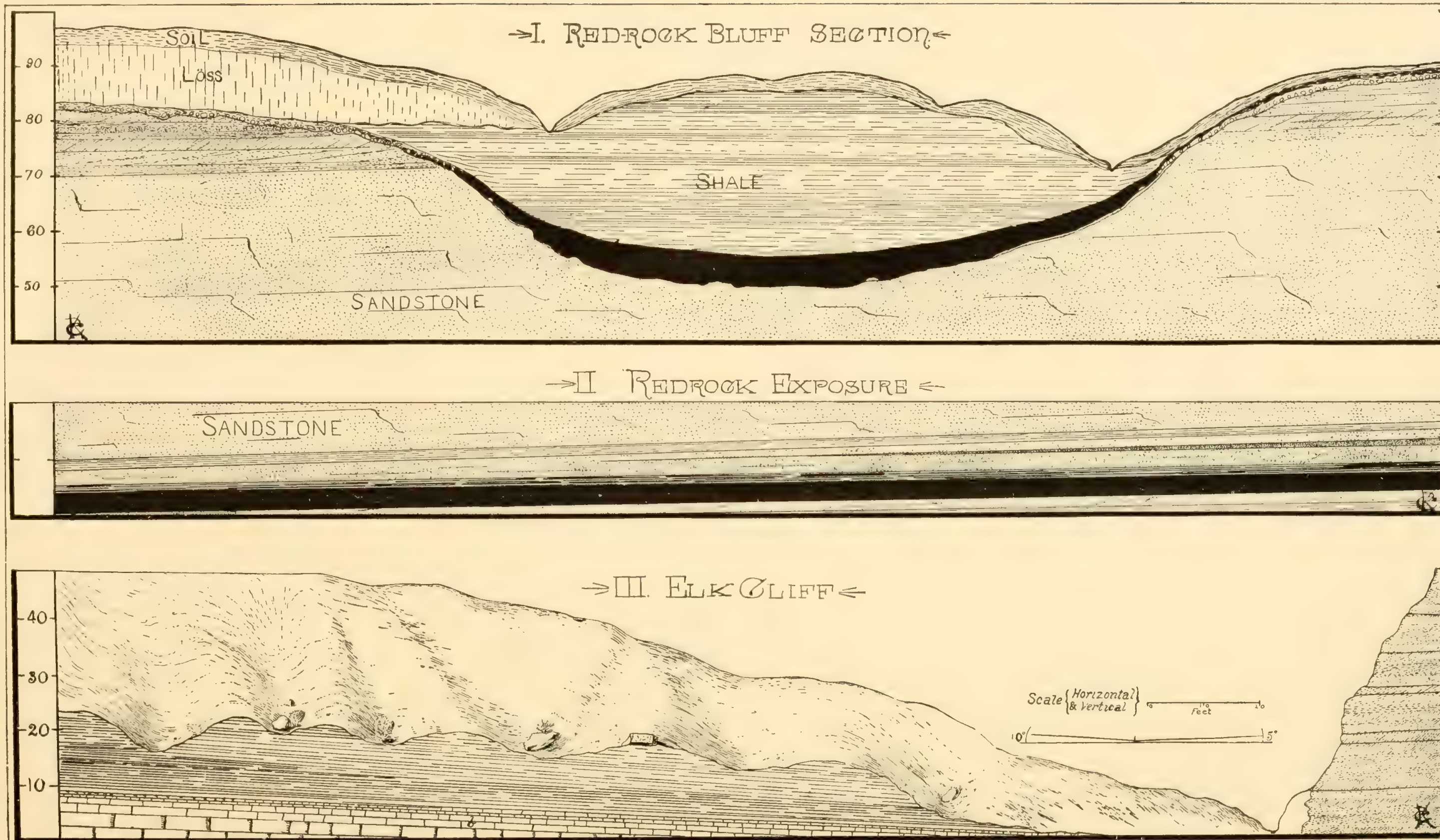
The basal coal seams in the Lower Coal Measures of Iowa appear to be much more extensive than those toward the top, where they may be only a few inches in vertical measurement and perhaps a hundred yards in extent—too small for representation in the general section. The coal may, therefore, be regarded as disposed in numerous basins of greater or less area, thickened centrally, but gradually becoming attenuated toward the margins. These are arranged in various horizons, interlocking with one another, but separated by varying thicknesses of shale or sandstone. Thus, at any one point a dozen or more seams may be passed through in sinking a shaft, only two or three perhaps being workable.

Thickness of the Lower Coal Measures.—In connection with this brief review of the leading geological features of central Iowa, as brought out by an examination of some of the natural exposures, allusion should be made to the information pertaining to the Carboniferous rocks below the datum line of the general section. While the notes already taken are quite voluminous, they are not at present in a shape suitable for presentation. All attempts to secure reliable accounts of the strata passed through in borings and the sinking of mine shafts have availed but little, since such information is almost invariably withheld by the parties in charge of the operations. For this reason the difficulties of working out the structural details of this part of the Carboniferous group were somewhat greater than they otherwise would have been; and the final results are thus considerably delayed.

As already stated, the general dip of the strata along the present line of investigation is southwestward. The mean thickness of the Lower Coal Measures, as shown by careful measurement of the various members, must originally have been considerably more than seven hundred feet. This determination was arrived at in the following way: At the most easterly exposure of the section, the distance from the St. Louis limestone to an easily recognizable bed near the top of the bluff was perhaps fifty feet in a direction normal to the dip. This particular layer was then traced to the point where it disappeared below the datum line and the measurement was repeated in the same manner as before. Of course it is not to be supposed that the present thickness of the Lower Coal Measures in central Iowa is nearly so great as the figures above given would suggest; for in reality the maximum vertical measurement of the beds is probably somewhat less than one-half that estimate. Erosion has largely removed the coal-bearing strata of the district, and therefore the original thickness of these rocks is not preserved in any one place.

Unconformities.—Perhaps the most notable feature in the consideration of the Lower Coal Measures of central Iowa is the existence of several well-marked unconformities. More than twenty years ago White* called attention to the unconformity of the Coal Measures of the state upon the St. Louis limestone, and of the latter upon the other members of the Lower Carboniferous. While the correctness of these views is very apparent in the first case, in the latter it is by no means so certain. The present investigation shows that the unconformity of the Lower Coal Measures upon the St. Louis limestone is much more pronounced than was at first suspected, and that in

* Geology of Iowa, vol. I, 1870, p. 225.



UPPER AND LOWER LIMITS OF THE REDROCK SANDSTONE.

the Lower Coal Measures there are several breaks in deposition of equal or even greater importance.

As to the relations of the upper and lower Carboniferous rocks along the line of the general section, the most instructive exposures are at Harvey and Elk cliff, two miles below the village of Redrock. At the former locality the limestone is overlain by a few feet of ash-colored, highly fossiliferous marl, whose upper surface everywhere has been disturbed by running water, while in many places gullies have been made down to the hard limestone. Upon this the Lower Coal Measure shales have been deposited. In some places at a subsequent time these have also been removed in part, and the whole is covered by drift material or löss. The Lower Coal Measure shales that immediately overlie the St. Louis rocks carry at least two workable seams of coal and supply characteristic upper Carboniferous fossils. The thickness of these shales is at least seventy-five feet before reaching the base of the Redrock sandstone. At Elk cliff, however, this sandstone apparently rests directly upon a low anticlinal fold of the St. Louis limestone, which at this place rises about fifteen feet above low water in the Des Moines river. The inference is that the limestone at this place formed a low island at the beginning of the later Carboniferous, and continued as such until the Redrock sand bed had commenced to accumulate.

The upper surface of the Redrock sandstone, however, offers the most remarkable illustration of unconformity in the region. At Redrock bluff, and above, the evidence in support of this statement is admirably exposed. Everywhere the sandrock has been worn and channelled, often to a depth of more than one hundred feet. In these narrow gorges and ravines, coal and shales have been laid down upon the rounded water-worn pebbles and small bowlders of the sandstone itself, which cover the old eroded surface.

A third noteworthy unconformity exists at the old town of Bennington, in the northwestern corner of Marion county. The inclined strata have been abruptly worn away on a line nearly parallel to the horizon ; and afterward there were deposited the materials of a shaly sandstone, which now shows no noticeable dip. It is possible that a double unconformity is represented at this place, and that the prominent coal seam rests on the worn surface of the compact massive sandstone, which is visible for a distance of ten feet above low water. In lithological characters this sandrock is in all respects identical with the Redrock sandstone, and probably it is really the summit of an eroded elevation of the great sand stratum.

There is also considerable evidence of the existence of minor unconformities, in connection with several of the coal seams, along the line of the section ; but in the absence of fresh artificial exposures their extent has not yet been satisfactorily determined.

Faunal Considerations.

An extremely interesting fauna has been disclosed along the line of the general section. It embraces some fifty genera, and between one hundred and fifty and two hundred species. A part of these have already been studied and full annotations made;* another part has also been critically examined, and the results will soon be announced; while the remainder will be subsequently considered. The special significance of these fossils lies: (1) in the great profusion of minute molluscan shells; (2) in the occurrence of a large number of species hitherto unknown within the limits of the state; and (3) in the presence of many forms which have been known from a few only or even single specimens, and from localities widely separated geographically. The peculiarities of the fauna alluded to are so striking and the biological and geological relations so important in their bearing on the geographic distribution of organisms during Carboniferous times, that a list of the species thus far identified is appended. Besides those mentioned, there are a considerable number of additional forms whose specific identity has not as yet been determined with sufficient accuracy to warrant incorporation in the present list.

Fossils from the Lower Coal Measures of Central Iowa.

PROTOZOA.

Fusulina cylindrica, Fisher.

CŒLENTERATA.

Lophophyllum proliferum, McChesney.
Rhombopora lepidodendroides, Meek.

ECHINODERMATA.

Archæocidaris edgarensis, Worthen and Miller.
Eupachycrinus, sp. und.

MOLLUSCOIDEA.

Synocladia biserialis, Swallow.
Discina nitida, Phillips.
Productus nanus, Meek and Worthen.
" *cora*, d'Orbigny.
" *muricatus*, Norwood and Pratten.

* Proc. Acad. Nat. Sci., Phila., 1888, pp. 222-246.

Chonetes mesoloba, Norwood and Pratten.
" *flemingi*, Norwood and Pratten.
" *lævis*, Keyes.
Athyris subtilita, Hall.
Lingula umbonata, Cox.
Streptorhynchus crenistriatum, Phillips.
Spirifera camerata, Morton.
" *lineata*, Martin.
" *rockymontana*, Marcou.
Retzia mormoni, Marcou.
Spiriferina kentuckensis, Shumard.
Rhynchonella uta, Marcou.

MOLLUSCA.

LAMELLIBRANCHIATA.

Myalina swallovi, McChesney.
Avicula longa, Geinitz.
Lima retifera, Shumard.
Aviculopecten coxanus, Meek and Worthen.
" *neglectus*, Geinitz.
" *whitei*, Meek.
Clinopistha radiata, Hall.
Solenomya soleniformis, Cox.
Astartella vera, Hall.
Nucula parva, McChesney.
" *ventriicosa*, Hall.
" *beyrichi*, Schlotheim.
Nuculana bellistriata, Stevens.
Schizodus alpina, Hall.
Macrodon obsoletus, Meek.
Pleurophorus permianus, Swallow.
" *subcuneatus*, Meek and Hayden.

GASTEROPODA.

Dentalium meekianum, Geinitz.
" *annulostriatum*, Meek and Worthen.
" *sublæve*, Hall.
Pleurotomaria brazoensis, Shumard.
" *modesta*, Keyes.
" *grayvillensis*, Norwood and Pratten.
" *carbonaria*, Norwood and Pratten.
" *valvatiformis*, Meek and Worthen.
" *sphærulata*, Conrad.

Bulimorpha minuta, Stevens.
" (?) *chrysalis*, Meek and Worthen.
Orthonema conica, Meek and Worthen.
Aclisina minuta, Stevens.
" *robusta*, Stevens.
Straparollus catilloides, Conrad.
" *pernodosus*, Meek and Worthen.
Bellerophon percarinatus, Conrad.
" *urii*, Fleming.
" *monfortianus*, Norwood and Pratten.
Loxonema scitula, Meek and Worthen.
" *multicosta*, Meek and Worthen.
Murchisonia quadricarinata, Worthen.
Sphærodoma medialis, Meek and Worthen.
Soleniscus newberryi, Stevens.
" *humilis*, Keyes.
" *gracilis*, Cox.
" *paludinæformis*, Hall.
Streptacis whitfieldi, Meek.
Anomphalus rotulus, Meek and Worthen.
Naticopsis nana, Meek and Worthen.
Trachydomia wheeleri, Swallow.

CEPHALOPODA.

Nautilus occidentalis, Swallow.
" *winslovi*, Meek and Worthen.
" *lasallensis*, Meek and Worthen.
Goniatites nolinensis, Cox.
Orthoceras rushensis, McChesney.
Orthoceras, sp. und.

ANTHROPODA.

Cythere nebracensis, Geinitz.
Phillipsia, sp. und.

VERTEBRATA.

Petrodus occidentalis, Newberry and Worthen.
" sp. und.
Deltodus intermedius, St. John and Worthen.
Thrinacodus duplicatus (?), Newberry and Worthen.

The large majority of these animal remains were obtained from bituminous shales immediately overlying coal seams; though nearly two scores of additional species are from the calcareous bands, *i. e.*, above the Lower Coal Measures as hitherto usually understood. The fossils of the black shales are chiefly molluscan, the lamellibranchs and gasteropods greatly predominating. All these are small forms, but they occur in vast numbers. The gasteropod shells are of particular interest, inasmuch as they represent a large number of species which have heretofore been known only from single specimens, or from the individuals upon which the species were founded. The peculiar significance attached to these shells will therefore require special consideration elsewhere.

The cephalopods, though not abundant, represent several important types. Among these may be mentioned *Nautilus,* which attained a diameter of no less than eight inches; *Orthoceras,* which reached a length of more than two feet, with a diametric measurement at the larger end of two inches; *Goniotites;* and a single *Cyrtoceras.*

A striking feature of the fauna of the Lower Coal Measures of central Iowa is the marked absence of strictly marine forms. In cases in which the latter do occur they are usually depauperate, attesting an environment very unfavorable to their complete development. On the other hand, the true mollusks, although for the most part small forms, are all of normal size, or in some instances even much larger than the average.

Résumé.

Summing up the more salient features in the present preliminary consideration of the Coal Measures of central Iowa, it may be said that:

1. The Lower Coal Measures of the state are very much thicker than has been hitherto supposed.

2. The so-called "Middle" Coal Measures are not so extensive, vertically, as was once supposed; and the designation as a formation name is of very doubtful utility, at least in so far as Iowa is concerned.

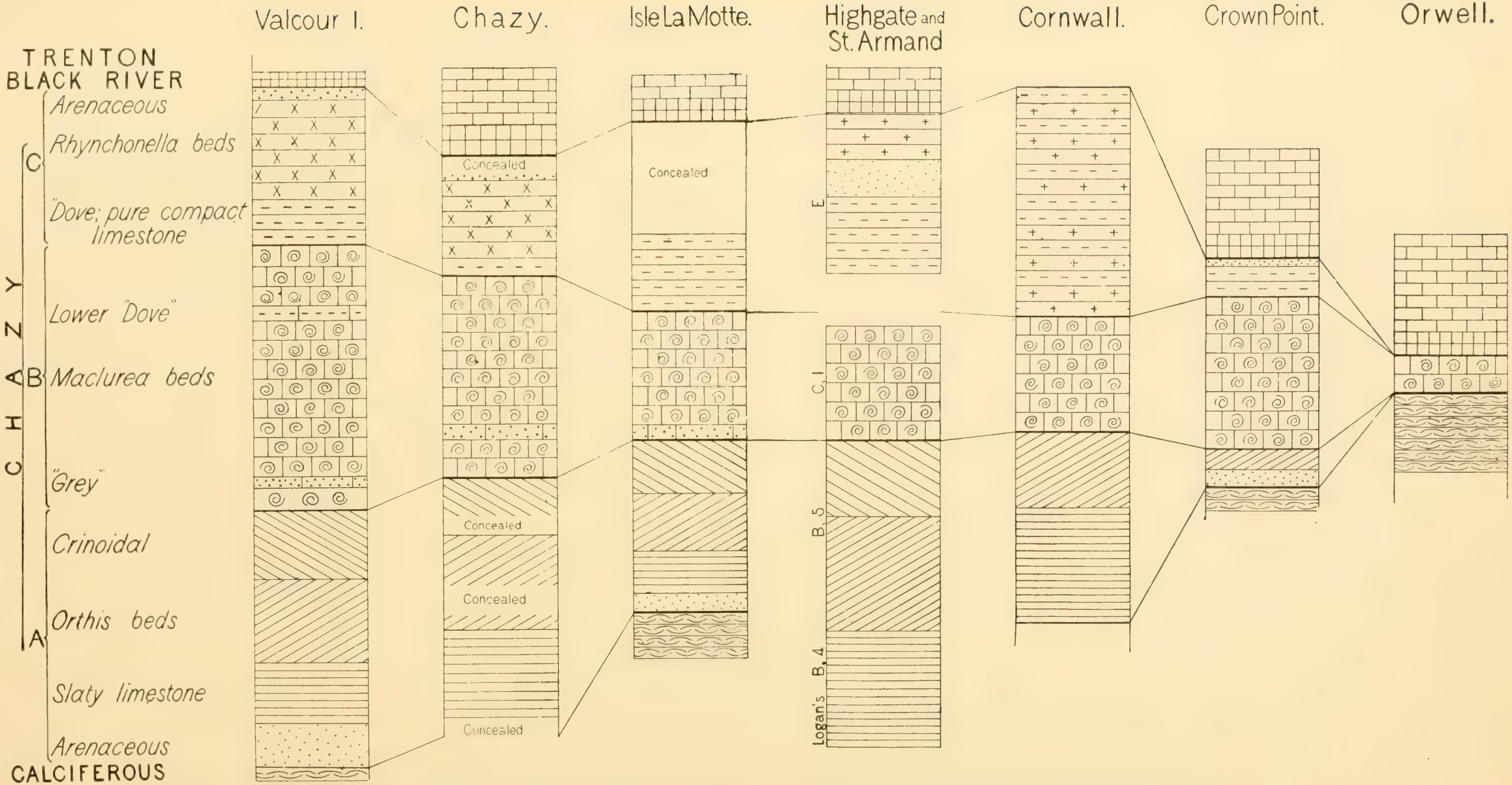
3. The recognition of the very subordinate importance of the "Middle" member suggests that the Coal Measures in Iowa may more properly be regarded as forming two, instead of three, divisions.

4. The unconformity of the Lower Coal Measures of Iowa upon limestones of the Lower Carboniferous is much more pronounced than heretofore suspected. The confirmation of this statement is found in excavations recently made at Elk cliff, at Harvey, at Fairfield, in Jefferson county, and elsewhere.

5. The striking unconformities in the Lower Coal Measures have never been so apparent as at present. The most remarkable instance of this sort is

the case of the Redrock sandstone. The vast sand bed had manifestly been consolidated and elevated above the surface of the sea for a considerable distance; then it was subjected to long-continued denudation, as is shown in the deep gorges and ravines which are still preserved in the hard sandstone. So wide-spread and intense was the action of the erosive agencies that the great sandstone, more than one hundred and fifty feet in thickness, was largely removed ; and at the present day only a few isolated outliers tell of its former great extent. When regional submergence again set in, the old gorges and shore depressions were occupied by coal swamps.

6. The earliest formed coal seams are far more extensive, both geographcally and vertically, than the later ones. On the whole, the coal of Iowa may be regarded as distributed in innumerable lenticular basins, sometimes several miles in diameter and six or seven feet in thickness centrally, sometimes only a few hundred yards in extent. These occur at many different horizons and interlock with one another, so that a boring may pass through a score or more coal horizons without meeting more than one or two veins of sufficient thickness for profitable working.



SECTIONS OF THE CHAZY IN THE CHAMPLAIN VALLEY.

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THE CHAZY FORMATION IN THE CHAMPLAIN VALLEY.

BY EZRA BRAINERD.

(*Read before the Society December* 30, 1890.)

CONTENTS.

INTRODUCTION.

The numerous islands and promontories of Lake Champlain afford excellent opportunities for the study of the Lower Silurian. Along its western border are the steep, high hills of the Archean, apparently the former shore of the old Silurian sea; along its eastern border stretch the hills of red sandrock and dolomite of the Cambrian age, brought up by the great overthrust that continues on northward to Quebec. East of this overthrust, toward the Green mountains, the Lower Silurian rocks are extensively crumpled and metamorphosed, and hard to decipher; but westward through the lake region they are less disturbed, retain their fossils, and present many remarkably fine exposures along the shores where the waves have washed away the soil.

The geological importance of this region was recognized by Professor Emmons, who, in his New York report in 1842, named these formations the Champlain group. Subsequently Professors Thompson, Adams and Hitchcock made valuable contributions to our knowledge of these strata; but it is safe to say that the work of these earlier geologists was left incomplete. Many of the best exposures were difficult of access, and seem not to have been visited. The details of stratigraphy were never worked out; the thickness and variety of the strata of the Calciferous and Chazy zones were greatly underestimated, and their wealth of fossils was unsuspected. Had it been otherwise, Billings would have had to describe fewer new species from the Lower Silurian of Canada, and some of the difficult problems of the "Quebec group" would have been more easily solved.

We purpose, in the present paper, to present a comparative view of several representative sections of the Chazy formation in the Champlain basin. We shall omit all details of stratigraphy, and present only the results of our study as regards the thickness and sequence of the strata and their characteristic fossils. These local details have been thoroughly worked out, and will be presented elsewhere with maps and sections giving actual profiles and dips. In the diagram herewith presented (plate 11) the strata are restored to the horizontal attitude so as to indicate more clearly the correlation of the beds in the several sections.

A further preliminary statement should be made concerning the boundaries of the Chazy. The upper boundary is the Black River, a black, massive pure limestone, 30 to 50 feet in thickness, easily recognized and remarkably uniform throughout the Champlain valley. The lower boundary, or the top of the Calciferous, is less distinctly recognized by geologists. We have considered it to be a tough iron-gray, fine-grained, magnesian rock, usually weathering yellowish or drab, 300 to 400 feet in thickness. Wherever this horizon is exposed in the lake region, these magnesian rocks appear, though they are wanting in the region east of the lake. The few fossils that occur in occasional beds of limestone, and the general lithological character of the mass, would seem to ally it to the strata below. Furthermore, whenever any of these outcrops are mentioned by the older geologists, the rock is always referred to the Calciferous.

The Detailed Sections.

Section at Valcour Island.—The first section of the Chazy to be described is that of Valcour island, about six miles south of Plattsburgh, New York. This island, two miles in length and one mile in breadth, with deep bays and high promontories, consists almost wholly of the Chazy rock, which here attains a maximum thickness of nearly 900 feet. The island seems to have been hitherto unexplored by the geologist. On Professor Emmons's map of Clinton county it is colored as Calciferous; but no Calciferous rock occurs except at the southern extremity just beneath the usual level of the lake. Above it appear the strata of the Chazy, dipping 20° or 30° eastward, and rising in cliffs 30 to 50 feet in height along the southeastern shore. It is the most impressive display of limestone to be seen along the lake. From a boat we can here behold, in one view, measures of the Chazy over 600 feet in thickness—in fact the whole formation, excepting the uppermost 80 feet and an interval of 200 feet covered by soil. The 80 feet here lacking are found at the northern end of the island underlying the Black River, and the concealed 200 feet are well displayed on the shores of the mainland toward the west and in the vicinity of the railway station recently built to accommodate the new Hotel Champlain at Bluff Point.

The strata of the Valcour section are as follows, in ascending order:

Group A (Lower Chazy).

	Thickness.
1. Gray or drab-colored sandstone, interstratified with thin (or sometimes thick) layers of slate, and with occasional thin layers of limestone at the base, containing *Camerella* (?) *costata,* Bill.	56 feet.
The slaty sandstone gradually passes into	
2. Massive beds, made up of thin alternating layers of tough slate and of nodular limestone, containing undetermined species of *Orthis* and *Orthoceras*	82 feet.
3. Dark bluish-gray, somewhat impure limestone, in beds of variable thickness; often packed with *Orthis costalis,* Hall, which occurs with more or less frequency through the whole mass. Other fossils are: *Lingula huronensis,* Bill.; *Harpes antiquatus,* Bill.; *Harpes ottawaënsis,* Bill. (?); *Illœnus arcturus,* Hall (=*I. Bayfieldii,* Bill.); *Lituites,* sp. (?)	110 feet.
4. Gray, tolerably pure limestone in beds 8 to 20 inches thick separated by earthy seams, the bedding being uneven. Many layers consist of crinoidal fragments, largely of *Palæocystites tenuiradiatus,* Hall. Near the middle of the mass, for a thickness of 10 feet, some of the fragments and small ovoid masses (*Bolboporites americanus,* Bill.) are of a bright red color; and these beds on the west side of Bluff Point are extensively quarried and furnish a fine marble for in-door use	90 feet.
Making for the total thickness of *A*	338 feet.

Group B (Middle Chazy).

1. Impure, nodular limestone, containing *Maclurea magna,* Leseuer.	25 feet.
2. Gray, massive, pure limestone, abounding in crinoidal fragments	20 feet.
3. Bluish-black, thick-bedded limestone, usually weathering so as to show pure nodular masses enveloped in a somewhat impure, lighter-colored matrix; everywhere characterized by *Maclurea magna.* Near the middle of this mass, for a thickness of about 30 feet, the fossils are silicified and of jet-black color. The more important, besides *Maclurea,* are species of *Strophomena, Orthis* and *Orthoceras*	210 feet.

	Thickness.
4. Dark, compact, fine-grained limestone, with obscure bedding, weathering to a light gray. This rock resists erosion, and is the upper stratum at Bluff Point, sloping upward from the lake at an angle of 5° to a height of 170 feet. In one exposure the basal portion is densely oölitic. Fossils are infrequent, but at a single locality there were collected *Orthis perveta*, Con.; *Orthis platys*, Bill.; *Leptæna fasciata*, Hall; *Asaphus canalis*, Con.; *Cheirurus polydorus*, Bill.; *Harpes* sp. und.; *Illænus incertus*, Bill.; *Lichas mingan-ensis*, Bill.; *Sphærexochus parvus*, Bill.; and several undescribed species	20 feet.
5. Bluish-black limestone like number 3, but less pure, containing *Maclurea magna*, Leseuer; *Orthis perveta*, Con.; *Strophomena incrassata*, Hall; *Orthis borealis*, Bill. (?); *Orthis disparilis*, Con., or *O. porcia*, Bill.	75 feet.
Total thickness of *B*	350 feet.

Group C (*Upper Chazy*).

1. Dove-colored compact limestone, in massive beds, containing a large species of *Orthoceras; Placoparia* (*Calymene*) *multicostata*, Hall; *Solenopora compacta;* and a large *Bucania* .	60 feet.
2. Dark impure limestone, in thin beds, abounding in *Rhynchonella plena;* at the base a bed 4 or 5 feet thick is filled with various forms of *Monticulipora* or *Stenopora* . . .	125 feet.
3. Tough, arenaceous magnesian limestone, passing into fine-grained sandstone	17 feet.
Total thickness of *C*	202 feet.
Aggregate thickness of the Chazy on Valcour island,	890 feet.

Chazy Section.—Eighteen miles north of Valcour island is the village of Chazy, from which the formation was named. We published an account of "the original Chazy rocks," with a map, in the American Geologist for November, 1888. The section is almost a repetition of the Valcour section, and we shall briefly note only some peculiar features.

It should be stated that the original Chazy, as defined by Emmons, was only what we have called Middle Chazy, or the portion characterized by the presence of *Maclurea magna.* The strata of Group *A* he placed in the Calciferous formation, though he recognized that they were higher than the strata elsewhere called Calciferous. The strata of Group *C* he classed with the Birdseye, as a peculiar development underlying the ordinary Birdseye. But Professor Hall four years later described the fossils of both these groups as belonging to the Chazy, and this view has been universally accepted.

In the exposures at Chazy the base of the formation is not reached. The interstratified slate and sandstone always seen along the lake wherever this horizon is exposed, is not disclosed at Chazy. The lowest rock seen is about 100 feet of iron-gray, fine-grained limestone, in beds one or two feet in thickness. It differs in appearance from the slaty limestone, number 2 of the Valcour section, and resembles the beds at the base of number 3, though it is of much greater thickness.

The remaining 200 feet of Group *A*, at Chazy, are quite the same as the corresponding strata at Valcour. We again meet with beds filled with *Orthis costalis*, strata consisting of crinoidal fragments, and the layer of red-spotted marble. About 90 feet from the top is the horizon of *Scalites angulatus*, found only at Chazy. Twenty-five feet from the top is a layer containing numerous gasteropods, *Bellerophon rotundatus*, *Bucania sulcatina*, *Raphistoma striata*, *R. staminea* and *Metoptoma dubia*, all described by Professor Hall.

Group *B* at Chazy is also essentially the same as at Valcour, only of less thickness by 80 feet. The twenty-foot gray layer is found 50 feet from the base, and is often oölitic.

The lower division of Group *C* here exhibits peculiar features. It is only 23 feet thick, and consists of alternating beds of two very distinct kinds of rock. One is a dove-colored, fine-grained, brittle and very pure limestone, containing small nodules of calcite; the other is a tough, silicious, iron-gray dolomite, weathering yellow. One of the upper beds of limestone contains undetermined species of *Murchisonia* and *Orthoceras* and the same large *Bucania* seen in the equivalent strata of Valcour island. Above these are the *Rhynchonella* beds, 100 feet thick. The middle portion of the mass is a pure, light-gray, coarsely granular limestone, sometimes with red spots, composed largely of crinoidal fragments. The uppermost 24 feet of Group *C* is concealed. If this be added to the measures already described, the total thickness at Chazy will become 732 feet, although there may be another hundred feet concealed at the base.

Isle La Motte Section.—Six miles east of Chazy village this formation is again exposed to view over the southern half of Isle La Motte. The strata, with a somewhat sinuous strike, dip northward at an angle of 3° to 5°. After 60 feet of the Calciferous, we have all the members of Group *A* well displayed along the shores and in numerous quarries:

1. Layers of sandstone and slate containing *Lingula* and *Orthis* . 23 feet.
2. Silicious limestone with seams of tough slate containing: *Camerella breviplicata*, Bill.; *Orthis porcia*, Bill.; *Strophomena aurora*, Bill.; *Strophomena camerata*, Con.; *Zygospira acutirostra*, Hall; *Asaphus canalis*, Con.; *Cheirurus vulcanus*, Bill.; *Illænus crassicauda*, Wahl. (?); *Remipleurides schlotheimi*, Bill. . . . . 55 feet.

3. Massive beds crowded with *Orthis costalis*, Hall . .	75 feet.
4. Crinoidal beds with the layer of univalves and the layer of red-spotted marble; *Columnaria parva*, Bill., occurs near the top	70 feet.
Total exposure	223 feet.

The *Maclurea* beds that follow are like those in the two former sections, but of less thickness. The gray oölitic bed is here at the base of the group and is largely quarried for ornamental marble. The overlying strata afford an excellent black marble much used for tiling.

The upper portion of Group *B* is assimilated at Isle La Motte to the lower portion of Group *C*. It consists of dove-colored, fine-grained limestone, almost devoid of bedding, rarely containing *Maclurea magna*, but full of large, light-colored wavy masses resembling *Stromatocerium*. Above this appears the ordinary "dove" limestone, with bands of magnesian limestone. We find here: *Cyrtoceras boycii*, Whitfield; *Orthoceras titan*, Hall (?); *Placoparia multicostata*, Hall; *Lichas champlainensis*, Whitfield; *Illænus*, sp. und.; *Bucania*, sp. und.

The upper portion of the Chazy at Isle La Motte is abraded and covered by a marsh, north of which the Black River and Trenton appear. The dip and strike are the same on both sides of the marsh. If we take this to be the dip and strike of the concealed strata, the total thickness of the Chazy at Isle La Motte would be 640 feet.

Highgate and St. Armand Section.—As we proceed northeastwardly from Isle La Motte, we pass over Utica and Hudson River slate for fifteen miles, until we reach the eastern shore of Missisquoi bay. The rocks of this tract have been mapped and described by Sir William Logan, and we shall adopt his estimates of thickness in our attempt to correlate these strata with those already described.

The lowest rock at Highgate springs is a dove-gray, compact pure limestone, interstratified in the upper portions with bands of buff-weathering dolomite from one to three feet thick. No fossils occur, but in lithological features the strata closely resemble the lower part of Group *C* at Isle La Motte. This is followed first by fifty feet of greenish-gray, calcareous, fine-grained sandstone, and then by sixty feet of blackish, thin-bedded, shaly, nodular limestones, partially magnesian, containing *Ptilodictya fenestrata*, *Orthis platys*, and *Ampyx halli*. Resting upon this come the Black River and the Trenton. The sandstone and shaly nodular limestones have, therefore, the stratigraphical position of the *Rhynchonella*-bearing beds seen on the opposite side of the lake.

The representatives of the Middle Chazy and Lower Chazy, we believe, are found in St. Armand and Stanbridge, just across the boundary line. We have elsewhere indicated that the lower portion (about 1,100 feet) of the

Philipsburgh section corresponds well in fossils and in lithological features to the Calciferous of the southern part of Lake Champlain. There is also evidence that the upper portion of this section (Logan's *B* 4, *B* 5 and *C* 1) corresponds to the Lower Chazy and Middle Chazy. Logan's *B* 4 is described as "black, slaty, thin-bedded, nodular limestone." In appearance it closely resembles the slaty limestone of Valcour island, though it has here a much greater thickness. *B* 5 consists of purer, dark-colored, more massive limestones, not unlike those of the *Orthis* and crinoidal beds. The evidence from fossils is incomplete, as the smaller forms are obscured by metamorphosis, while but few species have been described by Billings; but the Chazy genus *Eöspongia* occurs here, and the large specimens of *Orthoceras* and of *Lituites* seen in the ledges appear identical with those seen in this horizon at Valcour island. But the upper 50 feet of the Philipsburgh section undoubtedly belongs to the Middle Chazy, for it contains numerous specimens of *Maclurea magna*. These are to be seen on the hill 80 rods north of the railway station at St. Armand. Two miles south of the village of Bedford, the *Maclurea* beds are again exposed, and have a thickness of about 150 feet (Logan's *C* 1). In color, texture and massiveness, these beds are identical with those seen in western Vermont, where the rocks are partially metamorphosed. There remains, however, a possible gap between the *Maclurea* beds of Stanbridge and the dove limestone of Highgate springs. If Logan's view of the sequence of strata at Stanbridge is correct, there should be placed in this gap about 3,000 feet of slate and limestone conglomerates. Whether further investigation will sustain this opinion remains to be seen.

Cornwall Section.—In the town of Cornwall, Vermont, seventy miles south of Philipsburgh, there is an uplift in which all the Lower Silurian limestones are exposed, except the basal portion of the Calciferous. The rocks are even more altered by metamorphosis than at St. Armand, and the fossils are obscure; but several typical species have been identified, viz., *Ophileta complanata*, *Bathyurus saffordi*, *Bathyurus angelini*, *Maclurea magna*, and *Asaphus canalis*. The measures that answer to the Chazy are as follows:

A. Black, massive limestone, with frequent layers of tough, slaty matter, which, in weathered escarpments, protrudes in sharp ridges; followed by lead-colored pure limestone in beds one to three feet thick.* In all about	250 feet.
B. Lead-colored, compact, massive limestone, containing *Maclurea magna*	150 feet.
C. Pure, dove-colored, fine-grained limestone, in beds one or two feet in thickness, interstratified with numerous beds of dolomite, weathering buff, drab, or gray. Certain strata are crowded with brachiopods, supposed to be *Rhynchonella* .	300 feet.
Aggregate thickness	700 feet.

* The resemblance of these strata to those we consider their equivalent at Philipsburgh is very marked.

Crown Point Section.—Westward from Cornwall, toward Lake Champlain, the beds of the Chazy rapidly decrease in thickness. The same fact is noticeable southward from Valcour along the lake shore. The top and the bottom of the formation are the first to disappear. Neither the "*Rhynchonella* beds" nor the "slaty limestone" are to be seen south of Valcour. The Lower Chazy and Upper Chazy contract to small proportions, and finally disappear. Then the Middle Chazy begins to contract, and also disappears.

We present a carefully measured section at Crown Point fort to illustrate this fact. We find there in ascending order:

A	1.	Sandstone and slate interstratified	23 feet.
	2.	Impure limestone containing *Orthis platys*, Bill. . .	25 feet.
B.		Beds containing *Maclurea magna*, Leseuer . . .	200 feet.
C	1.	Dark-gray, massive limestone, weathering in darker stripes, an inch wide, containing the large *Bucania* seen elsewhere at this horizon	40 feet.
	2.	Tough silicious and magnesian rock passing into a two-foot bed of pure sandstone	17 feet.
		Aggregate thickness	305 feet.

Orwell Section.—An exposure in Orwell, Vermont, one mile northeast of the village, presents only 50 feet of *Maclurea* strata lying between the Calciferous and the Black River.

Distribution of the Chazy.

West and south of this point, through central New York and the tract west of the Adirondack region as far north as the Thousand Islands, the Chazy is altogether lacking. When it reäppears to the northward, along the Ottawa river and in the vicinity of Montreal, it apparently consists of the measures that first disappear to the south in the Champlain valley. They are described by Logan as whitish sandstones interstratified with bands of green shale, followed by beds "composed almost entirely of *Rhynchonella plena*," and are supposed not to exceed 150 feet in thickness. This answers well to the top and bottom of the Valcour section. No beds containing *Maclurea magna* are reported from Canada to the west of the outlet of Lake Champlain. These facts could be easily accounted for by supposing at the north an elevation of the sea-bed during the middle of the Chazy period, and at the south a simultaneous depression and submergence. If in the intervening region the submergence was continuous, we should have the whole formation and the maximum thickness at the northern end of Lake Champlain.


PIEDMONT PLATEAU
-IN-
MARYLAND
—1890—
0 10
Scale of Miles
CATOCTIN MOUNTAIN
NORTHERN SECTION
CENTRAL SECTION
SOUTHERN SECTION
PARR'S RIDGE
BALTIMORE
WASHINGTON
E
F
W
A
G
GF
Triassic Sandstone and Trap.
Frederick Limestone.
Coastal Plain Deposits.
Boundary of Semi-crystalline Rocks
axis.

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THE PETROGRAPHY AND STRUCTURE OF THE PIEDMONT PLATEAU IN MARYLAND.

BY GEORGE HUNTINGTON WILLIAMS OF JOHNS HOPKINS UNIVERSITY.

WITH A SUPPLEMENT ON

A GEOLOGICAL SECTION ACROSS THE PIEDMONT PLATEAU IN MARYLAND.

BY CHARLES R. KEYES.

(*Read before the Society December* 30, 1890.)

CONTENTS.

Introduction.

The three subdivisions which McGee has clearly shown to be equally characteristic of both the geology and topography of the middle Atlantic slope* are admirably contrasted by the cross-section made of them by the state of Maryland. The land area of the state may be set down in round numbers as 10,000 square miles. By a similar approximation, the western 2,000 square miles of this territory may be assigned to the Appalachian zone; the central 3,000 to the Piedmont region; and the eastern 5,000, which surround Chesapeake bay, to the coastal plain.

In the west the Paleozoic strata are thrown into broad and gentle undulations, which increase steadily in abruptness as we move eastward. Finally a certain amount of recrystallization accompanies the more intense disturbance, and positive evidence of the age of the oldest and most easterly strata seems to have been obliterated. Between the last Paleozoic beds whose exact horizon is fixed by fossils, and the broad transgressions of unconsolidated Mesozoic formations which occupy the eastern half of the state, there spreads out in Maryland an expanse of high, but nearly level, country which forms a portion of the Piedmont plateau. This is composed partly of semi-crystalline, partly of highly crystalline rocks, of whose age we have as yet no direct paleontological evidence. The accompanying map† (plate 12) exhibits the outline and drainage of this area, as well as the approximate line of boundary between its semi-crystalline and holocrystalline portions. The mapping and comparative study of these rocks, while still by no means completed in its details, strongly indicate the entire geological independence of these semi-crystalline and crystalline areas, as it will be the aim of this paper to show.

Physiography of the Piedmont Plateau in Maryland.

Topographical and geological Limits.—Topographically, the Piedmont plateau in Maryland may be considered to begin at the eastern base of Catoctin mountain, a sharply defined ridge of nearly uniform height (1,500 feet), extending from Point of Rocks, on the Potomac, northward to the Pennsylvania line, just west of Emmitsburg. East of the Catoctin mountain nearly three thousand square miles are exposed before the overlap of coastal clays and gravels is encountered. Geologically, however, the western

*Am. Jour. Science, 3d series, vol. XXXV, 1888, p. 121; also Seventh Annual Report of the Director of the U. S. Geol. Survey, Washington, 1888, p. 548.

†The capital initials upon the map (plate 12) and the sections (figures 1 and 2, p. 312) indicate towns as follows: *E*, Emmitsburg; *F*, Frederick; *W*, Westminster; *A*, Mt. Airy; *G*, Glencoe; *G F*, Great Falls.

boundary of the Piedmont region should be drawn considerably more toward the east. At the base of Catoctin stretches a broad transgression of Newark red sandstone, from beneath whose eastern border emerge the upturned edges of the Frederick valley limestone, which we now know to be of the same age (Trenton-Chazy) as the valley limestone of Virginia.* These two formations produce a broad fertile valley, east of which rises the more broken and rolling country composed of the crystalline and semi-crystalline rocks of undetermined age, which geologically characterize the Piedmont region proper. Through this valley meanders southward the Monocacy ("lazy-river" of the Indians) on its way to the Potomac. Near the southern end of its course there rises on its left bank the sandstone mass of Sugarloaf mountain. This is a thick monocline of easterly dipping beds, 1,360 feet in height, which in appearance, composition, and structure resembles a part of Catoctin. It would bound the Piedmont area of Maryland on the west topographically as it does geologically, were it not for the fact that it is abruptly cut off on the north and south, its isolated mass being represented farther toward the north by only a few insignificant patches of sandstone intercalated in the slates.

Drainage.—We may roughly outline the Piedmont reigon proper within the limits of Maryland as a trapezium, bounded on the north by the state line, on the east by the Baltimore and Ohio railroad from Wilmington to Washington, on the south by the Potomac, and on the west by the Monocacy river. The surface of this area is nearly level, or slopes very gently eastward and westward from its median divide, known as Parr's ridge. This well defined water-shed follows a course somewhat west of southward from the Pennsylvania line through the towns of Manchester, Westminister, and Mt. Airy, until, before reaching the Potomac, it becomes merged into the steady eastern slope from Sugarloaf to Washington. The average height of this ridge is about 850 feet. From it the streams flow westward into the Monocacy, at a height of 250 feet, and eastward into the Chesapeake, at tide level. It does not continue to be a prominent topographical feature far south of the Patuxent river, for in Montgomery county the drainage is west-by-southward, toward the Potomac.

The even surface of the Piedmont region has been so recently elevated that its streams are still excavating narrow precipitous channels. This imparts to the country a mild cañon type—the rock gorges suddenly becoming broad estuaries where they enter the coastal plain. There is, furthermore, evidence of a superimposed character in the drainage of this area to be found in the frequency with which even the smaller streams abruptly leave broad

* A year ago the age of the Frederick limestone could only be surmised from its lithological resemblance to the valley limestone of Virginia, but last June (1890) the welcome extension of the determined horizon east of the Trias, was accomplished by Mr. Charles R. Keyes, who obtained Chazy-Trenton fossils some three miles east of Frederick. See Johns Hopkins University Circulars, no. 84, vol. x, December, 1890, p. 32.

limestone valleys to cut their way for long distances through steep ridges of gneiss or schist. Nor do they here follow the line of least resistance, but cross the strike as often as they follow it.

Geological Subdivisions.—Geologically, the Piedmont region in Maryland is divided into an eastern and a western section with even greater sharpness than it is divided topographically. On the one side, disappearing beneath the coastal deposits, occur the holocrystalline rocks which, whatever be their origin, now retain no certain evidence of clastic structure; while on the west all the schists, limestones and sandstones are more or less clearly of sedimentary origin. The line separating these two divisions of the Piedmont plateau, which we shall hereafter designate as the semi-crystalline (western) and crystalline (eastern) areas, is not coincident with the crest of Parr's ridge, but lies on its eastern flank. Commencing in the south near Great Falls on the Potomac, it passes slightly west of Rockville and of Hood's Mills, then through Finksburg on the Western Maryland railroad, and thence by a north-northeastward course to the Pennsylvania line. Further eastward there is a large area of the semi-crystalline schists in Harford county, surrounding the Peach Bottom and Delta roofing slates. These appear to be infolded in the gneisses, and are possibly connected with the main area by a narrow tongue passing the Northern Central railroad near Whitehall. A similar infold of slates also occurs further southward, near Occoquan and Dumfries in Virginia. The lines of demarcation between these infolded areas and the surrounding gneisses are not less sharp than those separating the main crystalline and semi-crystalline areas themselves.

Sources of Difficulty in deciphering the Geology of the Piedmont Area.

Primary Sources.—Before turning to a special consideration of the petrography and structure of Maryland's crystalline and semi-crystalline areas, it may be well to briefly specify the chief sources of difficulty encountered in attempting to decipher the complex geology of the region. These are in the main three, viz., metamorphism, superficial decay, and extensive cultivation of the soil, all of which tend to obscure original contacts and structures, however sharp and well defined they may once have been.

Metamorphism.—This difficulty applies chiefly to the eastern or more crystalline area, where it has been carried so far as not merely to disguise the original structure of the rocks, but, in many cases, even to render it uncertain whether they are sedimentary or eruptive. Some of the rocks which were once probably sedimentary deposits have been wholly recrystallized and their new mineral constituents united in a quite massive aggregate; while other areas of undoubted eruptive origin have assumed the foliation and banding characteristic of gneisses. Another effect of this profound metamorphism has been to obliterate the originally sharp contact lines between diverse rock-masses. The chemical changes have brought about an interchange of material along such lines, so that rocks once very distinct now appear to grade imperceptibly into one another.

Superficial Decay.—This is another cause which renders both areal mapping and the deciphering ef the complicated structure difficult in the Piedmont region. In Maryland, as in all districts south of the glacial line, the rocks are in a state of incipient, if not advanced, decay at or near the surface. This tends to render similar rock-types indistinguishable, as in the case of many gneisses and granites which are composed of about the same constituent minerals. The same cause often develops a most misleading cleavage in many massive rocks. This is the case particularly in the large Sykesville granite area, a part of which was first mapped as gneiss until a deep opening into it revealed inclusions of other rocks, which placed its intrusive origin beyond a doubt.

This decay is also frequently the means of overturning the steep dip of the beds. This may be seen in many quarries, where the lower dips are in the opposite direction from those within ten feet of the surface.

Cultivation.—This tends, of course, to cover up rock exposures, often just where they are most necessary for the deciphering of the structure.

Petrography of the Piedmont Region in Maryland.

The marked contrast between the semi-crystalline and highly crystalline rocks of the western and eastern portions of the Maryland Piedmont region was recognized by Philip Tyson, and roughly indicated on his geological map of the state, published in 1860.* The line of boundary between the two areas has already been approximately traced by the writer. Their essential character will be clearly seen by a brief description of the various rock-types thus far identified and studied in each.

ROCKS OF THE WESTERN OR SEMI-CRYSTALLINE AREA.

Sedimentary Series: Phyllite.—Under this designation may most conveniently be included the semi-crystalline slates and finely fissile schists which compose so large a portion of the western Piedmont area in Maryland. They are capable of subdivision into a great number of varieties, all of which, however, fall clearly within the general characterization of *phyllite*, given by Credner.† They are beyond doubt argillaceous sediments which have undergone a greater or less amount of mechanical (cleavage) and

* First Annual Report of the State Agricultural Chemist to the House of Delegates of Maryland: Annapolis, 1860.

† Elemente der Geologie: 5th edition, 1883, p. 111.

chemical (recrystallization) metamorphism, though they do not lithologically differ from beds which in many other localities are known to be of Devonian, Silurian, or Cambrian age. Their most important mineralogical component is a silky white mica (sericite or kaolin), whose individual scales vary greatly in size in different specimens. This is sometimes wholly or in part replaced by green chlorite, which gives rise to subordinate intercalated beds of chlorite slate or schist. Quartz grains of varying size and outline are generally present, while feldspar is extremely rare. It is probably the alteration of this mineral in the process of weathering which has given rise to the abundant white mica. Iron oxide in very minute red hexagonal plates or rounded grains is common, and not infrequently composes a large proportion of the rock-mass. Tourmaline in minute crystals formed *in situ* is very common even in the less crystalline varieties, while the ultra-microscopic rutile needles (the *Thonschiefernadeln* of the Germans) are everywhere abundant. In certain bands of these rocks, ottrelite is also finely developed.

The phyllites have always a perfect cleavage and a satiny luster, which increases with the crystallization of new mica. Their color ranges from black through every shade of purple, blue and green to a pale gray. The darker varieties are largely worked as roofing slates. Evidences of clastic structure are not infrequently preserved in the shape of rounded grains and small pebbles of varying appearance and composition. Where least disturbed these slates are jointed and cut by cross-seams of chlorite or quartz. When they are more disturbed they become greatly puckered and filled with veins and eyes of quartz.*

The most clearly defined varieties of the Maryland phyllites thus far recognized may be enumerated as follows:

a. Clay slate (argillite): Along the eastern side of Frederick valley;

b. Roofing slate: Delta and Ijamsville, where it is quarried;

c. Sericite slate or schist (hydromica schist; talcose slate of Tyson and the older geologists);

d. Chlorite schist;

e. Ottrelite schist:† between New Windsor and Liberty, Frederick county.

Sandstone.—The sandstone of the western or semi-crystalline area always retains unmistakable evidence of its clastic origin. It is most typically displayed in the southwestern corner of the area on Sugarloaf mountain, whose mass it composes. It also extends in a series of isolated and unimportant patches north-northeastward from the mountain (parallel to Catoctin) until it finally disappears beneath the Newark red sandstone. On the east side of Sugarloaf its sandstone passes through gradual transitions of argillaceous sandstone and sandy slate into the overlying slates and schists. The detrital character of this rock, although plainly visible to the naked eye, is much

* It is these quartz veins, near the eastern border of the semi-crystalline area, that carry the gold of Montgomery county. See S. F. Emmons: Trans. Am. Inst. Min. Eng., Feb., 1890.

† Johns Hopkins University Circulars, no. 75, vol. VIII, 1889, p. 100.

more pronounced when seen under the microscope, as is more fully described and figured in the accompanying paper by Mr. Keyes. The cement, which is sometimes silicious (chalcedonic), sometimes kaolinitic, shows no recrystallization, nor even any enlargement of the clastic quartz grains. There are no new minerals developed, so that the rock cannot be regarded as having suffered any appreciable amount of metamorphism.

Marble.—The limestone, which is abundant in small thin lenses in the sericite schists north of the Baltimore and Ohio main stem, is intermediate between the blue uncrystalline rock of the Frederick valley and the coarse saccharoidal dolomites of Baltimore county. It is a marble of extremely fine, even grain—almost cryptocrystalline in texture—and of unusual hardness. Its color is sometimes snowy white, as at the Westminster quarries,* but more often streaked and variegated with black, gray, or red. This marble does not contain its argillaceous impurities in the form of crystallized silicates, as is the case with the more eastern limestones, but as narrow bands of sericite or chlorite schist. It is in connection with this compact marble that the copper (Liberty and New London) and lead (Union Bridge) deposits of Frederick and Carroll counties, which form contact-bodies against the adjoining schist, occur.

Eruptive Rocks.—The western area presents a marked contrast to the eastern and more crystalline area in the almost entire absence from it of eruptive material. What there is belongs either to the Mesozoic diabase or to serpentine whose origin is still in some doubt.

ROCKS OF THE EASTERN OR HOLOCRYSTALLINE AREA.

Sedimentary Series: Gneiss.—The rocks of the western area are for the most part devoid of feldspar, or, if this mineral is present, it is clearly of detrital origin. The rocks of the eastern area, on the other hand, are highly feldspathic, and this mineral has crystallized in its present position. The sedimentary rocks of the eastern area have been penetrated by vast quantities of eruptive material, often of a composition similar to that of the beds through which it breaks. Both of these have subsequently been subjected to such intense dynamic metamorphism that it is now not easy to distingush those of different origin. Several areas of what were at first regarded as typical sedimentary gneisses have been found by their inclusions, contact action and apophyses to be really eruptive granites, in which a foliation and even banded structure was subsequently developed by pressure. Other masses, now considered as representative gneisses, may hereafter also be referred to eruptive types. With our present knowledge we may, how-

* In slaty bands traversing these quarries, which lie very near the eastern border of the semi-crystalline area, Professor P. R. Uhler tells me he found fossils—well-characterized shells—about 1880. The specimens were, however, never described or identified, and were lost at the New Orleans exhibition. The lucky find has not yet been repeated.

ever, quite confidently assert the sedimentary origin of certain gneisses and schists among the eastern Maryland crystallines as follows:

a. Typical biotite gneiss or biotite-muscovite gneiss, highly feldspathic and containing thin parallel layers of varying composition, indicative of original bedding. These are now crystallized as biotitic, hornblendic, or epidotic schists. These gneisses are well exhibited at the great quarries which have been opened in them on Jones and Gwynn's falls, near Baltimore. They are cut by numerous dikes of coarse-grained muscovite-pegmatite, or biotite-pegmatite,* and are filled with an abundance of quartz or pegmatite eyes and lenses, intercalated parallel to their bedding. Similar rocks are also exposed in the vicinity of Washington, where well characterized beds of conglomerate have been observed in them.

b. Muscovite gneiss. This rock is composed mainly of muscovite and quartz, with comparatively little feldspar, but it is full of characteristic contact minerals, such as garnet, staurolite, cyanite, fibrolite, rutile, etc. This grades into a typical—

c. Mica schist, devoid of feldspar, but containing the same contact minerals. This is usually of very limited extent in the eastern area, and is to be regarded as a limited facies of the mica gneiss. Both of these rocks are full, as are the sericite schists in the western area, of veins of white quartz, colloquially known as flint.

Quartzite.—The highly siliceous rocks of the eastern area, though in all probability of sedimentary origin, have lost all traces of clastic structure through metamorphism, unless they were conglomeratic. The nearly pure quartz rocks of the eastern area show a much greater variety than those of the western, as will be seen from an enumeration of the following distinct types:

a. Quartzite or *Quartz-schist.* This is best exhibited in the abrupt east-west hill, north of Baltimore, known as Setter's (Tyson: "Sater's") ridge. It is here extensively quarried, and is such a clearly marked rock type that it serves at many other localities to fix a definite horizon. The rock is a completely crystalline mosaic of quartz grains which interlock by complicated sutures. It contains a small proportion of accessory minerals and no indication of original clastic structure. Its structure is illustrated in Mr. Keyes' figure 5 (page 321). There is always present a perfect foliation, due to parallel layers of muscovite at varying distances from each other. In these foliation planes there is an abundant development of black tourmaline, whose crystals are always transversely broken, and their fragments more or less separated, as if by stretching.

* See Johns Hopkins University Circulars, no. 38, vol. 4, 1885, p. 65.

b. *Orbicular quartzite*, of compact and fine grain, filled with hollow groups of radiating quartz crystals. This rock is exposed along the western edge of the Texas augen-gneiss area, and is quarried at the Poor-House. It occurs also in the marble at Brooklandville.

c. *White conglomeratic quartzite of Deer creek.* Among the most distinctly metamorphosed rocks of the eastern area is a belt of white conglomeratic sandstone in the center of Harford county, known as the "Rocks of Deer creek." The band is not over four miles long and from a quarter to a half a mile broad. Its hardness has caused it to resist erosion, so that where it is cut by the stream and railroad it towers up as a narrow ridge to a height of nearly three hundred feet. The microscopic structure shows that this rock has suffered almost complete recrystallization, although this has not always obliterated the original pebbles. During this process, which was probably assisted by fumarole action, a number of new minerals were abundantly developed. These are, muscovite, in continuous wavy membranes; blue cyanite in large radiating tufts; chlorite; magnetite and tourmaline, garnet and rutile. This formation, which has not yet been studied in any detail, lies just on the boundary between the holocrystalline rocks and the semi-crystalline schists surrounding the Peach Bottom slates. It cannot as yet be assigned with definiteness to either area, but its position suggests that it may not impossibly represent a basal conglomerate of the latter. This rock presents many points of petrographical resemblance to the metamorphic sandstone of Willis mountain, Buckingham county, Virginia, described by W. B. Rogers.*

Marble (Dolomite).—The limestone of the eastern area occurs in the form of highly crystalline marble. It stretches in irregular and sharply folded patches through Harford, Baltimore and Howard counties, but it has not been anywhere encountered in Maryland south of the Patuxent. This marble is a dolomite with a varying proportion of $MgCO_3$, whose average is perhaps about 40 per cent.† It is extensively quarried as a building-stone at Cockeysville, fourteen miles north of Baltimore. A very coarse-grained variety, locally known as alum-stone, occurs somewhat south of this place at Texas, where it is quarried for burning or for a flux. This highly crystalline marble presents a marked contrast to the finer-grained marbles of the western area in having its impurities crystallized out as silicate minerals instead of being intercalated as argillaceous bands. Among these accessory silicates may be mentioned phlogopite, tremolite, white pyroxene, tourmaline, scapolite and rutile.

* Geology of the Virginias, 1884, p. 71.
† For Analyses, see Bull. U. S. Geol. Survey, no. 60, 1890, p. 159.

Eruptive Rocks.—The rocks of undoubted eruptive origin within the eastern or more highly crystalline area of Maryland are very abundant and varied. The extensive dynamic metamorphism to which they have been subjected has developed in them many features tending to disguise their original character and to confuse them with highly altered sediments. These rocks have been the most carefully studied and described of any occurring in Maryland, so that for the present purpose it will be sufficient to merely enumerate the more distinct varieties, together with references to the various articles which contain details of their character and alterations. These eruptive rocks may be arranged under three distinct types: *

Intermediate Type (the most ancient), comprising:

- *a.* Hypersthene gabbro; †
- *b.* Gabbro-diorite and its metamorphic product, hornblende schist; ‡
- *c.* Quartz gabbro, Harford county;
- *d.* Norite, Harford county;
- *e.* Diorite, Ilchester; §
- *f.* Hornblendite;
- *g.* Hornblende-biotite-quartz-diorite, Washington.

Basic Type, comprising: ||

- *a.* Pyroxenite (Websterite); ¶
- *b.* Lherzolite; **
- *c.* Cortlandtite, Ilchester; ††
- *d.* Serpentine, resulting from the alteration of all the preceding basic rocks.

Acid Type, comprising:

- *a.* True or binary granite, Guilford;
- *b.* Granitite, with allanite-epidote growths; ‡‡
- *c.* Hornblende granite, Garrett Park; §§
- *d.* Granite porphyry, Ellicott City;
- *e.* Augen-granite gneiss, Texas, Baltimore county;
- *f.* Felsite (quartz-porphyry), in dikes at Relay;
- *g.* Pegmatite (muscovite-biotite). ||||

Rocks whose eruptive origin is either undoubted or most probable cover at least half of the now exposed surface within the eastern or more crystal-

* See Am. Geologist, vol. 6, July, 1890, p. 36.
† Bull. U. S. Geol. Survey, no. 28, 1886, p. 18.
‡ Ibid., p. 27.
§ Hobbs: Johns Hopkins University Circulars, no. 65, 1888; and Trans. Wis. Acad. Sci., vol. 8, November 10, 1890, p. 157.
|| Bull. U. S. Geol. Survey, no. 28, 1886, p. 50.
¶ Am. Geologist, vol. 6, 1890, p. 40.
** Ibid., p. 38.
†† Hobbs: Loc. cit.
‡‡ Hobbs: Johns Hopkins University Circulars, no. 65; Tschermak's min. petr. Mitth., vol. 11, 1889, p. 1.
§§ Keyes: This volume, p. 321.
|||| Johns Hopkins University Circulars, no. 38, vol. 4, 1885.

line area. A much less proportion can be assigned with any degree of probability to sedimentary formations, while the remainder possess the characters of both classes to such a degree that their origin must still be considered undecided.

Structure of the Piedmont Plateau in Maryland.

Description of Sections across the Region.—The outline map (plate 12) placed at the beginning of this article serves to elucidate the physiography of the Piedmont plateau in Maryland, and to approximately locate the boundaries of its semi-crystalline and highly crystalline formations. The structure of this region may best be shown by three generalized sections laid across it from west to east, each about fifty miles in length. The two more northerly of these sections are given here.* The third is made the subject of the next succeeding paper by Mr. Charles R. Keyes. They follow in the main the three lines of railroad which traverse the region (the Western Maryland, the Baltimore and Ohio main stem, and Baltimore and Ohio Metropolitan branch), although the northernmost section leaves the Western Maryland railroad where it turns southward, at Finksburg, and is continued eastward to Glencoe, a point on the Northern Central railroad directly north of Baltimore.

The most striking feature of these sections is their radiating or fan-like structure, and the fact (shown also on the map) that the vertical strata forming the axis of this fan follow a direction neither parallel to nor coincident with the boundary between the crystalline and semi-crystalline rocks. These two lines start from the same point on the Potomac (Great Falls), but diverge more and more toward the north. The fan, therefore, while its axis is throughout composed of semi-crystalline rocks, has its western flank made up of the least crystalline, and its eastern flank of the most crystalline portion of the Piedmont region.†

If the sections be followed from west to east, it will be observed that the oldest formation of known age—the Frederick limestone—emerges from beneath the transgression of Triassic (Newark) sandstone as a series of considerably folded beds, which are succeeded on the east and apparently overlain by carbonaceous and hardly altered shales. These are like those which occupy a similar position above the same limestone farther westward, and may represent the Hudson River horizon. Still beyond there follow with

*The capital letters used in these sections are the same as those already explained for the map (p. 302). For distinguishing the various rock-types, abbreviations in small letters are employed as follows: *gn.*, gneiss; *gr.*, granite; *gb.*, gabbro; *m.*, marble; *sp.*, serpentine; *sl.*, slate or schist; *l.*, limestone; *s.*, sandstone; *f. l.*, Frederick limestone; *d.*, diabase (trap); *t.*, Triassic (Newark) sandstone; and *c. s.*, Catoctin sandstone.

†For this reason the structure of the Piedmont area in Maryland has no true analogy with the so-called fan-structure (Fächerstructur) of the Alps and other great mountain chains, where the axis of the fan is always the most crystalline portion.

the same easterly dip the thick beds of sandstone which compose Sugarloaf mountain. These thin out toward the north to a few insignificant sandstone patches, while toward the south they soon disappear beneath the Newark transgression. The Sugarloaf sandstone passes on its eastern side upward by a gradual transition through shaly layers into sandy slates, and these again into the succession of sericite and chlorite schists, which compose the mass of the semi-crystalline area. Beneath the sandstone the shales are more disturbed, and, as there is here no such transition, this surface may represent a fault or thrust, as suggested by Mr. Keyes.*

The main body of semi-crystalline rocks in the Piedmont region are slatesand soft schists and, north of the Baltimore and Ohio main stem, narrow limestone bands, which preserve a constant north to north-northeast strike. The dip of these rocks is always toward the east as far as a line (the axis of the fan) which runs nearly north from Great Falls, where they become vertical. Toward this axis the dip becomes constantly steeper and steeper, yet the character of the rocks is but little changed save that they become gradually more shattered and crinkled.

After passing the vertical axis, the same structure is observed on the east as on the west, but in an inverse order. The dip of the strata turns gradually toward the west, becoming less and less steep as we proceed from the axis toward the coastal plain. As may be seen from the map, all the westerly dipping strata in the southern part of the Piedmont region, where the axis is nearly coincident with the boundary between the eastern and western

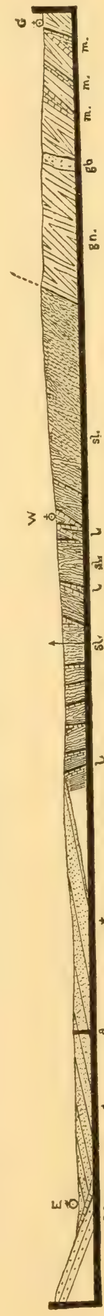

FIGURE 1—*Northern Section through the Piedmont Region in Maryland.*

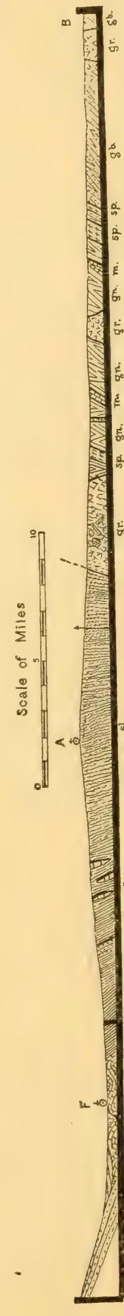

FIGURE 2—*Central Section through the Piedmont Region in Maryland.*

* The course of the great Triassic trap dike, which extends from Emmitsburg entirely across the state (see map), is worth noticing in this connection. It is nearly parallel to the synclinal axis of the Piedmont plateau, and may represent a preëxisting line of weakness in the crust.

areas, belong to the more crystalline rocks. Further northward, however, there is a considerable expanse of the semi-crystalline schists on the eastern side of the axis. These do not differ in any way from those on the western side, except in the direction of their dip. The same *general* strike and dip are also unmistakably displayed within the completely crystalline rocks forming the eastern area; but here there is far less uniformity in structure than is to be found among the semi-crystalline strata. Many disturbances attendant upon successive eruptions, dislocations and foldings, all anterior to the movement which gave the schists and slates their present position, have left their record in a much more irregular distribution and a much more complex structure; a fact which, as we shall see beyond, is of great significance in the interpretation of the sections here described.

Contrast in Character of the Eastern and Western Areas.—Aside from the fundamental difference between the holocrystalline and semi-crystalline (clastic) rocks composing the two portions of Maryland's Piedmont region, which the preceding petrographical descriptions have made sufficiently clear, the most marked contrast between these areas is to be found in the much greater *variety* of rock types in the eastern division, together with their much more irregular areal distribution.

The rocks composing the semi-crystalline area show evidences of considerable, but by no means the most intense, regional metamorphism. They were once, almost without exception, ordinary sediments. The intercalated limestone bands, occurring abundantly north of the Baltimore and Ohio railroad main stem, have been changed to fine, almost cryptocrystalline marbles, seamed by parallel argillaceous layers. The sandstones are hardly altered; not even recrystallized to an appreciable extent. The slates are perfectly cleaved in a direction not greatly differing from their bedding. Within them have been developed, in varying degrees, sericite, chlorite, ottrelite, tourmaline, rutile, and other metamorphic minerals; though such secondary silicates as garnet, sillimanite, staurolite, and cyanite or biotite, which appear to be the product of more intense metamorphism, are found only within the holocrystalline area. The rocks of the western area are not on the whole so crystalline as the fossiliferous schists of western Norway, and it is not improbable that their age may hereafter be definitely settled on paleontological evidence.*

In spite of the apparent constancy of their dip, the horizontal extent of the semi-crystalline rocks cannot be taken as any measure of their real thickness. The cleavage has much obscured the bedding, and the succession must be many times repeated by sharp folds and faults. Such dislocations are now, however, almost entirely obscured by (1) the perfect and uniform cleavage, (2) the even surface to which they have all been worn down, and

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* See foot-note on p. 307.

(3) the extensive superficial decay to which they have been subjected. As we approach their eastern boundary the semi-crystalline rocks exhibit the effects of more intense dynamic action. Along the axis, where they stand vertical, and also east of it, they are much broken, crinkled, and corrugated. Still, all the disturbance and alteration observed in the semi-crystalline schists may be readily accounted for by a single earth-movement; *i. e.*, by a force acting for a long time in a single direction.

The rocks of the eastern area, as the preceding petrographical descriptions have shown, are, in spite of a certain correspondence of sedimentary types, broadly distinguished from the schists and slates of the western area. They have, indeed, by the most complete metamorphism and recrystallization, lost nearly all traces of any clastic structure which they may once have possessed. This general distinction is admirably illustrated by Mr. Keyes in his two figures of the microscopic appearance of the quartz-schist of the eastern area, and a sandstone of the western area (this volume, page 321). These rocks may once have been nearly identical, but, if so, the former has lost its original structure quite completely.

The much greater variety of rocks within the eastern area is largely due to the ancient eruptives, which are there so abundant. But these hard and resistant masses have suffered hardly less complete foliation and metamorphism than the sediments which surround them, while in both this action is far in excess of what has taken place in any portion of the western area.

Another point of great importance is the abruptness of the passage from the semi-crystalline to the holocrystalline rocks. The schists at Westminster are hardly more crystalline than those bordering the Frederick valley, while so soon as we pass the boundary line between the two areas we meet gneisses as granitoid and perfectly crystalline as any to be found within the whole eastern district.

The holocrystalline rocks occupy all the Piedmont area in Maryland east of the eastern base of Parr's ridge, except the infolded and overturned mass of soft schists surrounding the Peach Bottom and Delta roofing-slates, which descend in a south-southwesterly direction from York and Lancaster counties, Pennsylvania* (see map, plate 12). Throughout all of the Piedmont area in Maryland east of the axis there is the general tendency to westerly dip above alluded to, and yet this feature is so much less constant in the holocrystalline than in the semi-crystalline rocks that it indicates a structure added to others which it has only partially obliterated. The very irregular areas occupied by the different rocks, the abrupt changes in trend and structure, and the much more intense alteration of the sedimentary beds, all bear

*There is a similar occurrence of slates between Occoquan and Quantico, in Virginia, apparently wholly on the eastern side of the crystallines; but here the rocks lying still farther eastward are buried beneath the formations of the coastal plain. At Occoquan the granite west of the slates is intrusive into them.

witness to successive periods of compression and disturbance to which the western schists could never have been subjected. No action of a force from a *single* direction can be made to account for the implicated structure of the eastern rocks, as it can for those further west. These must have been wrenched, folded and faulted at *different* times, and in this respect the two portions of the Piedmont region in Maryland present one of their strongest contrasts.

Interpretation of the Structure of the Piedmont Region in Maryland.

To account for the structure of the Piedmont plateau in Maryland as outlined in the preceding section, three hypotheses have successively suggested themselves. Two of these have, however, been already found to be more or less at variance with facts observed; and although it cannot of course be asserted that, as the work of mapping in detail progresses, the third hypothesis in its present form will be found to stand the final test, it may be provisionally accepted as best in accord with our knowledge of the facts at this time.

These three hypotheses are:

1. That the rocks of both the eastern and western areas are of the same age, and that they have been bent into a broad synclinal whose flanks are so sharply folded, faulted and thrust as to simulate the fan-structure observed in high mountain chains; and that the eastern flank of this synclinal or fan was much more highly metamorphosed than the western both by more intense dynamic action and by intrusion of a great amount of eruptive material.

2. That the more highly crystalline eastern area is greatly older than the western schists, and served as a rigid buttress against which these were thrust and folded.

3. That the eastern area is composed of rocks far more ancient than the western, which extend out under these, forming the floor upon which they were deposited; and that although already much folded and metamorphosed, this crystalline floor underwent at least one more folding after the schists had been laid down, carrying these with it and involving them in a considerable but not an extreme amount of disturbance and metamorphism.

The first of these hypotheses, which was held by Tyson, is naturally suggested by the close correspondence of sedimentary rock types in the western and eastern areas, and also by the structure in making a section across the region. A sufficient cause of the increased metamorphism and disturbance on the east was sought in the vast amount of eruptive rocks, which are absent from the western area. As conclusive, however, against the identity of age for the semi-crystalline and holocrystalline rocks we may summarize the following points:

a. The structure is not really a synclinal, but a fan-like divergence of dip from a central vertical axis, such as could not be produced by any synclinal bending in a continuous series of similar beds.

b. Any cause altering any part of an original series more than another would not make an *abrupt* contact, such as we find between the semi-crystalline and highly crystalline rocks of Maryland, but a gradual transition.

c. Any cause altering one flank of a synclinal more than the other would make the contact between the two kinds of rock and the axis of the synclinal coincide, as is not the case in Maryland (see map, plate 12).

d. The eruptive rocks of the eastern area are found in many places in close proximity to the slates or schists, without having effected their alteration; hence they are either not the cause of metamorphism, or they are themselves older than the semi-crystalline rocks; and, moreover, the sudden disappearance of the abundant eruptive rocks at the edge of the western area is itself a strong reason for supposing that it is of later age.

e. We cannot suppose that excessive dynamic action was the cause of the metamorphism, because where we should expect the folding force to have acted equally we find the hardest rocks (eruptives) much more altered, foliated, and disturbed than the soft argillites.

In face of the facts, we seem, therefore, obliged to admit that the boundary line between the semi-crystalline and holocrystalline portions of the Maryland Piedmont area represents a great time-break. Their contact is not an absolutely sharp line, nor indeed is this to be expected, since, as Professor Pumpelly has recently pointed out, one formation may pass gradually into one lying unconformably above it in consequence of superficial rock decay;* and also since any metamorphism such as both these areas has undergone tends strongly to obliterate sharp lines of contact. Still, while not absolutely sharp, this contact is far too abrupt to accord with any supposition of a gradual or progressive metamorphism through the entire series from west to east.†

The second and third of the above-mentioned hypotheses assume the difference in age of the western schists and eastern gneisses and eruptives, which it is the main object of this paper to establish. The second hypothesis (*i. e.*, that there was a passively resistant buttress of crystalline rock) is,

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* This volume, pp. 209-224.

† If the boundary of the semi-crystalline rocks of Maryland against the holocrystalline rocks really represents a great time-break, it may seem remarkable that basal conglomerates have not been encountered near this line. These may exist, but as yet they have not been clearly identified. Their presence is, of course, not necessary to prove the unconformity, although they are to be looked for. It is not impossible, as stated on page 309, that the conglomeratic sandstone which occurs on Deer creek, Harford county, between the gneiss and Peach Bottom slate area, may be of this nature.

however, as little in accord with the facts as the first, since it cannot possibly be reconciled either with the conformity in dip and strike of the schists and gneisses along their contact, or with the infolding of the slates and schists *in* the gneisses, as may be seen in the Peach Bottom-Delta area and at Occoquan, Virginia.

We are therefore driven to the third hypothesis as the most reasonable explanation of the facts. This supposes an ancient and crystalline floor, upon which were deposited the sediments now forming the western slates, sandstones, limestones and schists. At the time of the Appalachian uplift this crystalline floor underwent a final folding, which involved the overlying sediments, and thereby folded, faulted, cleaved and altered them. This hypothesis seems to account for the difference between the rocks of the two areas and for the abruptness of their contact, while at the same time it explains the conformity along this contact, and the fact that this boundary and the axis of the synclinal or fan are not coincident. We may therefore accept it as the most probable one unless future exploration shall render some modification of it necessary.

As to the age of the eastern and western Piedmont areas in Maryland, we can as yet offer no definite conclusions. It seems most probable that the boundary of the Paleozoic should be pushed eastward, not merely past the Frederick limestone but quite to the limit of the semi-crystalline schists, in which case the holocrystalline rocks below them would be assigned to the Algonkian or Archean. But the proof of this and the working out of many interesting details remain for future exploration, which it is hoped will decide on paleontological evidence many points now in doubt.

DISCUSSION.

Professor W. M. Davis: I would ask if the line of contact between the Archean to the east and the Triassic (Newark) beds to the west is a line of faulting? It will be noted that there is an apparent resemblance in the Piedmont section described by Dr. Williams to the fan structure of the Alps. Both the fan structure and faulting suggested by the section indicate enormous denudation of overlying masses. The region seems to represent the base-level of erosion of an old mountain range that has been elevated perhaps the twentieth time, and is now again being eroded.

Major Jed Hotchkiss: I have in my possession an unpublished section by Professor W. B. Rogers, which strikingly resembles that constructed by Professor Williams. I wish to call particular attention, however, to certain topographical features of the Piedmont plateau region. There is on the west, the Appalachians; to the east of this, the coastward range, which, however, dies out toward the north; and between these is a plain, to which I think the name Piedmont should be restricted. East of the coastward range lies an undulating plain, for which I suggest the name *Midland plain;* and east of the Midland plain lies the *Marine plain,* sloping down to tide-water.

Referring to the suggestion of enormous denudation, I consider the Appalachians the western abutment of a range from which 15,000 feet of strata have been eroded.

Mr. CHARLES S. PROSSER: Dr. Williams mentioned the occurrence of fossils in the Triassic (Newark) of Maryland. This is a very interesting as well important paleontological discovery. So far as I know, the only discovery of Triassic fossil plants in Maryland hitherto announced is by Professor J. P. Lesley, in a report on the geology of Chester county, Pennsylvania, where a "plant bed in Frederick county, Maryland," is mentioned.* Will Dr. Williams kindly give us the localities in which these fossils were found, and also tell us something about their systematic position? Are they fossil vertebrates, invertebrates, or plant remains?

Dr. WILLIAMS: Fossils have recently been found in two localities in the Triassic of Frederick county, Maryland: first, by Professor Philip R. Uhler, about two miles west of Frederick; and, secondly, by Mr. S. L. Powell, not far from Utica Mills. Those collected by Mr. Powell are from the red shales, and are very abundant. Some of the forms resemble nuts; others may be interlacing roots.

I have often considered the points mentioned by Professor Davis. The fan structure is a false resemblance. The evidence that this structure is rather apparent than real is: (1) The divergence of the synclinal axis from the contact; (2) The occurrence of the crystalline rocks on one side only (east) of the axis.

*Second Geol. Surv. Pa., C 4, 1883, p. 29.

A GEOLOGICAL SECTION ACROSS THE PIEDMONT PLATEAU IN MARYLAND.

BY CHARLES R. KEYES.

(*Read before the Society December* 30, 1890, *as a Supplement to the Memoir by Dr. Williams on the Petrography and Structure of the Piedmont Plateau in Maryland.*)

The broad elevation lying between the coastal plain and the first range of the Appalachians is known as the Piedmont plateau. In Maryland its median water-shed is called Parr's ridge, and rises from 600 to 900 feet above the sea-level. To the northward, Parr's ridge forms a prominent topographical feature; but along the line of the section here considered, the central water-shed has merged into the general level of the plateau. The eastern flank of the Piedmont plain is made up chiefly of gneisses, with numerous intrusive rocks. The western half consists principally of sericitic schists, with some sandstone. On the extreme western border occurs a broad limestone area.

In connection with a recent attempt to determine, from paleontological evidence, the age of this (the Frederick) limestone, which is the most easterly of the unaltered calcareous formations within the limits of the state, a section was made across the valley of Monocacy river from the Catoctin to Sugarloaf mountain, a distance of ten miles. The results then obtained suggested the continuation of the section eastward. This has lately been done, with considerable detail, as far as Washington, where the more ancient rocks are hidden from view by the coastal plain deposits. The course of the section (illustrated in figure 3) is therefore approximately along the line of the Metropolitan branch of the Baltimore and Ohio railway. The general course is indicated on plate 12 (facing page 301).

The finding of fossils in the Frederick limestone* has already been announced. The forms include several important types, of which the crinoids and brachiopods are the leading representatives. Of the first group, there are, however, only a few plates, perhaps belonging to *Glyptocrinus.* Of the second, a good series of several species was obtained. They represent chiefly the *Leptœna* group of *Strophomena.* The form is the type of a large assemblage of described species, having a wide geographic distribution and a very considerable range in time. One of the varieties is regarded as representing

* Johns Hopkins University Circulars, 1890, vol. X, p. 32. (Separates distributed in advance, July, 1890.)

the widely spread *Leptæna sericea*, Sowerby. Meek's *Orthis desmopleura* from the Chazy of Colorado seems to be very closely related. The species here noticed are characteristic of the Trenton period. This fact, taken in connection with the stratigraphic position of the fossiliferous horizon, leaves little room to doubt that the strata here referred to are of Trenton age. But, as already intimated elsewhere, the entire series of limestones and shales between the two great sandstones of the Catoctin and Sugarloaf mountains probably represents the Chazy, Trenton and Hudson River formations of the more northern localities.

In passing westward along the line of the section, the Piedmont plateau gradually increases in elevation above sea-level from about 200 feet on the eastern border to nearly 600 feet at the base of Sugarloaf mountain. This prominence rises abruptly to a height of almost 1,300 feet above mean tide. The broad Frederick valley beyond has an elevation scarcely higher than the eastern part of the plateau. Lastly comes the Catoctin range, which rises nearly to an equal height with Sugarloaf. Both mountain crests are formed of hard sandstone, shown in thin sections to be of unmistakable clastic origin (figure 4). The rocks between are contorted limestones and slates, the former being overlain by Newark (Triassic) sandstone for more than half its supposed extent. The Sugarloaf sandstone is seemingly identical with that of the Catoctin. By a double thrust it apparently presents twice its actual thickness, the upper member forming Sugarloaf itself, and the other member forming a somewhat lower elevation immediately west of the mountain. By the intercalation of numerous thin argillaceous bands the great sandstone rapidly loses its sandy character and passes gradually into typical phyllites. These schistose rocks, in broad alternating hydromicaceous and chloritic belts, have a superficial extension half way across the plateau. At first the cleavage planes have a low angle and are parallel with the inclination of the great sandstone; but gradually the inclination becomes greater and greater until near the axis, at Derwood station, it is perpendicular. Near Sugarloaf these planes have the appearance of being coincident with the lines of strati-

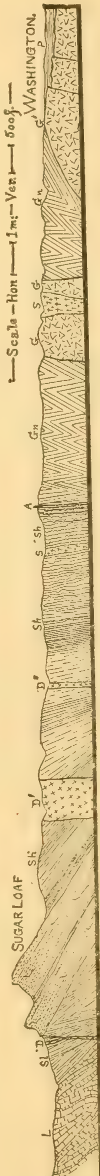

FIGURE 3.—*Southern Section through the Piedmont Plateau in Maryland.*

C = Catoctin sandstone; N = Newark (Triassic) red sandstone, with northwesterly dips; L = Frederick valley limestone; Sh = Hydromicaceous and chloritic schists; Sl = Slates; D = Mesozoic diabase dike; D' = Buck Lodge diabase; D'' = diabase dike; S = Serpentine (two belts); A = Axis, near Derwood station; Gn = Gneiss; G, G = Granitoid gneiss, with abundant inclusions; G' = Granite, in part hornblendic; P = Potomac clays and coastal plain deposits.

fication, but eastward the schists are very much puckered. The area is broken through in several places by Mesozoic diabases.

East of the axis the rocks are contorted gneisses with general westerly dips, nearly perpendicular at first, but by degrees assuming a lower and lower angle. Several narrow serpentine belts traverse these rocks, which are also disturbed in numberless places by later eruptive granites. The latter

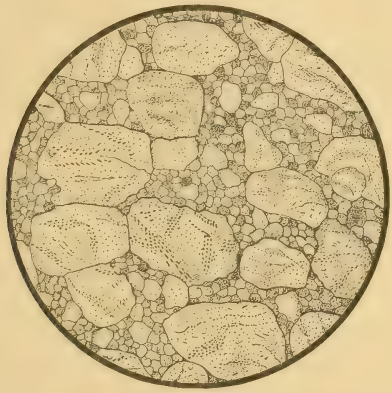

FIGURE 4—*Thin Section of Sugarloaf Sandstone* × 25.

Showing the rounded grains of quartz which exhibit undulatory extinction, and the unchanged interstitial materials. Between crossed Nicols.

FIGURE 5—*Thin Section of Quartzite from Baltimore County* × 25.

Showing complete recrystallization of the silicious matter, and also mica plates. The undulatory extinction in the quartz is very marked in this case also. Between crossed Nicols.

exhibit typical hornblende varieties at Garrett Park and elsewhere. From all appearances the gneiss area was originally largely granitic, but through the agency of enormous orographic pressure has been squeezed into its present gneissic condition. This is well shown by the microscopical examination of thin slices of the rock. The mineralogical constituents all present great mechanical deformation, the edges and angles being ground away and the fragments still filling the interstices. The larger quartz grains exhibit, between crossed Nicols, marked undulatory extinction—a ph nomenon quite characteristic of granitic masses that have been subjected to great dynamic action.

Considerable interest attaches to the structure of Sugarloaf mountain, which was incidentally a subject of consideration in the construction of the section across the plateau proper. The thick massive sandstone forms a monoclinal with easterly dip. As regards the somewhat lower elevation to the west of the mountain, two hypotheses are presented, either of which would offer a satisfactory explanation; but the substantiation of one or the other is immaterial in the present connection. There may have been a double thrust, thus giving the sandstone a measurement twice as great as the actual thickness; or the crests of the two elevations may represent parts of the same formation in which only a small amount of sliding movement has taken place. The former of these suggestions, however, appears the more probable.

As already stated, the upper portion of the sandstone passes gradually, by intercalation of thin argillaceous bands, into the schists lying to the eastward. These schists, for a considerable distance from the mountain, show no apparent contortion. Thin cleavage planes are coincident with the dip of the Sugarloaf sandstone. The regular succession of numerous thin argillaceous and sandy layers above the massive portion of the great sandstone would, therefore, seem to indicate that the cleavage directions of these rocks are true planes of stratification. In some of these undisturbed transition beds toward the superior limit of the great sandstone the alternation of different lithological materials is so marked that layers of sandrock, in every respect identical with the Sugarloaf stratum, and only from four to twelve inches in thickness, regularly succeed equally thin seams of fine clayey sediments. In places the effect of the light buff color of the narrow sandstone bands and the dark blue-black layers of the argillites is very striking.

The slates on the western side of the Sugarloaf prominence are variously inclined, from nearly perpendicular to a comparatively low angle. They appear in places considerably puckered.

When the region was subjected to intense orographic pressure, the softer rocks were finely crinkled and puckered. On the other hand, the great thickness of sandstone was but little affected internally. It was faulted and, acting in large units, apparently slid over the softer layers. The facts as here presented show that below the sandstone the shales are more or less disturbed; while above, the argillites are not at all affected, and appear interstratified with the upper portions of the arenaceous formation. This would point strongly to the conclusion that the plane of movement or thrust was at the bottom rather than the top of the great Sugarloaf sandstone.

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VOL. 2, PP. 323-330 MARCH 16, 1891

TERTIARY AND POST-TERTIARY CHANGES OF THE ATLANTIC AND PACIFIC COASTS;

WITH A NOTE ON

THE MUTUAL RELATIONS OF LAND-ELEVATION AND ICE-ACCUMULATION DURING THE QUATERNARY PERIOD.

BY JOSEPH LE CONTE.

(*Read before the Society December* 31, 1890.)

CONTENTS.

THE ATLANTIC COAST AND ITS CHANGES.

Physical Geography of the Coast.—It is well known that the North American continent is bordered on both sides by a submarine plateau sloping gently seaward until it attains a depth of about 100 fathoms, and that from this 100-fathom line the bottom drops off rapidly into deep water. This submarine plateau may be regarded as a submerged coastal plain, and its margin as the true boundary between the continent and the ocean-basin, *i. e.*, as the submerged continental margin.

It is also well known that on the eastern coast this submarine plateau is trenched with deep submarine troughs running out from the mouths of the great rivers to the submerged continental margin and there opening into deep water. The best known of these submarine channels are: (1) One running from the mouth of St. Lawrence river through St. Lawrence bay and over the submarine plateau to the deep ocean-basin; (2) Another, equally distinct, extends from the mouth of the Hudson river through New York harbor and out to deep water; (3) Still another stretches from the mouth of the Delaware through Delaware bay and thence seaward; (4) Officers of the U. S. Coast Survey have recently located a well defined channel in Chesapeake bay and beyond its opening into the Atlantic; (5) Beyond the mouth of the Mississippi, even beyond its submarine delta deposit, a similar channel is found running out to the margin of the abyssal region of the Gulf of Mexico. Doubtless others will hereafter be found.

These are all off the mouths of existing rivers and are direct continuations of the adjacent river valleys, or rather of the much greater Tertiary river-channels underlying the present river channels. They are the submerged lower portions of the old Tertiary river beds.

Coast Changes.—As long ago pointed out by Dana and more recently by Dr. Spencer, the submarine channels are evidence of a former more elevated condition and wider extent of the continent. They were hollowed out by erosion at a time when the continent stood much higher than now and the shore-line was at or beyond the present 100-fathom line. The former elevation shown in this way is estimated by Spencer as at least 2,000 to 3,000 feet above the present condition.

The hollowing of these channels was undoubtedly the work of the Tertiary, and probably of the later Tertiary. The continental elevation probably commenced in the late Miocene, increased through the Pliocene, and culminated at the end of the Pliocene, or more probably in the early part of the Quaternary, and was at least one of the causes, perhaps the main cause, of the glacial cold of northern regions. Following the elevation and probably assisted by the weight of the accumulating ice-sheet, there was a subsidence which carried the continent below its present level. From this depressed condition, as the ice was removed, the continent rose again to its present position, which, however, is far below that at the end of the Tertiary and beginning of the Quaternary. This fact, I may remark, is proof positive that there were other causes of subsidence besides mere weight of ice.

Such are, in brief, the phenomena and such the explanation, on the eastern coast. On the western coast there are also found submarine channels; but in those off the California coast there are some significant peculiarities.

The Pacific Coast and its Changes.

Physical Geography.—Commencing northward, we find off the mouth of Puget sound and the Gulf of Georgia (*i. e.*, off the Strait of Fuca) a wide and deep channel cutting into the submarine plateau and passing seaward to deep water. Professor Davidson, however, thinks that this may be due to the scouring action of the powerful tidal currents characteristic of this strait. Off the mouth of the Columbia river nothing remarkable has been discovered; and the mouths of the Umpqua, the Rogue, and the Klamath rivers have not been investigated. It may be, therefore, that the phenomena on this part of the coast do not greatly differ from those on the eastern coast.

But along the California coast the phenomena are quite different. The researches of Professor Davidson have brought to light some twenty or more submarine channels on the coast from Cape Mendocino to San Diego, a distance of about 700 miles. To mention only the most important: there are four very marked ones within 25 miles of Cape Mendocino going southward, and a fifth, long known and very distinct, in the Bay of Monterey. But strange to say there is none off the Golden Gate. Going still southward, there are two or more about the Santa Barbara sound, and one or two about San Diego. These all have distinctive features of subaërial erosion-channels, and show a former elevation of the continent of at least 2,000 to 2,500 feet above its present level. But the distinctive feature about these, as contrasted with those on the eastern coast, is that they have no obvious relation to existing rivers. They are not a submarine continuation of any system of river valleys on the adjacent land. On the contrary, they run in close to shore, and abut against a bold coast, with mountains rising in some cases to 3,000 feet within three to five miles of the shore-line, and wholly unbroken by any large river valleys. It is impossible to account for this except by orogenic changes which diverted the lower courses and places of emptying of the rivers since the channels were made. Moreover, we can, I believe, fix with more certainty than we can at the east the date of these changes.

Orogenic History.—The Coast ranges of California, as is well known, were formed at the end of the Miocene. Until that time, the Pacific shore-line was somewhere east of the Coast range, and the place of this range was a marginal sea bottom receiving abundant sediments in preparation for the future mountain. Evidently, then, the hollowing out of the submarine channels was the work of the Pliocene alone; and the greatness of the work was such that it must have occupied the whole Pliocene. It follows, therefore, that the orogenic changes which diverted the rivers from these channels must have occurred about the end of the Pliocene or beginning of the Quaternary, and were therefore probably coincident with the enormous orogenic changes, with lava-flows and consequent displacement of the rivers, which took place at that time in the Sierra region. We have abundant examples in the Coast range, also, of lava flows on a prodigious scale, even forming mountain ridges. Such are the ridges 1,000, feet high, bounding Napa valley on either side and culminating in Mount St. Helena, over 4,000 feet high. All the region about Clear lake and northward, is covered with great lava-flows; similar flows are found also in abundance in the region south of the Bay of San Francisco. None of these flows are older than the Pliocene, and many of them undoubtedly belong to the Quaternary. There is, therefore, abundant evidence of orogenic changes in late Pliocene and early Quaternary times sufficient to divert the lower courses of the rivers.

In brief, then, the general character of the changes in the Coast range region was as follows: During the Miocene the coast line was somewhere to the east of the Coast range, and the place of that range was marginal sea-bottom. At the beginning of the Pliocene the Coast range was formed, and the coast line was transferred westward beyond its present position to the border of the submarine plateau. During the Pliocene, continental elevation commenced, and culminated at its end or perhaps in the early Quaternary. All the islands bordering the coast, especially the high islands off the coast of southern California, were added to the continent. Meanwhile the rivers, whether rising in the Coast range or breaking through gaps in that range, cut their channels deeper and deeper. At the beginning of the Quaternary, coincident with the great orogenic changes and lava-flows of the Sierra, there occurred also great lava-flows in the coast region which modified the orographic forms of the Coast range and changed the lower courses of the rivers. Soon after these orogenic changes the coast region went down to, or indeed considerably below, its present level and the deserted lower channels were submerged. The fact that they were deserted, and that therefore they were unmodified by subsequent sedimentation, is the reason they run in so near shore and are so distinct. From this subsided condition, abundantly shown by elevated sea margins both on the mainland and on the high islands off the southern coast, the land was again raised to its present level. This, however, is far below its former position, and therefore the channels remain submerged.

Changes in Rivers.—Concerning the courses of the Pliocene rivers which cut these channels we know nothing and it is vain to speculate; this must be left to future investigation. But there is one river, and that the greatest in California, concerning which some words may be not wholly profitless.

At the present time the tributaries of the Sacramento and San Joaquin pour their united waters into the Bay of San Francisco and through the Golden Gate into the Pacific. But this outlet certainly did not exist in Pliocene times, for there is no submarine channel off the Golden Gate. Where then did the river empty at that time? Probably far southward into the Pacific, off the Bay of Monterey. Professor Davidson tells me that a depression of 100 feet at the divide between the bays of San Francisco and Monterey would now empty the waters of the former into the latter. Is it not probable, then, that the deep channel running in close to shore in Monterey bay may be the submerged Pliocene outlet of this great river? If so, then the history of this river may be as follows:

During the Pliocene, when the coast region stood 2,000 to 2,500 feet above its present level, the Bay of San Francisco did not exist, except as a valley between mountain ridges. The waters of the united Sacramento and San Joaquin rivers at that time flowed through the region now occupied by the bay, then through the valley continuations of the same southward and into the Pacific ocean by the submarine channel of Monterey bay. About the beginning of the Quaternary, the orogenic changes which submerged its lower course cut off also its mouth and opened another through the Golden Gate.*

Comparison of Eastern and Western River Beds.—Nothing can be more interesting than a comparison of the river beds of the two coasts of the United States, and the changes they have undergone, both in their upper and in their lower courses. On the eastern coast the old or Pliocene river beds underlie the present river beds; the new are in the same places as the old, but at a higher level, because by *continental subsidence* the land is lower now than then. In California, on the contrary, the Pliocene rivers were displaced from their beds by lava streams; and the new beds have been cut far below the old beds, because by *mountain elevation* the height and slope of the Sierra have been greatly increased since that time. An exactly similar difference is found in the case of the lower courses, and is due also to similar causes. In the east the submarine channels are a direct continuation of the old river beds, because the changes were continental, not orogenic. In California, on the contrary, in addition to these continental movements which submerged their lower courses, there were also orogenic changes in the Coast ranges, by which the places of discharge of the rivers into the sea were entirely changed. These two events, viz., the displacement of the upper courses of the rivers in the Sierra and the displacement of the river-mouths on the coast, were probably coincident, or nearly so.

Brief History of the Rivers and Ranges of California.—The Sierra was formed, as we now know, by lateral crushing and strata-folding at the end of the Jurassic. But during the long ages of the Cretaceous and Tertiary this range was cut down to very moderate height, with gentle slopes eastward and westward from a crest which was probably situated along a line just above the Yosemite and Hetch-hetchy valleys; for there the erosive biting into the granite axis seems to be deepest. The rivers by long work had finally reached their base-levels and rested. The scenery had assumed all the features of an old topography, with its gently flowing curves. The continental elevation of the Pliocene did not affect greatly the river slopes of this part. At the end of the Tertiary came the great lava streams running down the river channels and displacing the rivers; the heaving up of the Sierra crust-block on its eastern side forming the great fault-cliff there and transferring the crest to the extreme eastern margin; the great increase

* Whitney concludes on other grounds that the break forming the Golden Gate was made during or at the end of the Pliocene.—"Auriferous Gravels," 1880, p. 26.

of the western slope and the consequent rejuvenescence of the vital energy of the rivers; the consequent down-cutting of these to form the present deep cañons, and the resulting wild, almost savage, scenery of these mountains. So, too, in the history of the Coast range there are two striking epochs. This range also was made by lateral pressure and strata-folding at the end of the Miocene. During the Pliocene, on account of the great continental elevation of that period, this range was powerfully sculptured by erosion; and deep and wide channels were made by its rivers, the upper courses of which are yet unknown. At the end of the Pliocene, probably coincidently with the great changes in the Sierra, there were here also great lava-flows, and perhaps orogenic movements, which changed the places of the river outlets. Subsequent continental subsidence submerged the deserted channels, and they remained unknown until discovered by Professor Davidson.

Thus, rivers are among the best indicators not only of continental movements, but also of orogenic changes; yet they are very differently affected by these changes according to their rate: If the orogenic lifting across the course of a river be slower than the rate of channel-cutting, then the river will cut the mountain to its base and maintain its course. Fine examples of this are found in the plateau region described by Powell. But if, on the contrary, the orogenic dam be lifted more rapidly than the river can cut—which must always be so in lava-flows, and may be in other cases—then the river will be ponded and the waters may find an outlet somewhere else. The rivers of California are examples of this.

Review.

Perhaps it will be thought that I have constructed a somewhat elaborate hypothesis on a too slender basis of ascertained facts. It may indeed be so; but it is difficult to conceive any explanation of the submarine channels of California except by some such changes as I have suggested. It remains for future investigations to work out the details. The changes in the Sierra and in the upper courses of the rivers are tolerably well known through the investigations of Whitney and others, but those of the Coast range and of the lower courses of the rivers are almost wholly unknown. Attention has only recently been drawn to them by Professor Davidson, and their full geological significance is now pointed out for the first time.

It is impossible to conceive a more inviting field for the study of the higher problems of geology than is afforded by the phenomena of the river-beds of California. The main object of this short paper is to direct attention and stimulate investigation. Whether the views presented above be verified or refuted, or whether, as I think more probable, they are corrected and modified by such investigation, it matters little, if so be the truth is established.

NOTE ON

THE MUTUAL RELATIONS OF LAND-ELEVATION AND ICE-ACCUMULATION DURING THE QUATERNARY PERIOD.

It is generally agreed that the Quaternary was characterized by remarkable oscillations of land-level, and corresponding oscillations of climate and of ice-accumulation in northern high-latitude regions. But the most opposite views are held regarding the time-relations of these two sets of phenomena. Some hold that the land-elevation was coincident with the cold and the ice-accumulation, and was at least one of its causes, and that the moderation of temperature and removal of the ice was coincident with the depression, and was its effect. Others, on the contrary, take exactly the opposite view; they hold that the ice-accumulation, which was the result of entirely different and perhaps extra-terrestrial causes, produced crust depression by its weight, and the subsequent removal of the ice and relief of pressure caused the reëlevation of later times.

There is doubtless much to be said for both of these views; there is in both a mixture of truth and error. The error in the first is in neglecting the undoubted effect of load and relief on crust-level: The error in the second is in neglecting other causes of crust movement than load and relief; especially in this case in neglecting the land-elevation, which commenced in preglacial times. I believe that the two extreme views may be reconciled and all the facts satisfactorily explained by supposing, (1) That the continental elevation which commenced in the Pliocene culminated in the early Quaternary and was at least one of the causes of the cold and therefore of the ice-accumulation; (2) That the increasing load of ice was the main cause of subsidence below the present level; (3) That the removal of the ice-load by melting was the cause of the reëlevation to the present condition; but (4) That all these effects lagged far behind their causes. This lagging of effects behind their causes is seen in all cases where effects are cumulative. For example: the sun's heating power is greatest at midday, but the temperature of earth and air is greatest two or three hours later; the summer solstice is in June, but the hottest month is July; and in some cases the lagging is much greater. The cause of sea breezes, *i. e.*, the heating power of the sun, culminates at midday, but the effects in producing air currents culminate late in the afternoon and continue far into the night, long after the reverse cause, *i. e.*, the more rapid cooling of the land, has commenced. Now, in the case under consideration, it is probable that the lagging would be enormous, in consequence of the reluctant yielding of the crust and the capacity of ice to reproduce the conditions of its own accumulation. Although the elevation produced the cold and therefore the ice-accumulation, yet the latter culminated long after the former had ceased and even after a contrary movement had commenced.

I have been accustomed to illustrate this view by the accompanying diagram, figure 1. In this diagram, which, for simplicity's sake, treats the glacial epoch as one, the horizontal line, *A B*, represents time from the later Pliocene until now; but it also represents the present condition of things both as to land-level and as to ice-accumulation. The full line, *c d e*, represents the oscillations of land (and presumably of temperature) above and

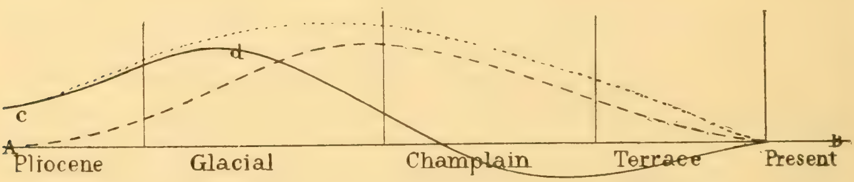

FIGURE 1.—*Graphic Representation of Quaternary Climate and Land-Altitude.*

below the present condition. The broken line represents the rise, culmination and decline of ice-accumulation. The dotted line represents the crust-movement as it would have been if there had been no ice-accumulation.

It is seen from the diagram that the ice-accumulation culminated at a time when the land, under the pressure of the ice-load, had already commenced to subside; and that the subsidence was greatest at a time when the pressure had already commenced to diminish. But the fact that the land, after the removal of the ice-load, did not return again to its former height in the Pliocene, is proof positive that there were other and more fundamental causes of crust movement at work besides weighting and lightening. The land did not again return to its former level because the cycle of elevation, whatever its cause, which commenced in the Pliocene and culminated in the early Quaternary, had exhausted itself. If it had not been for the ice-load interfering with and modifying the natural course of the crust movement determined previously and primarily by other and probably internal causes, the latter would probably have taken the course represented by the dotted line. It would have risen higher and culminated later, and its curve would have been of simpler form.

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ON THE LOWER CAMBRIAN AGE OF THE STOCKBRIDGE LIMESTONE.

BY J. E. WOLFF.

(*Read before the Society December* 30, 1890.)

CONTENTS.

INTRODUCTION.

Geography of the Area described.—The village of Rutland, Vermont, is situated near the western base of the main range of the Green mountains, at the junction of Otter creek with a large tributary from the north, called East creek. The village occupies a small portion of a wide valley extending some twenty-five miles southward to the head of Otter creek, and, after crossing a low divide, considerably further on southwardly flowing waters. Toward the north a low divide terminates the drainage basin within four miles; but beyond this the broad valley, in the continuation of Otter creek, extends far northward nearly in the same line. The location of the village with respect to the more prominent features of the topography as well as the structural features is shown in the accompanying diagram, figure 1.

This "valley of Vermont" is about three miles wide at Rutland. It is bounded on the east by the abrupt slopes of the first or outer range of the mountains; on the west by a north-and-south ridge over a mile wide, called Pine hill, through which Otter creek has cut its way westward at Rutland, turning northward again in the succeeding narrow "Centre Rutland valley." A second and still narrower north-and-south ridge separates the second valley from a third, or "West Rutland valley," which in turn is bounded by the higher ridges of the Taconic range.

In the high, abrupt frontal range of the Green mountains there occur crystalline schists, often gneissic, which pass eastward into the gneissic rocks

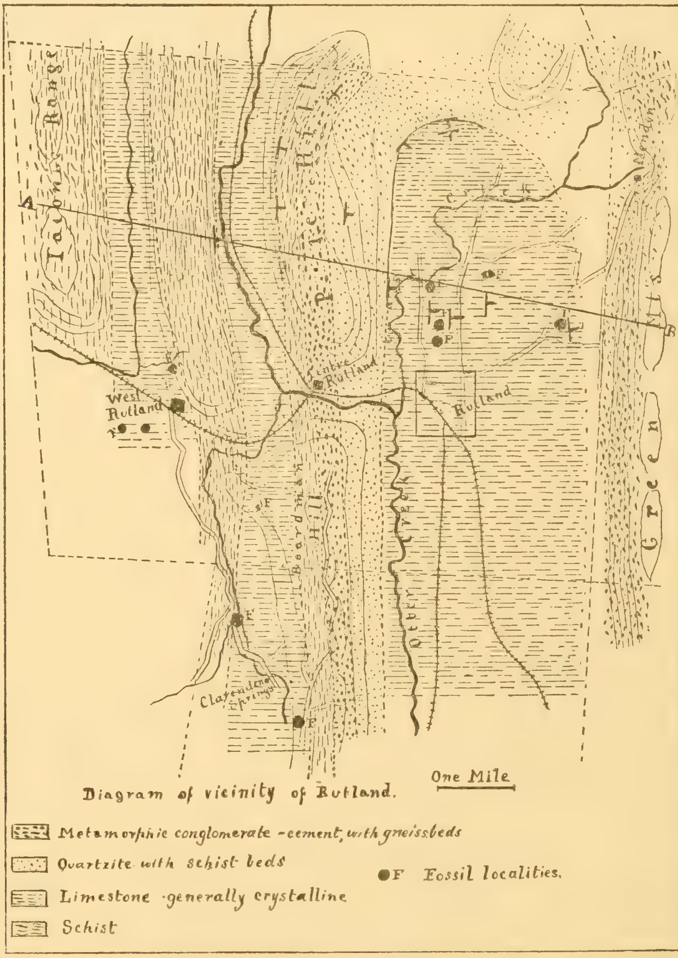

FIGURE 1.

proper of the Green mountains. These schists contain beds of true conglomerate, with a metamorphosed crystalline cement, and pass westward, on the slope, into the quartzite of Vermont, which the discoveries of C. D. Walcott prove to be of lower Cambrian age (*Olenellus* zone). This is succeeded by a broad belt of limestone occupying the Rutland valley; next, in Pine hill, we find a partial repetition of the series in the "frontal" range, namely, massive quartzite underlain by a transitional gneissic series; then, on the western crest of the hill, a band of black schist in contact with the band of crystalline limestone which occupies the second or Centre Rutland valley. The narrow ridge west of this valley is again formed by black schists, succeeded by a third band of crystalline limestone in the West Rutland valley; and finally, black and greenish schists form the slopes of the Taconic range.

Earlier Opinions concerning the Rocks.—The limestones of these three valleys belong to the Eolian limestone of the Vermont geological report. In the limestone of West Rutland, Reverend Augustus Wing found Chazy fossils, as described by J. D. Dana in the well-known articles in the American Journal of Science,* where the term "Trenton-Chazy-Calciferous" was applied to the Eolian limestone in general. Mr. Wing found no fossils in the Centre Rutland or Rutland limestone belts, but was inclined to refer the quartzite of Pine hill to the Potsdam and the Centre Rutland limestone to the upper Calciferous and Quebec, or perhaps, including all the formations, to the Trenton. The slates on either side of the West Rutland valley he considered younger than the limestone, or of Hudson River age.

In the geological map accompanying Mr. Walcott's paper on "The Taconic system of Emmons," etc.,† the slates or schists of the Taconic range west of West Rutland are colored as lower Cambrian (Georgia).

A paper on "The Taconic iron ores of Minnesota and of western New England," by N. H. and H. V. Winchell, appeared in the American Geologist for November, 1890, in which the conclusion is reached from a critical review of the literature that a part of the Eolian limestone, noticeably that in proximity to the *Olenellus* quartzite on the east, must be of Cambrian age.

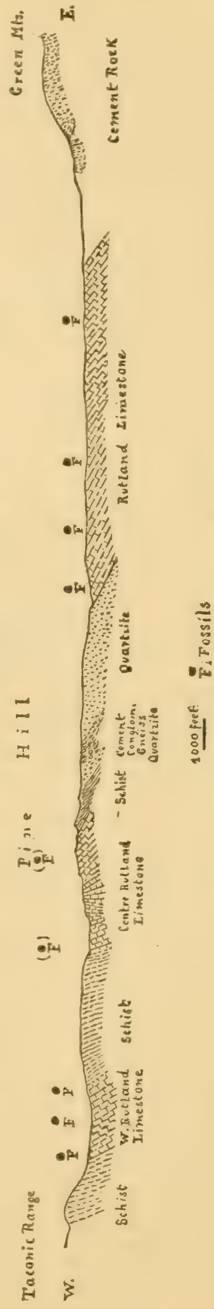

FIGURE 2—*Profile and Section along the line A-B in Figure 1.*

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*3d series, vol. XIII, 1877, pp. 332–347. 405–419.
†Am. Journ. Science, 3d series, vol. XXXV, 1888, pp. 229, 401.

Results of Recent Researches.

Discoveries of Fossils.—During the past summer the writer has spent some time in this region endeavoring to determine the relation of the quartzite series of Pine hill to the similar series of *Olenellus* age in the main range. For a while he had the assistance of Dr. A. F. Foerste, who searched for fossils in favorable places. All but two of the fossil localities were found by Dr. Foerste, to whose trained eye these more important results are due, and whose paleontological determinations are here followed.

The character and position of the rocks are as follows: On the slopes of the "frontal" range the Cambrian quartzite varies greatly in lithological character; it is massive or micaceous, contains beds of schist, and passes into the metamorphic conglomerate and cement which intervene between it and the gneisses proper of the Green mountains eastward. This cement rock contains a small bed or beds of crystalline limestone, the rocks are very much folded, and the structure is complicated by secondary schistosity and cleavage. The dip of the quartzite is eastward and very steep at this point. Its contact with the limestone of the Rutland valley on the west is, at the place of the section (figure 2), covered by drift; but it is found to be conformable further south.

The limestone is variable in character; it is in some beds white, coarsely crystalline; in others fine-grained, gray, dolomitic. It is often filled with small rounded detrital grains of quartz, so that it resembles phases of the quartzite save that the quartz cement is replaced by lime. It has at the place of the section, throughout its width, a low easterly dip, varying between 25° and 30°; sometimes flatter, and rolling. It extends many miles southward in this valley, but toward the north it is cut off by the rocks of Pine hill, which bend around to join the main range of quartzite. In this respect existing geological maps need correction, for in them this limestone is made to join the next belt westward, in Pittsford.

At its western edge the Rutland limestone is found resting conformably on the quartzite of Pine hill, both dipping eastward 25° to 30° and connected by transitional layers of calcareous quartzite. This contact line can be followed from the section northward two miles and eastward one mile, the strike turning to east-and-west with a gentle southerly dip; drift then covers the contact. It is evident, therefore, that the limestone lies in a trough of the quartzite which dies out northward.

At the first favorable locality visited with Dr. Foerste, he found fragments and more or less perfect specimens of a *Kutorgina* of middle or lower Cambrian type; associated fragments seemed to belong to a *Lingula*. This is a mile and a quarter north of Rutland, near the banks of East creek, and about three hundred feet, measured across strata, above the quartzite. The locality is on the Proctor estate, back of the barn. The fossils were found in a fine-grained white limestone, in a layer two or three feet thick, and could be detected for about twenty-five feet along the line of strike.

Dr. Foerste subsequently found similar fragments some hundreds of yards southeast of this locality; and a quarter of a mile southwest of this second locality, and almost on the line of strike, on the western side of a hill quarried for building stone, a third was discovered. The latter localities both lie in the rectangle formed by Grove street, Field avenue, and Main street, two-thirds of a mile north of the depot in Rutland. At the third place, numerous perfect specimens were found of a *Salterella*, closely resembling or identical with the *Salterella curvatus* of the *Olenellus* Cambrian of North Attleboro', Massachusetts. This is some thousand feet of strata, more or less, above the quartzite of Pine hill.

Subsequently the writer found fragments of the *Kutorgina* at two other localities: one nearly in the center of the valley, about two miles north of Rutland, four hundred yards east of the main Pittsford road, and one hundred yards south of a branch road to Mendon; the other about two miles northeast of Rutland, on the main road to Mendon, just through the fence bordering the road and near the eastern edge of the valley.

The quartzite of Pine hill underlying this limestone forms the eastern slope and part of the crest of the hill. It is a massive, vitreous variety, with frequent thin beds of black schist, and dips gently eastward. This passes, on top of the ridge, into a variable series composed of micaceous quartzite, metamorphic conglomerate, cement rock, one small bed of crystalline limestone, and some beds of gneiss, which is the exact counterpart of the similar series belonging with the *Olenellus* quartzite lying *east* of the limestone. This series has a general easterly dip, although highly contorted. It is succeeded by the band of black schist with numerous lenticular quartz layers, the cleavage of which dips rather steeply eastward, though the stratification planes are irregularly crumpled. This lies on the limestone of the Centre Rutland belt in apparent conformity, dipping at the contact from 30° to 60° eastward.

The limestone of this belt is very irregular in dip, which varies from steep eastward to westward. Owing to the apparent conformity of the series and the stratigraphical position of the Pine hill quartzite underlying the Rutland limestone and continuous with the eastern quartzite, Pine hill appeared to be an overturned anticlinal, and the Centre Rutland limestone, therefore, the equivalent in part of the Rutland limestone. No fossils, however, were found in this limestone on the line of section; but on the continuation of the belt south of the railroad Dr. Foerste found three fossil localities.

The first, about three miles south of the railroad, half a mile southeast of Clarendon Springs, is on the north side of a barn standing on the west side of the hill road to Centre Rutland. The bluish sandy limestone contains numerous crinoid stems and occasional plates, and rarely a small branching bryozoan with large cells. The forms are identical with those in the West Rutland valley. The locality is near the eastern border of this (Centre Rutland) belt.

The second locality is a few feet from the contact of this limestone with the schists on the west. It is in the northwestern corner of Clarendon township, in the bed of a stream crossed by the road from West Rutland to Clarendon Springs, about two hundred feet east of the covered bridge. A few crinoid stem rings were found here. This locality is about two and a half miles south of the railroad.

The third locality is barely a mile south of the bend made by the railroad in passing from Centre Rutland to West Rutland. It is on Boardman hill (the southern continuation of Pine hill), a few hundred yards south of the road ascending the hill from West Rutland, three hundred feet northwest from a new marble quarry, and about two hundred feet across the strike from the western edge of the limestone. The fossils found consist of a few crinoid stems.

The belt of limestone in which the fossils occur at these three localities was traced almost without break to Centre Rutland and into the Centre Rutland belt. In the same way the schists bounding it on the west were followed into the schist ridge separating the Centre Rutland and West Rutland limestone belts.

It seems therefore established that the Centre Rutland belt is of the same general age as that of West Rutland ("Trenton-Chazy-Calciferous"), and that the Cambrian Rutland limestone is either not represented in it at all, or at best by a very small strip.

Conclusions as to Structure.—The writer has given little attention to the structure of the schists between the Centre Rutland and West Rutland valleys. The cleavage dips steadily eastward, but the positions of the stratification planes can be seen to vary greatly both in direction and amount of dip, so that only careful study can determine the true structure. The same statement must be made regarding the West Rutland limestone and the schists of the Taconic range beyond.

The facts here stated prove that the limestone of the Rutland valley is of lower Cambrian age; that in Pine hill it overlies conformably a massive quartzite, with associated beds of metamorphic conglomerate, cement rock, crystalline limestone, and gneiss, which bend around to join the similar series lying east of the limestone; and that the Pine hill quartzite must therefore be of *Olenellus* age, while the limestone, bounded on the east and west by the quartzite series and disappearing to the north, lies in a trough of the quartzite.

The whole series has an easterly dip, but the apparent great thickness of the Cambrian limestone—3,000 feet, if the strata lie in a simple overturned synclinal—seems improbable, especially as it is near the shallow ending of a trough. Repeated folding of a thinner series may have produced this structure.

Whatever be the true thickness of the limestone, it cannot be represented in the Centre Rutland belt, since the fossils make this Lower Silurian; hence, either (1) the Pine hill series is younger than the Cambrian limestone (underlying it by inversion) and there is a continuous inverted series from the eastern *Olenellus* quartzite to the Lower Silurian limestone; or (2) the Pine hill series is Cambrian, underlying the Rutland limestone as an anticlinal overturned toward the west, and the great thickness of limestone and quartzite is absent on the western side or represented by the Pine hill schist only, through sudden change of deposition; or, more probably, (3) that a great thrust plane exists on the western side of Pine hill, by which the Cambrian is made to lie on the Lower Silurian limestone.

The first explanation seems impossible on account of the trough structure of the Cambrian limestone and the perfect lithological identity of the Pine hill series with the eastern quartzite series. The second, while not impossible in this region, in which the Cambrian beds are liable to sudden great changes in thickness and lithological character, is certainly improbable; and the third therefore remains as a working hypothesis, to be established by further discoveries of fossils and observation of the actual thrust plane. The writer is inclined to place this on the western face of Pine hill, at the junction between the limestone and schist band, where indications, but not decisive proof, of such a thrust plane have been observed.

No statement is here made as to the age of the schists in the next ridge westward or in the Taconic range, nor as to the true structure of this part of the section.

DISCUSSION.

Mr. J. F. James: The discovery of fossils in the limestone of Rutland, as noted by Dr. Wolff, is of interest, inasmuch as it establishes a new locality for Cambrian strata. The lower Cambrian has a great thickness in Washington county, New York, to the southwest, and at Georgia, Vermont, to the north of Rutland; and while the presence of the fossils mentioned (*Kutorgina* and *Salterella*) is perhaps sufficient to indicate rocks of *Cambrian* age, it seems rather slender data, in a region where the structure is so complicated, to state the exact horizon to which the strata should be referred. As, however, the rocks in both Washington county and in Georgia are of lower Cambrian age, it seems probable that the "*Olenellus* quartzite," as it is termed by Dr. Wolff (although *Olenellus* is not stated to be found in it) is really lower Cambrian. Further information is greatly needed to settle this point, and it is hoped that Dr. Wolff will be able, from future investigations, to furnish the information.

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VOL. 2, PP. 339-348 MARCH 18, 1891

COMPOSITION OF CERTAIN MESOZOIC IGNEOUS ROCKS OF VIRGINIA.

BY H. D. CAMPBELL AND W. G. BROWN.

(*Read before the Society December* 30, 1890.)

CONTENTS.

GENERALLY UNIFORM COMPOSITION OF MESOZOIC TRAP.

No one has ever studied the earlier Mesozoic formation along the Atlantic border without being struck by the numerous ridges and dikes of trap which are found in connection with it, and no one has ever studied the trap found in these ridges and dikes without being impressed by its uniformity of composition.

J. D. Dana* has pointed out the wonderful uniformity of these eruptive rocks, calling them all dolerites; rocks made up essentially of labradorite and pyroxene, with more or less magnetic iron ore in disseminated grains or crystals. He says that the aspect of specimens from Nova Scotia to North Carolina is closely the same, and that the density varies little from 3. The lowest density which he quotes is 2.94, and the highest 3.16.

Chemical analyses of these rocks by G. H. Cook,† W. G. Mixter,‡ S. T. Tyson,§ F. A. Genth || and G. W. Hawes ¶ all show their chemical composition

* Am. Jour. Sci., 3d ser., vol. VI, 1873, p. 105.
† Geology of New Jersey, 1868, p. 215; Am. Jour. Sci., 3d ser., vol. VI, 1873, p. 106.
‡ Am. Jour. Sci., *loc. cit.*
§ *Loc. cit.*, p. 107.
|| Geol. Surv. Pa., Report C, 1874, p. 122; and Report CCC, 1877, p. 275.
¶ Am. Jour. Sci., 3d ser., vol. IX, 1875 p. 185.

to be nearly the same. The large amount of magnesia (10.3 per cent.) in G. H. Cook's analysis of the trap from the palisades of the Hudson is worthy of notice.

E. S. Dana* made a microscopic examination of numerous specimens of trap from Connecticut, and of a few individual specimens from Nova Scotia, New Jersey, Pennsylvania and North Carolina, and found that, so far as microscopic structure goes, the rock from these distant localities is hardly to be distinguished from the trap of the Connecticut valley. He gave the composition of the rock to be "pyroxene, labradorite and magnetite, with also occasionally some chrysolite and apatite." He, too, called it dolerite.

G. W. Hawes† discovered a glassy ground-mass in certain modifications of these rocks, and mentioned the occasional presence of biotite and hornblende. Excepting local modifications, he considered the rocks to be like the ordinary old diabases, and in microscopic features to be monotonously alike wherever fresh stones occur.

J. P. Iddings‡ examined microscopically the igneous rocks occurring in the earlier Mesozoic area at Orange, New Jersey, and found some of them to be holocrystalline and others to contain glass. He says the former should be called dolerites and the latter basalts.

N. H. Darton, § in speaking of the igneous rocks of the New Jersey Mesozoic region, says that they are remarkably uniform petrographically, as they are all basalts, varying mainly in structure and development.

These references are sufficient to show that the trap rocks of the earlier Mesozoic areas upon the Atlantic border have been considered essentially alike in mineral and chemical composition, whether called dolerites, diabases, or basalts.

Traps of exceptional Composition.

Varieties.—We are glad to be able to bring to notice two interesting varieties to break the monotony of these igneous rocks. On account of the conspicuous occurrence of hypersthene in one variety, and of olivine together with hypersthene in the other, we have called the former *hypersthene-diabase* and the latter *olivine-hypersthene-diabase.*

The palisade area of Triassic rocks extends from the Hudson river, through New Jersey, Pennsylvania and Maryland, into Orange county, Virginia. As early as 1839, W. B. Rogers|| called attention to the trap of the part of this area lying in Virginia as being a very conspicuous feature from a geological point of view. He mentioned the occurrence of ridges, knobs and

* Am. Jour. Sci., 3d ser., vol. VIII, 1874, p. 390.
† Proc. U. S. Nat. Mus., 1881, p. 129.
‡ Am. Jour. Sci., 3d ser., vol. XXXI, 1886, p. 331.
§ Bulletin U. S. Geol. Survey, no. 67, 1890, p. 15.
|| Geology of the Virginias, 1884, p. 475.

dikes of "greenstone," composed of hornblende and white feldspar. It was in a specimen from Culpeper county, Virginia, near the southern end of this Triassic area, that we first noticed the presence of hypersthene.

Localities of Occurrence.—A few localities where the rocks to be described below occur in their typical form may be mentioned:

About three miles north of Rapidan, a station on the Virginia Midland railroad, are to be seen two rounded knolls of similar shape and size, as rather conspicuous objects in the landscape. They are sometimes called the "Twins," although several other names are given to them by the people in the neighborhood. On the top of the knob nearer to the railroad, beautiful perpendicular, pentagonal and hexagonal basaltic columns form the face of a cliff. Some of these columns are sixty feet high and from twenty to twenty-five feet in diameter. A ridge runs around from one knoll to the other, making a curve like a horseshoe. The cliffs face the center of the curve. The stone from the side of the "Twins" is quarried under the name of granite. It is in reality hypersthene-diabase. Along the railroad between Rapidan and Mitchell stations for a mile or more the same rock appears in the cuts.

A few miles east of Culpeper Court-House, Mount Pony stands out prominently as an isolated peak, commanding such an extensive view from its summit that it has been used as a signal station upon various occasions. The greater part of this peak is composed of a rock of the same character, although the hypersthene is less conspicuous in it than in the other specimens.

Not far east of Brandy station, on the same railroad, a hummock called the "Dumpling" is hid away in the woods. This hillock is composed of the same rock. Other knobs and dikes occur in this region.

Similar rocks occur in New Jersey and Pennsylvania, as we have learned through the courtesy of Mr. N. H. Darton, who kindly put into our hands for examination the collection of New Jersey trap rocks made by him for the United State Geological Survey. In the thin section number 152, from "three miles south of Milford, New Jersey, in Pennsylvania," we find hypersthene to be abundant. The rock seems to be identical with that from the "Twins." Section number 294 shows the same rock as occurring at Point Pleasant, New Jersey. With reference to the latter rock Mr. Darton says* that it is very similar to the typical palisade trap. Several other of these sections show the probable presence of an orthorhombic pyroxene.

These localities will suffice to show that the hypersthene-diabase is not merely a local variety.

At only one locality have we thus far noticed the olivine-hypersthene-diabase. A dike of considerable width occurs crossing the Virginia Midland

* Bulletin U. S. Geological Survey, no. 67, 1890, p. 68.

railroad in Culpeper county, Virginia, about two miles north of Rapidan station. This rock weathers into globular masses and contains olivine throughout, so far as we could judge from making numerous thin sections.

Description of the Hypersthene-Diabase.—The hypersthene-diabase has a medium grain and is of a dark-gray color. The darker varieties have a somewhat greasy luster. The unaided eye can detect two dark minerals, the one nearly black, and the other deep honey-yellow or brown in a very light-colored background. Sometimes the light material occurs as small irregular veins running through the darker rock.

In thin sections we were able to distinguish triclinic feldspar, diallagic augite, hypersthene, biotite, apatite and occasional quartz, hornblende and probably zircon. Black opaque grains were also present, and as these were magnetic and some of them showed a trace of titanium, they were considered to be magnetite and ilmenite.

The structure is generally ophitic. It seems to be intermediate between the granular structure of gabbros or norites and the porphyritic structure of the holocrystalline varieties of the augite-porphyrites, shading sometimes into the former, sometimes into the latter. It is owing to the predominant ophitic structure alone that we place these rocks among the diabases. The mineral composition would give them a place among the gabbros, for the monoclinic pyroxene is diallagic. The hypersthene, however, more closely resembles that found in the hypersthene-andesites. These rocks afford another illustration of the view that the difference between gabbros and diabases is structural rather than mineralogical.

Constituents of the Hypersthene-Diabase.—The feldspar makes up all of the light material which is visible to the naked eye. In thin sections under the microscope it appears principally as lath-shaped crystals, polysynthetically twinned. In typical specimens these crystals are rarely larger than 1.5 mm. in length by 0.3 mm. in width, the majority being much smaller than these. Tabular crystals also occur, but they are not very common. Truly idiomorphic crystals are rare. Zonal structure is frequently visible with crossed Nicols, and the angle of extinction of the central part is greater than that of the margins. Minute crystals of apatite and other inclosures occur here and there. The angle of extinction, measured between twins which extinguish equally on two sides of the twinning plane, was as large as 36° in a number of instances, which points to the presence of anorthite.

Two analyses of pure white material, separated by means of the Klein solution, between the densities 2.672 and 2.704 gave the following results:

Analyses of Feldspar.

	I.	II.	Ratio of I.	
SiO_2	51.40	51.03	.856	.856
Al_2O_3	30.98	31.15	.304	.305
Fe_2O_3	.22		.001	
MnO	trace	trace		
CaO	13.40	13.92	.240	.250
MgO	.45	.59	.010	
K_2O	.39	.39	.004	.050
Na_2O	2.85	2.85	.046	
	99.69	99.93		

$\overbrace{R_2O : RO}: R_2O_3 : SiO_2 = \overbrace{1 : 5} : 6 : 17$, which gives 5 $(Ca_2Al_4Si_4O_{16})$: 2 $(Na_2Al_2Si_6O_{16})$ or 5 An : 2 Ab.

The analyses show this part of the feldspar to be labradorite. The optical properties mentioned above point to the presence of anorthite. We judge, therefore, that there are at least two varieties of feldspar present.

The monoclinic pyroxene is nearly black when the grains of it are seen in reflected light. In thin sections the grains always have an irregular outline. Very feeble diochroism from greenish gray to greenish yellow can be detected. In most sections the interference colors are brilliant. Crystals cut parallel to the clinopinacoid show an angle of extinction slightly greater than 40°. Sections in which the perfect prismatic cleavage is at right angles give an axis in converging light. Such sections also show cleavage parallel to the clinopinacoid and interpositions and cleavage parallel to the orthopinacoid. This latter cleavage is the principal, if not the only, way of distinguishing between diallage and augite in thin sections. The resemblance to the diallagic augite, described by E. Boricky as occurring in the melaphyres from Bohemia,* is in some particulars quite striking. The interpositions are so numerous as to give the augite a fibrous appearance in ordinary transmitted light. They can be resolved with a high power into fine needles lying in planes parallel to the base, with their long direction parallel to the orthodiagonal. Hence, in sections from the orthodiagonal zone, they appear as parallel lines of acicular microliths, while in clinopinacoidal sections they appear as points, arranged in lines making an angle of about 74° with the prismatic and pinacoidal cleavages.

Simple and polysynthetic twinning parallel to the orthopinacoid is quite common. Clinopinacoidal sections of such twins show the lines of interpositions meeting each other at an angle of about 150°. In polarized light, lamellæ parallel with these lines indicate polysynthetic twinning parallel to the base.

The diallagic augite is the first mineral in this rock to undergo decomposition.

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* Rutley; The Study of Rocks, 1880, p. 125.

Two analyses of fresh material from the "Twins" separated by the Klein solution between the densities 3.105 and 3.29 gave the following results:

Analyses of Diallagic Augite.

	I.	II.	Mean.	Ratio.	
SiO_2	49.01	49.66	49.33	.822	.822
Al_2O_3	8.85	9.44	9.15	.089	.091
Fe_2O_3	none	.54	.27	.002	
FeO	9.05	9.05	9.05	.126	.783
MnO	trace	trace	----	---	
CaO	16.94	15.89	16.36	.292	
MgO	14.51	14.66	14.58	.365	
K_2O	.19	.19	.19	.002	.010
Na_2O	.55	.55	.55	.008	
Ignition	.25	·25	.25		
	99.35	100.23	99.73		

$RO : R_2O_3 : SiO_2 = 17 : 2 : 18.$

Characters of the Hypersthene.—Hypersthene is the most conspicuous mineral in the typical specimens of this rock. The grains, when isolated, are of a deep honey-yellow color. They are usually larger than those of the augite, and have a better defined outline. Under the microscope they are strongly pleochroic. Rays vibrating parallel to the brachydiagonal are brownish-red; those vibrating parallel to the macrodiagonal are yellow; those vibrating parallel to the vertical direction are green.

In thin sections this pleochroism is distinct but not so marked. When the sections are very thin it is quite feeble. The crystalline form is fairly well defined, but the edges are usually irregular, owing to penetration by the smaller crystals of feldspar. When cut parallel to the prismatic zone the crystals are two or three times longer in the direction of the vertical axis than in the other direction. The length rarely exceeds 4 mm., and is more frequently only about 2 mm. Sections perpendicular to the vertical axis show the prisms truncating the edges between the much more strongly developed pinacoids.

Cleavage parallel to the prism of about 92°, as well as cleavages parallel to the brachypinacoids and macropinacoids, can be seen in cross-sections of these crystals. Imperfect cleavage perpendicular to the vertical axis and others parallel to the terminal faces are seen in longitudinal sections.

The interference colors are low compared with those of augite.

The direction of extinction is parallel to the pinacoidal cleavages and diagonal to the prismatic. Hence all sections will extinguish parallel to the longitudinal direction of the crystals.

Sections which show yellow and green pleochroism give an acute bisectrix in converging light. Sections showing prismatic cleavage at right angles give an obtuse bisectrix in converging light. Hence the optical character of the mineral is negative, since the vertical direction is that of least elasticity.

The inclosures so commonly found in massive hypersthene are entirely absent. The mineral has the same microstructure as the hypersthene which occurs in the porphyritic rocks. Well defined crystals of feldspar and grains of augite are nearly always inclosed in the hypersthene crystals. Bands of augite are sometimes intergrown with the hypersthene.

An intergrowth between hypersthene and a colorless mineral, which is probably plagioclase, exhibits granophyre structure in a section from the "Dumpling."

The material for the analyses I and II, given in the table below, was separated by the Klein solution at the density 3.356, after removal of the magnetite. The grains seemed to be fresh and pure when examined under the microscope.

Analyses of Hypersthene.

	I.—Twins.	*II.—Twins.*	*Mean.*	*Ratio.*		*III.—Buffalo Peaks.*
SiO_2	52.06	52.256	52.16	.886	.886	50.043
Al_2O_3	2.97	3.03	3.00	.030	.033	2.906
Fe_2O_3	0.26	0.64	0.45	.003		
FeO	15.16	15.16	15.16	.210	.868	17.812
MnO	0.37	0.35	0.36	.005		0.120
CaO	6.00	5.88	5.94	.106		6.696
MgO	21.82	21.96	21.89	.547		21.744
K_2O	0.04	0.04	0.04	.0004	.003	0.274
Na_2O	0.16	0.16	0.16	.0026		
Ignition	0.08	0.08	0.08			
	98.92	99.55	99.24			99.595

$RO : R_2O_3 : SiO_2 = 27 : 1 : 28.$

Upon comparing the analyses of the hypersthene from the "Twins" (I and II) with the analysis (III) by W. F. Hillebrand* of the hypersthene occurring in the hypersthene-andesites from Buffalo peaks, Colorado, it will be seen that the resemblance is as striking as that shown by the examination of thin sections.

Associated Minerals.—Biotite occurs in minute crystals here and there throughout the rock. Its outline is usually irregular, but occasionally angles of 120° were measured in basal sections. It occurs usually among the crystals of feldspar, either alone or surrounding magnetite. It may also be seen within the hypersthene and augite or along the edges of these minerals.

The apatite occurs inclosed in the feldspar or in the other minerals, having the form of fine needles.

*"On hypersthene-andesite," etc., by Whitman Cross: Bulletin U. S. Geol. Surv., no. 1, 1883, p. 29.

Quartz was noticed under the microscope in the rock from the "Dumpling" as isolated grains with fluid inclosures, and also intergrown with the feldspar, showing granophyre structure.

Green hornblende has been noticed in several sections.

Description of the Olivine-Hypersthene-Diabase.—This rock has a coarser grain, a more greasy luster and a darker color than the one described above. It weathers into globular masses. In thin sections the crystals of hypersthene are conspicuously larger than in the other rock, some of them measuring 6 mm. in length and 3 mm. in width. Olivine occurs quite abundantly as fresh crystals, with well defined outline, varying in size from 0.2 mm. to 4 mm. in diameter. Alteration has begun to take place along only the cracks. Biotite seems to be more common in this rock than in the hypersthene-diabase. The other constituents of the latter rock make their appearance here also, with perhaps the exception of quartz, which we have not observed.

The composition of this rock and its relations to the hypersthene-diabase as well as to a normal Mesozoic diabase from Connecticut are shown in the following analyses:

Chemical Analyses of Diabases.

	I.—Hypersthene-diabase. *Sp. gr.* = 3.09.	*II.—Olivine-hypersthene-diabase.* *Sp. gr.* = 3.10.	*III.—Diabase. West Roek, New Haven.* *Sp. gr.* = 3.03.
SiO_2	51.31	50.88	51.78
Al_2O_3	13.64	13.17	12.79
Fe_2O_3	0.52	1.11	3.59
FeO	8.49	9.66	8.25
MnO	trace	trace	0.44
CaO	12.41	10.19	10.70
MgO	12.73	13.05	7.63
K_2O	0.32	0.31	0.39
Na_2O	1.40	1.17	2.14
TiO_2	trace	----	1.41
P_2O_5	trace	----	0.14
Ignition	----	0.14	0.63
	100.82	99.67	99.89

The material chosen for analysis was perfectly fresh. The hypersthene-diabase (I) came from the quarry on the "Twins," in Culpeper county, Virginia. The olivine-hypersthene-diabase (II) came from a dike in the railroad cut not far from the "Twins."

We wish to call attention to the occurrence of hypersthene, a mineral rich in magnesia, in a diabase (I) which contains a large percentage of magnesia (12.73 per cent.) in contrast with the absence of this mineral in the normal diabase (III), which contains a very much smaller percentage of magnesia (7.63 per cent.). The olivine, together with hypersthene, also occurs here in a diabase rich in magnesia (13.05 per cent.). It will be interesting to determine whether such a relationship exists between the mineral and chemical composition of all the diabases of the Atlantic border.

In the above paper the chemical work is by W. G. Brown, the petrographical work by H. D. Campbell, and the conclusions by both.

Washington and Lee University,
Lexington, Va., *December*, 1890.

DISCUSSION.

Professor W. M. Davis: How does this variation in the composition of the Mesozoic traps affect Professor Dana's statement that their uniformity of composition is evidence of derivation from great depth?

Dr. J. E. Wolff: A colorless orthorhombic pyroxene is a constituent in certain Connecticut traps.

Mr. F. L. Nason: In New Jersey, at Bull's island, a light-colored variety of trap occurs which evidently contains a considerable element of pyroxene. There seems to be a progressive change in the chemical composition of the traps from the palisades southward.

Professor B. K. Emerson: Is there any distinction of degree of change in these rocks? The larger trap sheets in New England were more chloritized than the smaller sheets.

Dr. G. H. Williams: Hypersthene and olivine occurring together are found to play a complementary rôle in volcanic rocks. In the large eruptive area of the hypersthene-gabbros of Baltimore the magma is completely differentiated. In certain facies, the alumina nearly disappears, and with it all of the feldspar. The remaining magma crystallizes, if the proportion of silica is high (54 per cent.), as a pure pyroxene rock (pyroxenite); if, on the other hand, the proportion of silica is low (45 per cent.), as a pyroxene-olivine rock (peridotite).

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THE CINNABAR AND BOZEMAN COAL FIELDS OF MONTANA.

BY WALTER HARVEY WEED.

(*Read before the Society December* 31, 1890.)

CONTENTS

THE DISTRIBUTION OF COAL IN MONTANA.

The coal-bearing rocks of Montana belong to three geological horizons, all of Mesozoic age, and over three-fourths of the 145,000 square miles comprised within the boundaries of the state is underlain by these rocks. The larger part of the great plains, that monotonous expanse of arid, treeless country forming the eastern two-thirds of the state, is underlain by seams of lignite, which occurs in great quantity and is often of exceptional purity. The banks of the smaller streams and the bluffs of the rivers very frequently show the outcrops of these lignite seams, and their dark lines can be traced continuously for many miles in the buttes of the so-called "bad lands."

Approaching the mountains, the low relief of the plains is broken by outliers of the Rocky Mountains, and as we near the eastern slopes of these ranges the younger strata of the plains are found to be upturned upon the

Paleozoic rocks, which rest at steep angles against a core of metamorphic gneisses and granites. At the base of the mountains are the seams of coal which form the chief source from which Montana's great mining and smelting industries must derive their supply of fuel. Unlike the lignites of the plains, these are true bituminous coals of excellent quality, and vary from dry steam coals to excellent coking varieties. These bituminous coals are all older than the lignites, and belong to two geological horizons: Those of Sand coulée, Deep creek and other localities in the vicinity of Great Falls, on the Missouri, have recently been determined by Professor J. S. Newberry to be of Kootanie age. In Montana the Kootanie rocks have not been found on the eastern slopes of the Rockies, save in the vicinity of Great Falls and in the Judith basin. Over half the entire coal product of the state is obtained from strata of later age, which are found in the two fields forming the subject of this paper.

The relative amounts of coal mined in the state in 1889, from the three geological horizons, were as follows:

Lignite	5,263 tons.
Later Cretaceous	191,138 "
Kootanie	166,480 "

These amounts will be exceeded during the present year (1890), but the figures will show quite as small a percentage of lignite mined, despite the wide range of this variety of coal throughout the state. So far as known, the bituminous coals are limited in their occurrence to the eastern and mountainous regions of the state.

Aside from the Kootanie coals of Great Falls, bituminous coals are known to occur only in the following fields: In the Upper Gallatin basin; near Virginia City; in the Cinnabar field on the Upper Yellowstone; in the so-called Bozeman coal field, and in its continuation eastward, the Rocky fork field.

The Cinnabar field was studied in some detail last summer, in connection with a geological examination of the region for the United States Geological Survey, in continuation of the geological survey of the Yellowstone National Park under Mr. Arnold Hague, and the identity of its coal-measures with those of the Bozeman field was established. The coal-bearing strata of the latter field were traced for a distance of about 100 miles.

The Cinnabar Coal Field.

Location.—The small field known by this name is immediately north of the Yellowstone National Park, on the banks of the Yellowstone river. After leaving the deep cañons of the Yellowstone National Park, the Yellowstone river flows through a narrow valley, in which Cinnabar mountain is a small but conspicuous topographic feature, through Yankee Jim cañon to the broad mountain-encircled Paradise valley, and thence onward through the Gate of the Mountains to the terraced valley about Livingston, where it begins its long wanderings through the plains of Montana.

The Cinnabar coal field takes its name from Cinnabar mountain, a low mass of upturned strata exposing a fine section of the geological series from the Archean to the coal-measures of later Cretaceous age. The title of the mountain is a misnomer, however, since the bright red streak forming so prominent a feature in its structure is a band of red sandstone, probably of Triassic age.

General Geology.—On the western side of the valley the coal-bearing strata form a high and flat-topped mountain ridge, extending down from the sharp and rugged summit of Electric peak, the highest point in the region, and ending in the upturned strata of Cinnabar mountain. North of this block of Cretaceous coal-bearing strata there is an extensive area of volcanic rocks that form the rugged mountain peaks of the Gallatin range, and consist of breccias of fragmental volcanic ejectamenta, together with numerous flows of andesite and basalt. A fault, whose line corresponds very nearly with the course of Cinnabar creek, brings the sandstones of the coal-bearing strata directly against these volcanic rocks.

On the east an equally profound fault separates the sedimentary beds from the breccias forming Sepulchre mountain—a rugged mass of lava which lies between the coal-bearing rocks of Electric peak and those within the Yellowstone National Park which form Mount Evarts.

On the eastern side of the valley the steep slopes of Sheep mountain rise abruptly from the river, and the gneisses and granite extend eastward beneath the volcanic breccias, which form a series of snowy mountain peaks. In the upper or southern portion of the valley, a narrow block of coal-bearing rocks is found on the northeastern side of the Yellowstone river, the beds dipping steeply toward a fault which separates them from the gneisses toward the north. They are capped by a sheet of basalt, which is in turn overlain by very extensive deposits of hot-spring limestone or travertine, formed by springs of which no other traces now remain.

The Mesozoic Section.—In the upturned beds of Cinnabar mountain may be seen a section giving the relations of the Cinnabar coals to the older rocks. Resting upon metamorphic gneisses there lies about 2,500 feet of limestone, the upper portion containing Carboniferous fossils. The beds are vertical, but are so crushed that the Carboniferous, Devonian, Silurian, and Cambrian strata are not readily separated. Above these limestones there is an arenaceous zone, overlain by the vermilion-red sandstone forming the Devil's

Slide. The following section shows the sequence of the beds from the coal-bearing strata down to the Carboniferous limestones (the same sequence being represented graphically in plate 13, figure 1):

The Cinnabar Section.

	Number of bed.	*Thickness in feet.*	
Laramie.	29	800	Sandstones, containing coal.
	28	5	Coal seam.
	27	125	Sandstones, white, massive, cross-bedded.
Colorado and Montana.	26	240	Fissile, argillaceous sandstones and shales.
	25	450	Shales, generally crumbly, with layers of black bituminous shale and harder sandy ledges.
	24	225	Shaly sandstones and limestones.
	23	40	Sandstone.
	22	165	Sandy, splintering, gray shales and limestones.
	21	500	Black bituminous shales.
	20	40	Limestone.
	19	400	Black shales, sometimes arenaceous.
	18	10	Sandstone.
	17	250	Black and dark-blue shales.
	16	15	Sandstone.
	15	75	Sandy shales.
	14	10	Sandstone.
	13	340	Thinly laminated arenaceous shales.
	12	15	Sandstones.
	11	75	Shales.
Dakota.	10	30	Quartzite.
	9	10	Limestone.
	8	150	Sandy shales.
	7	50	Red earthy limestones, magnesian.
	6	40	Conglomerate.
	5	95	Sandstone and shales.
	4	151	Sandstone.
Jurassic.	3	85	Red earths.
	2	20	Coarse, arenaceous limestones.
	1	160	"*Myacites* beds." Earthy, crumbling limestones.

The lowest beds in this section, designated as Jurassic, are earthy, crumbling limestones, characterized by numerous fossils, *Myacites subcompressa* being extremely abundant, together with many other forms common to the Rocky Mountain Jura, such as *Gryphœa*, *Pinna*, *Trigonia*, *Gervillia*, *Pentacrinus asteriscus*, etc.

Overlying these Jurassic shaly limestones is a hard ledge that is often a coarsely crystalline limestone, passing into sandstone and even into grits and conglomerates. It is characterized by an abundance of shell fragments, with many specimens of *Rhynchonella myrani*, *Camptonectes*, and other Jurassic forms. This horizon is very persistent, occurring wherever the Jurassic has been identified in the mountains of Montana, and forms a very useful datum plane in looking for the coal-bearing strata.

The conglomerate bed (number 6 of the section) undoubtedly represents the Dakota, but no fossils have been found either in it or in the transitional sandstones. Above this Dakota conglomerate there is a very persistent bed of limestone (number 9 of the section), which is distinguished by great numbers of small gasteropod shells, undoubtedly a fresh-water species, but as yet neither identified nor described. Above the limestone lies a bed of very dense quartzite (number 10), which has yielded no fossils.

In the shaly sandstones above the quartzite (number 12), specimens of the peculiar *Ostrea anomioides* have been found, both in this and in other localities. Above these shaly sandstones there is a series of beds which, in this section, are not like typical Fort Benton shales, but are harder and more sandy and include sandstone layers. Number 21 of the section is, however, a crumbly, black, bituminous shale, weathering down to a black earth, and these beds gradually pass into sandy shales, often rather hard, and weathering out as ledges. Where this series (numbers 21 to 26) is exposed in a cliff face, as is the case on the eastern side of the Electric-Cinnabar mountain ridge and in the cañon of Gardiner river, inside the national park boundary, they appear as leaden-gray, thinly bedded muddy limestones, with square jointing and numerous harder brown layers which sustain the vertical face of the cliff, the whole exhibiting the usual facies of the marine Cretaceous series. These beds form the sag south of Cinnabar mountain.

Above these muddy sandstones and shales there is an abrupt change in the sedimentation to creamy white, quite pure sandstones (numbers 27 to 29). The coal seams of workable thickness all occur in this series of very light-colored, cross-bedded sandstones, which aggregate some 600 feet in thickness. Although generally rather soft and sometimes loosely compacted rock easily crumbled between the fingers, these sandstones frequently form conspicuous bluffs, the underlying beds often weathering into steep and bare slopes capped by mural ledges of this sandrock series.

These coal-measure sandstones are very generally cross-bedded, while a predominating leafy structure is conspicuous on weathered surfaces, the rock splitting into plates of one-half or even one-quarter of an inch in thickness. This structure produces very picturesque forms of weathered ledges. Although the coal-measure series is generally sandy, there are thin belts of shale and clay associated with the many thin seams of coal.

The Coal-Measures and the Workings.—The accompanying figure 1 shows the number and relative position of the workable coal seams at the various openings in this field. As, however, the outcrops of the coal seams are always covered by débris and sand, it is impossible to obtain a perfect section showing all the seams.

The sections made at the Horr and Craig mines show three workable seams, and it was noticed that while there is little doubt that the same seams of coal are worked at these two mines, yet the thickness of sandrock between them varies at the two localities. Careful measurements made in prospecting the field show that the thickness of sandstone between the two upper seams varies from 180 feet to 200 feet. At present, coal is mined at three localities, the Horr mine being the most important. The company controlling this mine own the extreme end of the Electric spur. The workings are all in faulted blocks, which was at first supposed to preclude the possibility of successful mining. A large block about a mile wide at the northern end of this ridge has been dropped some 600 feet by a fault, while the extreme end is formed of smaller blocks tilted at various angles. The coal is of excellent quality, however, and makes such fine coke that it has secured a ready market, and considerable mining has been done.

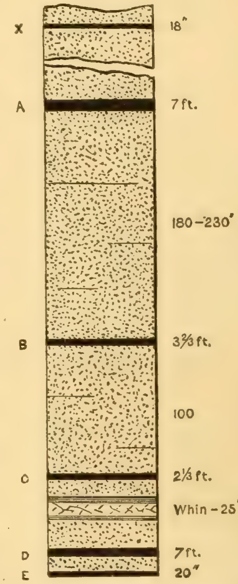

FIGURE 1—*Section of the Cretaceous Coal-Measures of the Cinnabar Coal Field.*

The oldest opening was in the lowest of the three workable seams, and was mined to the extent of 100 tons a day. A new tunnel is now worked in the northern part of the property, in the same seam, and a considerable output comes from a tunnel in the middle main seam (or *B*). The total output for 1889 was 22,400 tons. It was expected that the output for December (1890) would exceed 250 tons a day. The upper seam has not been mined as yet, though the outcrop has been opened at a few places to ascertain its character.

The present workings consist of the three tunnels mentioned, the coal being mined by the ordinary methods.

The sections represented in figure 2, taken at the ends of the tunnels at the different mines, show the character of the lower seam now worked.

The lowest seam (*E*, figure 1) found at the Horr workings is about one foot thick. Some 30 feet above it is the lower of the two seams now being worked. Above this seam the sandstone is broken by a layer of intrusive rock, called "whinstone" by the miners, which is about 10 feet thick. Three feet above this layer the baked shale carries fossil leaves. An examination of the mine shows this seam to vary considerably in thickness, the bed rolling, and the dip, which is some 20° at the opening, increasing to 60° within 300 feet from the mouth of the tunnel.

The southern entry is the old opening on the lower of the coals. The seam, as exposed here, shows the rapid variation of the benches. Thus one section shows the following thicknesses: top coal 12 inches, parting 36 inches, lower coal 36 inches; while on the southern side of the same workings the top coal is 36 inches and the bottom coal 12 inches, with the same thickness of parting.

The "main" or middle seam (*B*, figure 1) is overlain by a heavy, massive sandstone, which forms a smooth and hard roof, requiring but little timbering.

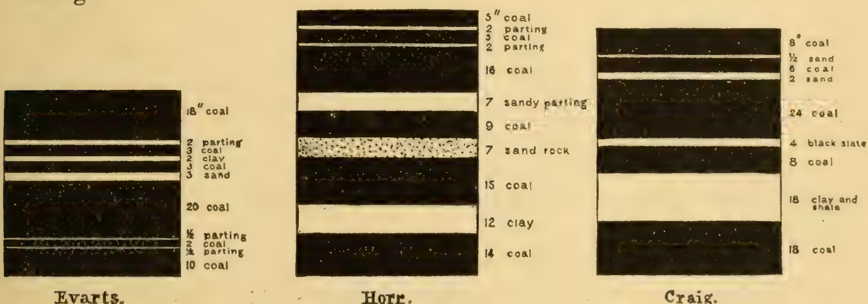

FIGURE 2—*Sections of workable Coal Seams in the Cinnabar Field.*

Notwithstanding the disturbances to which this part of the field has been subjected, it will no doubt be thoroughly exhausted before abandonment, owing to the excellent quality of coal which the seams yield.

The most promising part of the Cinnabar field is southwest of the Horr workings. The slope east of Cinnabar creek is dotted with prospect holes, and the coal seams have been traced southward to the park boundary and the base of Electric peak. A part of this area is controlled by the company now developing the Craig mine.

The sag south of Cinnabar mountain is formed of the argillaceous rocks underlying the coal-measure sandstones, somewhat crushed and broken by the sharp synclinal break. South of this sag the coal-bearing sandstones form outcropping ledges dipping toward the west. Near the little lake back of Cinnabar mountain these sandstones end in a very sharp synclinal upturn, which brings up the underlying argillaceous series, faulted against volcanic rocks. The three entries of the Craig mine are driven in the coal seams at this synclinal, the longest being made for an expected output of 500 tons a day.

On the eastern side of Yellowstone river the Bowers mine is the only one now worked. The mine is in a triangular block of the coal-measures, lying faulted against the gneiss on the northern side of Trail creek. The coal is excellent and meets with a ready market, but the property must necessarily be limited by the fault, although the owner is convinced that the coal runs under the gneiss.

An incline follows the coal, which dips eastward at an angle of 40° at the surface, but becomes 60° some 100 feet below. At present this incline is 175 feet deep, and the seam is but little worked on the levels. The seam shows two to three feet of clean, brilliant coking coal, underlain by a thin parting, with a lower bench of bony coal that is not worked.

About 40 feet above this seam the outcrop of another large seam shows the following section:

Top coal	15	inches.
Fire-clay	4	"
Coal	30	"
Clay	½	"
Coal	3	"
Parting	¼	"
Bottom coal	4	"

An igneous rock similar to that found at the Horr mine occurs in the coal rocks on this side of the river, and is clearly intrusive, cutting across the beds.

A section of the beds on the southern side of Trail creek, at the Bowers mine, shows eleven seams of coal aggregating 21 feet; but only two of the seams can be worked. The following section shows the position of the veins:

Section of Coal-Measure Sandstone at the Bowers Mine.

Number of bed.	*Thickness in feet.*	
28	30	Massive sandrock, firm, light-gray.
27	½	Coal seam.
26	10	Sandstone, breaking into small angular fragments.
25	1	Shale, dark-gray.
24	6	Coal seam.
23	12	Shale, hard and slaty.
22	10	Sandstone, with shelly structure.
21	3	Coal; middle seam.
20	6	Red limestone, very magnesian.
19	3	Sandstone.
18	¾	Coal; called by the miners "upper bastard vein."
17	30	Sandstone, thinly fissile, brown.
16	¾	Coal.
15	10	Sandstone, shaly at top.
14	4	Coal.
13	20	Fissile and leafy sandstone.
12	30	Sandstone, massive, with jointed surfaces rounded.
11	6	Coal; poorly defined; vein 2 or 3 feet; the rest shale.
10	15	Sandstone, massive, brown, much pitted by weathering.
9	2	Coal.

Number of bed.	*Thickness in feet.*	
8	3	Sandstone.
7	8	Coal and slate.
6	3	Sandstone, very fissile and soft.
5	10	Sandstone, hard and firm.
4	1½	Coal.
3	3	Shale.
2	18	Sandrock.
1	2	Coal.
		Intrusive andesitic rock.

From this place southward to the park boundary the bluff on the eastern side of the river is formed of the coal-bearing sandstones, the seams having been prospected at a few points but not worked.

The Mount Evarts coals have been worked but the single entry is now abandoned. This part of the field is not, however, available for mining, as it lies within the boundaries of the Yellowstone National Park.

The following section shows the number of seams found here:

Mount Evarts Section of Coal-bearing Strata.

Number of bed.	*Thickness in feet.*	
23		Shelly sandstones, cubical fracture.
22	100	Very massive sandrock.
21	10	Shales, bituminous and dark.
20	2	Sandrock.
19	2	Shales, bituminous, baked.
18	7	Baked sandstones.
		Basalt intrusion.
17	2	Coaly shale.
16	100	Sandstones, like number 14.
15	3	Coal.
14	90	Sandstones, in ledges from 2 to 5 feet thick, alternating with shaly beds.
13	5	Coal.
12	15	Sandrock.
11	5	Sandy limestone.
10	8	Sandstones, dipping 25° eastward.
9	1	Coal seam; small.
8	10	Sandrock.
7	5	Coal and shale.
6	30	Sandrock.
5	10	Sandrock, massive; rounded outcrop.
4	5	Coal and shale.
3	5	Sandrock.
2	25	Shaly beds, with two coal seams.
1	5	Tunnel and coal outcrop.
		Gray shaly series, corresponding to those under the coal-measure sandstones of the Cinnabar section.

Although the Cinnabar field is quite small and the coal-measures are scattered and broken, so that very extensive workings are not possible, yet as the measures yield an excellent quality of coal the portions now worked will no doubt be thoroughly exhausted before the field is abandoned.

The Bozeman Coal Field.

Location, Extent, and General Geology.—Some 40 miles north of the Cinnabar coal field is the so-called Bozeman field, the best-known and longest-worked coal field of Montana. Although the coals of this field were known in 1871 and were examined by the geologists of the Hayden survey,* no exploitation was attempted until after the organization of the Northern Transcontinental survey, for whom Mr. George H. Eldridge† made a careful examination of the field, resulting in the purchase and working of the most promising portions at Timberline and Cokedale.

In its entire extent, the Bozeman coal field embraces the foot-hills lying at the northern base of the Boulder mountains and their continuation in the Snowy range westward to Livingston and over the Missouri–Yellowstone divide to Rocky cañon, where the outcrops swing around and occur at the eastern base of the Bridger range, having been traced northward some 25 miles. The field thus occupies the angle between the northerly trending Bridger mountains and the east-and-west range of the Snowy and Boulder mountains.

The general geological structure is that of a large synclinal basin whose southern and western borders are the mountains just mentioned. These ranges are formed of steeply upturned Mesozoic rocks, resting conformably upon Paleozoic limestones, which lie at a steep angle upon metamorphic gneisses. The chief feature of the region is a sharp folding of the sedimentary rocks, in general parallel to the line of contact with the Archean.

There is generally a strike fault, or its equivalent fold, running along the range before the beds flatten out toward the lower country on the north and east.

In the angle formed by the meeting of the Bridger mountains and the eastern ranges, this structure is disturbed by three sharp anticlinal folds, whose axes pitch steeply toward the north; so that while erosion has exposed the Carboniferous rocks on the ridges the productive (Mesozoic) coal-measures curve uninterruptedly around their ends. The western anticlinal is cut at right angles by the picturesque gorge of Rocky cañon, through which the Northern Pacific railway passes to the Gallatin valley. The larger streams issuing from the mountains, particularly the Yellowstone and

* 1st Ann. Rep. U. S. Geol. and Geog. Surv. Terr., 1871, p. 46; 2nd Ann. Rep., 1872, p. 113.
† Report 10th Census, vol. XV: Mining Industries, 1884, p. 739.

Boulder rivers, have each cut fine sections across the steeply dipping strata forming the northern flanks of the mountain masses toward the south.

The importance of the Bozeman field lies not only in the amount and excellent quality of its coal, but also in its proximity to the Northern Pacific railway; throughout its entire extent the outcrops of the coal strata are readily accessible and near the main railway line.

The Rocky Fork district, which was not visited, is very probably an easterly extension of the Bozeman field, the coal-measures in the western part of the Crow reservation being buried beneath an accumulation of volcanic breccias which form the rugged and rough, though not lofty, mountains east of the Boulder river. On this river and its branches the coal-measures cover a considerable area, the seams having a low inclination (10° to 15°) toward the north, so that they could be worked upon an extensive scale. From the Boulder river the coal-measures can easily be traced westward to the border of the great terraced valley of the Yellowstone at Livingston; but in the western part of their course the seams dip at steep angles (40° to 70°), so that the amount of coal available is not so great as it is farther eastward. Throughout this part of the field there is not a single productive mine; in fact, but few prospect pits. Natural exposures showing a workable thickness of coal are, however, not rare.

West of Livingston the coal lies in folds, due to the three anticlinal axes already mentioned, and the seams usually dip at angles of 50° to 90°. This is, however, the most important part of the field, as all the productive mines are situated in this portion. For a few miles west of Livingston the coal-measures dip northward at an angle of 40° to 45°, and it is in this portion of the field that the very productive mines of Cokedale are located. A little way west of this town the coal-measures are nearly vertical and the outcrop is S-shaped as the strata bend about the buried end of the first anticlinal axis; and there are no productive workings from here to the main divide. West of the anticlinal axis forming this divide the coal strata have been somewhat extensively worked at Timberline, and less extensively at Mountainside and Chestnut, where the strata cross the line of the railroad.

The remainder of the field lies on the eastern flanks of the Bridger mountains where the coal measures dip eastward at an angle of about 40°. At present there is not a single productive mine in this part of the field.

The Horizon of the Coal-Measures.—Seven miles west of Livingston is the little mining town of Cokedale. A north-and-south section, from the high ridge south of this place northward through the coal-measures to the summit of the high ridge north of the railroad, shows the following beds:

Cokedale Section.

	Number of bed.	*Thickness in feet.*	
Laramie.	38	3,000	Green and gray shales, with interbedded sandstone, poorly assorted.
	37	2,300	Sandstones of varying degrees of coarseness, poorly bedded, of volcanic material, the finer-grained layers like volcanic tuffs, carrying leaf remains.
	36	2,500	Sandstones and local beds of conglomerate; particles subangular, wholly of volcanic material.
	35	30	Conglomerate.
	34	140	Sandstone.
	33	2	Limestone.
	32	210	Sandstone.
	31	5	Coal.
	30	15	Shale.
	29	5	Coal.
	28	250	Sandstone; contains several seams of coal.
Colorado, Montana.	27	75	Massive sandstone; white, cross-bedded.
	26	150	Sandstone; "Tombstone" beds.
	23–25	1,150	Sandy shales and earthy limestones.
	22	25	Sandstone, forming prominent hog-back.
	21	300	Calcareous shales, muddy limestones and sandy shales.
	20	30	Sandstone, with conglomerate belt at top.
	17–19	630	Dark gray earthy shales, with sandy belt in center.
	11–16	765	Earthy gray and blue shales, with two sandy belts.
Dakota.	10	60	Quartzite.
	7– 9	250	Red, earthy magnesian limestones and fissile sandstones.
	6	35	Conglomerate.
Jurassic.	3– 5	150	Red earthy sandstones and shales.
	2	30	Limestones passing into sandstones and grits; Jurassic fossils.
	1	200	"*Myacites* beds." Limestones and shales.

The section is represented graphically and in greater detail in the diagram forming figure 2 in plate 13.

The uppermost beds of the section form the valley of Billman creek. The sandstones form bold combs and ledges, with intervening beds of very soft and crumbly green clays. A detailed section of these beds, or of the beds beneath, lying between them and the coals, is of comparatively little value, as the sandstones vary both vertically and laterally from fine-grained rocks, showing little evidence of bedding, to cross-bedded and rather friable sandstones, with local beds of conglomerate.

Beneath these beds lie sandstones (number 36), free from clays but of extreme variability, sometimes conglomeratic and often so fine-grained, as to resemble volcanic tuffs; indeed there is a striking resemblance to the Tertiary volcanic leaf-bearing beds found in the volcanic breccias of the park. The more friable sandstones crumble into coarse brown sand on weathering, while the harder beds break into fine angular fragments. The conglomerates are usually thin, and local layers, composed of pebbles of volcanic andesites rarely over three inches in diameter, occur; no other material being found. The first noticeable change in the rock is a thin belt of limestone (number 33) beneath this series and some 210 feet above the coal. This is underlain by lighter-bedded gray sandstones, forming the top of the coal series.

The coal-measure sandstones (number 28) are some 600 feet thick, and very much like the same beds in the Cinnabar field. Being in strong contrast to the earthen-gray shales beneath and to the somber volcanic sandstones above, this coal belt is readily traced. The sandstones are very light-colored, cross-bedded, with massive outcrops, and are characterized at certain horizons by dark brown-surfaced bowlder-like concretions from one to two feet in diameter. The beds at the base of the series are fissile, and weather out on slopes into lines of tombstone-like ledges.

Beneath these coal-bearing sandstones there are several great belts of shale, with beds of sandstones between.

As is generally the case at the base of the Rocky Mountains, the beds of the Colorado group are not typically developed, the shales being quite arenaceous and containing thin beds of sandstone. No attempt has been made to separate the series into the groups established by Hayden, nor into the more recent divisions, Colorado and Montana;* and it will be possible to make the separation in this section only after careful search for and collection of fossils. The Colorado is, however, readily separated from the quartzite forming the summit of the Dakota group—a dense pink quartzite, whose detritus covers the hillside below the crest of the "hog-back" formed by its outcrop. The red magnesian limestones beneath grade into a conglomerate of quartz pebbles, the typical Dakota conglomerate of this region, which forms the usual "hog-back" ridges; the sandstones and conglomerates resting upon the Jurassic sandstones (number 2 of the section) and being separated from the Paleozoic limestones by a sag cut in the soft Jurassic limestones (number 1 of the section).

A comparison of the Cokedale section with that of Cinnabar shows a satisfactory correspondence, and I have little doubt that the coal-bearing sandstones of the two fields are of the same age. The two sections show that the lower seam of workable coal occurs at about 3,600 feet above the Jurassic limestone.

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* "Some suggestions upon the Method of Grouping the Formations of the Middle Cretaceous, and the Employment of an Additional Term in its Nomenclature;" by George H. Eldridge: Am. Jour. Sci., 3d ser., vol. XXXVIII, 1889, p. 313.

Character of the Coal Seams.—Throughout the coal-bearing sandstones of the Bozeman field, seams of coal occur at frequent intervals, but thus far only three seams have proved to be of workable thickness. The field has been quite extensively prospected, and at several localities the workings afford good sections of these seams, so that their characteristics are readily determined.

The sections show that the seams are composed of benches of coal, separated by partings of sandstone and of clay, the bony coals being rare, so that the coals are mined quite clean. The sandstone partings are extremely variable in thickness, but very persistent throughout the extent of seam developed. Average sections of the highest seam worked show it to consist of from 4 to 7 feet of clean coal, in three to four layers, separated by sandstone partings from half an inch to 6 inches thick. The varying thickness of these partings is accompanied by a variation in the thickness of the adjacent layers of coal. The middle and lower seams show from 5 feet to 7 feet of firm, clean coal separated by similar partings of clay and sandstone.

The clean, clear coal very often rests directly upon a sandstone floor, without any intervening layer of fire-clay. A peculiarity of the floors of the two upper seams, which was first observed by Mr. Eldridge in the part of the Bozeman field so far developed, is the unevenness of the surface on which the coal rests and whose depressions it fills. The resulting unevenness of the seam, with the frequent "rolls" and occasional total failure of the coal, is a considerable detriment to economical development.

The roof over the seams, on the other hand, is very generally quite even and regular, usually a firm, compact sandstone, so that only a small amount of timbering is required in mining.

Analyses of these coals, though showing a slight variation, indicate a low percentage of ash and water and entire freedom from sulphur.

Workings.—That portion of the field lying between Livingston and the Gallatin valley has been very carefully prospected. The only mines worked at present are those at Cokedale, Timberline, Mountainside and Chestnut. At Cokedale the output was 49,400 tons in 1889, and is much larger for 1890. Seventy-eight coke ovens were in operation during the summer, with some eighteen more undergoing repairs. The mines are worked from an incline 650 feet deep, with three levels, the longest a mile in length. As the coal dips at 45° to 50°, the lowest depth at which the coal can be economically mined will be reached before long. At Timberline and Chestnut the mines are operated by tunnels and inclines, and the methods in use present no points of special interest. The output at Timberline for 1889 was 43,838 tons. The character of the coal varies from a good coking variety at Cokedale to a dry steam coal at Timberline and westward.

Above the anticlinal folds already mentioned there has been more or less slipping of the strata, and the coal is more broken than in the less disturbed portions of the field.

Age of the Coals.

The stratigraphical evidence, which has been given in the preceding pages, shows that the coal-bearing series is of later age than the marine Cretaceous, and that it forms the base of the Laramie series. This conclusion is supported by the available paleontological evidence.

Niobrara fossils have been found in the shaly belt of the section at Cokedale, but no positive identification of the Fox Hills sandstones could be made. *Unio* shells were found associated with the coal seams of the Cinnabar field, and fossil leaves obtained from the shales between the middle and upper seams have been placed in the hands of Professor Lester F. Ward. Mr. F. H. Knowlton has examined a part of this material, and identified *Gymnogramma haydenii*, Lx., and *Abietites dubius*, Lx., both very good specimens, together with *Salisburia* (*Gingko*) *polymorpha*, Ung., and *Gingko adiantoides*, Ung., from the beds overlying the coal seams, associated with *Platanus*, *Vitis*, and a leaf of *Ericaceæ*. These are all lower Laramie types.

A large collection of fossil leaves made by Dr. A. C. Peale from the rocks overlying the coal seams of the Bozeman field, west of Timberline, at various times from 1871 to 1888, and in recent years by Mr. Knowlton, have not as yet been exhaustively studied by Professor Ward; but after a brief examination he says that they closely resemble the collections from the coal strata of Bitter Creek, Wyoming; the following genera from these beds being represented: *Quercus*, *Viburnum*, *Betula*, *Vitis*, *Populus*, *Ficus*, *Gingko*, *Zizyphus*, *Sequoia*.

The earlier collections of Dr. Peale from these same beds were examined by Professor Leo Lesquereux, and the list of species published in his Tertiary Flora embraces the following:

Abietites dubius, Lx.;
Salisburia polymorpha, Ung.;
Quercus chlorophylla, Ung.;
" *ellisiana*, Lx.;
" *pealii*, Lx.;
Dombeyopsis platanoides, Lx.

Invertebrate fossils obtained by Dr. Peale from the sandstones beneath the principal coal seams have been placed in the hands of Dr. C. A. White, by whom specific determinations will be made. Dr. White has identified *Viviparus* and *Corbula* for me from a sandstone four feet below the coal, and tells me the shells found with the coal in the Cinnabar field are probably *Unio bridgerensis*. These fossils prove the rocks to be brackish water deposits.

The Bozeman coals were placed provisionally in the Fort Pierre group by Professor Pumpelly in his report upon the coals of Montana.

Conclusion.

While the evidence presented in this paper is not considered conclusive, and while the work upon the district is not far enough advanced to warrant a final statement, yet is believed that the facts show that the coal-measures of the Cinnabar and Bozeman coal fields are probably of Laramie age, occurring at the very base of the Laramie series; and that they are conformably overlain by a totally different series of rocks, composed entirely of volcanic material and containing an abundant fossil flora of recognized Laramie types, in turn overlain by beds of fresh-water clays and sandstones of undetermined age, but belonging to what has heretofore been considered as undoubtedly Laramie strata.

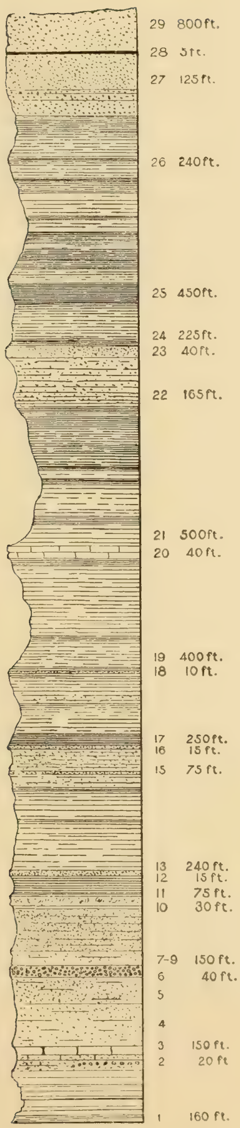

Figure 1, Cinnabar.

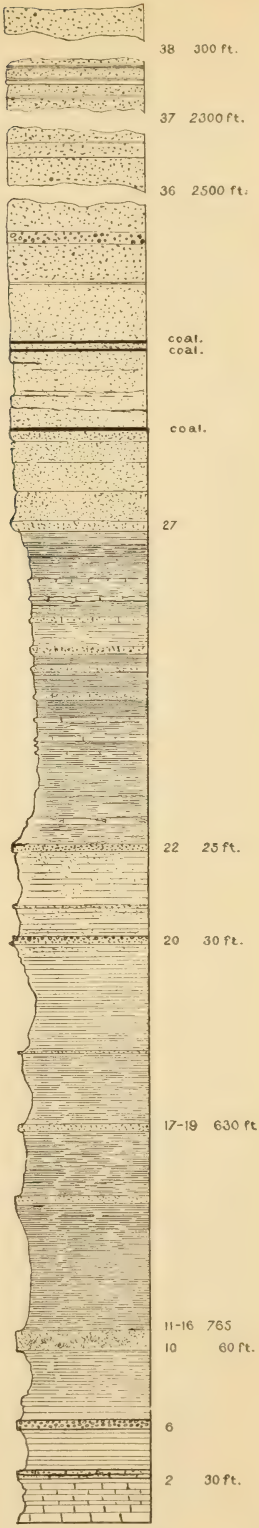

Figure 2, Cokedale.

Sections at Cinnabar and Cokedale, Montana.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 365-382, PL. 14 MAY 4, 1891

ON THE RECOGNITION OF THE ANGLES OF CRYSTALS IN THIN SECTIONS.*

BY ALFRED C. LANE.

(*Read before the Society August* 19, 1890.)

CONTENTS.

INTRODUCTION.

Applications of the Problem.

§ 1. The morphologic properties of crystals, that is to say, their outer forms and their structural planes, whether the latter are of cleavage, of twinning, of enclosures, or of alteration, are among their most important properties. They are, in fact, the only ones by which we can recognize complete pseudomorphs. They are also of great help to the petrographer in determining minerals, for the habits of minerals are so constant and the important planes so few that we may often pretty surely recognize them, either from external forms, or from cleavage, etc. Yet our assurance is often not so great but that we should welcome tests of the correctness of our assumptions, which would give them objective as well as subjective validity.

I wish to show how such tests may be applied; and I shall illustrate the more general cases by applications to one or two simple cases typical of those

*Work for the Michigan Geological Survey, published by permission of M. E. Wadsworth, State Geologist.

most commonly arising. I do not pretend to work out all applications, but I hope to give the method clearly enough to enable any one to modify it to suit special cases.

The Stereographic Projection.

§ 2. As the stereographic projection will be much used in illustrations and in solutions, a few notes on this projection and its properties, designed to introduce shortened terminology and simplified constructions, may be pardoned.

The surface planes, or a plane section, of a crystal may be represented by normals drawn to them from a given point, O (figure 1;* see Dana's "Text-book," appendix, figure 756). These normals may in turn be represented by the points N_1, N_2, N_3, etc., at which they cut the surface of a sphere about O. This is a spherical projection. These points (N_1, N_2 N_3) may in turn be represented in a plane by the points P_1, P_2, P_3, where the lines N_1A, N_2A, N_3A, which join them to any point of the sphere (A) cut the diametral plane perpendicular to the radius OA. These points P_1, P_2, P_3 represent in stereographic projection the faces of the crystal. We call them *face-points*, and by the angle between them we mean the normal angle between the faces to which they correspond (*i. e.*, the angle through which one face must be turned to become parallel to another, or the supplement of the angle given by the ordinary hand goniometer).†

Points in the same hemisphere as A may be projected by producing the lines of projection. Their face-points lie outside the circle, which may be called the *primitive*, in which the diametral plane cuts the sphere. P_1P_2 P_3P_4, in figure 2, is such a primitive.

The properties of this projection that we shall need to use may be summarized as follows:

(1) The distance of a given face-point P_2 from the center C (figure 2) is *tan* $\frac{1}{2} < C : P_2$, the radius of the primitive being unity.

(2) Angles between edges are projected into equal angles; whence it may be shown that—

(3) Circles are projected from the sphere into circles; so that—

(4) Face-points making a given angle with a given face-point lie on a circle; and in particular—

(5) Face-points making an angle of 90° with a given face-point (*i. e.*, belonging to a zone) lie on a circle that has a diameter of the primitive for chord. Call such circles *zone-circles* (*e. g.*, P_1S, figure 2).

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* The figures referred to in this memoir are grouped on plate 14, facing page 382.

† It is a pity that the scale of this instrument is not reversed, so that the angle read by "reflection-goniometers" and "application-goniometers" would become the same.

(6) The angle two zone-circles make with each other is equal to the exterior angle between the two sides of the crystal face (represented by the point of intersection of the zone-circles), common to the two zones and corresponding to the two zone axes. This is important for us, since, if we can find the exact position of a section of a crystal referred to its axes, we can locate its projection (*i. e.*, *section-point*) S. Then, if we join by means of zone-circles (SP_1, SP_2, SP_3, etc., figure 2) this section-point and the face-points (P_1, P_2, P_3) of the planes we think we recognize, the directions of these circles at S will correspond to the directions of the traces of those planes in the section of the crystal, *and their radii from* S (viz., SC_1, SC_2, SC_3, etc.) *may be taken as the traces.*

(7) The centers of all zone-circles meeting at a given point S lie on a straight line perpendicular to the radius through S at a distance from C equal to *cot* $< C : S$. If S is within the primitive, C lies between it and this center-line. This line is a common chord of a circle about C with any radius, x, and a circle about S with radius $\sqrt{x^2 + 1}$.

(8) The angle between two face-points ($O_1 O_3$, figure 3) is measured by the arc of the primitive (B_1B_3) lying between straight lines (O_1B_1, O_3B_3) drawn from the face-point A of a face perpendicular to the given faces.

By means of these propositions we can solve graphically every ordinary problem in spherical trigonometry, and therefore in crystallography. We can construct a zone-circle through two given points ($O_1 O_2$), since its center is the intersection of their center lines. We can construct a zone-circle (SX_1, figure 2) through a given point (S), making a given angle with a given zone circle (PSm), since their radii (C_4S and $C_{x1}S$) at the point S will make the same angle, and the center of the circle will be the intersection of the radius $C_{x1}S$, with the center line of S. We can find the locus of any point at a given angular distance from a given point, thus: First, find two such points (L and M, figure 4) on the same ground-circle radius ($\beta\gamma$) with it (γ), which may be done most quickly by computing their distances from β. Then LM is a diameter of the locus sought. We can thus readily construct the projection of a spherical triangle from the requisite data.

One problem only needs especial mention, viz., that in which one side ($\gamma\beta$, figure 4), the opposite angle ($\gamma S\beta$), and the length of another side (γS) are known. In this case we take the projection on the face opposite the side of known length, *i. e.*, on β; thus $\beta\gamma$ is radial. We can construct first the circle on LM, which is the locus of S, taking $L\gamma$ and $M\gamma$ as equal to the known value of γS. Let O be the center of that circle; then $< \beta SO = < \beta S \gamma$

(where $S\gamma$ is an arc of a circle and SO a straight line tangent to each other at S). Then we describe a circle upon $O\beta$, which will include the given angle ($ROS\beta P$). The intersections of the circles $ROS\beta$ and $RLSM$, viz., R and S, give a double solution for the vertex sought.

All these constructions are much facilitated by a paper scale of tangents and long chords to the radius of the primitive as unity. Such a scale is represented in figure 5. By its use we may rapidly construct the spherical projection (as in figures 2, 3, and 4) representing any observed section, and obtain numerical results by solving the spherical triangles, *if the position of the section can be fixed.*

Location of a random Section.

Solution of the Problem with Aid of an Axial Image.

§ 3. This general problem may sometimes be roughly solved with the help of convergent light, if we can see a bisectrix, as in figure 4*a*, since the position in which the hyperbolas of a biaxial image close into a cross is that in which the axial plane is parallel to one of the principal sections of the Nicols. Therefore, the direction of the trace of β normal to the axial plane will be given. We can also note the direction in which the bisectrix (say γ) emerges. Thus we get the angle $\beta S\gamma$, (figure 4). We can also estimate the apparent obliquity of emergence of the bisectrix, and reduce it to its true value in the same manner as that in which we find $2V$. This will give us γS. Then we can construct figure 4 as previously described, and can determine the positions of S and R.

Which of the two solutions of the general problem is the true one may commonly be determined by something else, *e. g.*, pleochroism, dispersion, or form.

Obviously this method cannot be applied when the axial image is entirely outside the field of view; yet, so long as even one axis appears and the direction of the axial plane may be inferred, we may apply it, although with increasing inaccuracy as we see less of the axial image.

In uniaxial crystals we know that a direction of extinction is parallel to the basis. It has the same value, therefore, as the trace of one face. The determination of the obliquity of the axis will only limit S to a certain circle.

Solution for three traced Faces.

§ 4. Another method of locating the section is by the traces of three faces or crystal planes that we think we recognize. The solution of this problem is the spherical counterpart of the three-point problem in trigonometry. In figure 3, for example, the angles between the traces of the three faces represented by C, O_1 and O_2, in the section S, are the angles between the zone-circles CS, O_1S and O_2S. These are equal to CT_1S and CT_2S. In plane trigonometry the solution is simple, since the locus of a point at which two given points subtend a given angle is a circle. Hence S would be found as the intersection of two circles. In spherical trigonometry, or in the stereographic projection, the locus of the face-point of the section in which a given solid angle (α) traces a given plane angle is a curve of the third or fourth degree.

Figure 6 shows a set of these curves for $\alpha = 45°$ and several different values of β. In other words, if P_1 and P_2 are two faces of a crystal, making a normal angle of 45° with each other, the traces of those faces in a section whose face-point lies on a curve marked, say 60, will be at a corresponding angle, *i. e.*, 60°. This diagram applies nearly to augite or diallage, letting P_1 be (100) and P_2 (110). Their general equation is (if the plane of projection is perpendicular to the faces, $r = CS = \tan \frac{1}{2} \angle CS$, $\varphi =$ angle from the bisectrix of P_2CP_1 to CS, $\alpha = \angle P_2CP_1$ and $\beta = \angle P_2SP_1$):

$$r^4 - 2\, r^2 \cos 2\, \varphi \frac{\csc \alpha}{\cot \alpha + \cot \beta} + \frac{\cot \alpha - \cot \beta}{\cot \alpha + \cot \beta} = 0. \tag{1}$$

This equation is obtained as follows: Let S be (x, y), $P_1 = (m, n)$ and $P_2 = (m, -n)$, and let the center of the zone-circle SP_1 be at (a_1, b_1) of the zone-circle SP_2 (a_2, b_2). The equation of the circle SP_1 is—

$$(x - a_1)^2 + y - b_1)^2 = r^2; \tag{2}$$

whence, substituting (m, n), since P_1 is on the circle—

$$(m - a_1)^2 + (n - b_1)^2 = r^2. \tag{3}$$

Subtract (3) from (2) and we have—

$$x^2 - m^2 - 2\, a_1\, (x - m) + y^2 - n^2 - 2\, b_1\, (y - n) = O; \tag{4}$$

but it is easy to prove that—

$$\frac{a_1}{b_1} = \frac{-n}{m} = -\cot \tfrac{1}{2}\, a. \tag{5}$$

Substitute (5) in (4) and find a_1:

$$a_1 = \frac{x^2 + y^2 - (m^2 + n^2)}{2\left(x - \frac{m}{n} y\right)}. \tag{6}$$

This we may write, letting $x^2 + y^2 = r^2$, and $\frac{m}{n} = p$, since $m^2 + n^2 = 1$ as usual—

$$a_1 = \frac{r^2 - 1}{2\,(x - py)}. \tag{6}$$

By combining (5) and (6) we get—

$$b_1 = \frac{r^2 - 1}{\frac{-2}{p}\left(x - py\right)}.$$

Since in the figure (6) P_2 and P_1 are symmetrical with regard to the axis of abscissas, we change n into $-n$, (*i. e.*, p into $-p$) in order to get a_2 and b_2; $\therefore$—

$$a_2 = \frac{r^2 - 1}{2\,(x + py)};$$

$$b_2 = \frac{r^2 - 1}{\frac{2}{p}\left(x + py\right)}.$$

The angle β between the circles at S is the angle between the radii of those circles (from S to a_1, b_1 and a_2, b_2 with slopes λ_1 and λ_2). If, then, $tan\ \beta = \frac{1}{k}$—

$$\frac{1}{k} = \frac{\lambda_1 - \lambda_2}{1 + \lambda_1\,\lambda_2}, \tag{7}$$

while

$$\lambda_1 = \frac{y - b_1}{x - a_1}, \qquad \lambda_2 = \frac{y - b_2}{x - a_2}; \tag{8}$$

then, by substituting for a_1, b_1, a_2, b_2 their values found above (6), we have—

$$\left.\begin{aligned} x - a_1 &= \frac{2\,x^2 - 2\,pxy - r^2 + 1}{2\,(x - py)}, \quad y - b_1 = \frac{2\,y^2 - 2\,xy/p - r^2 + 1}{-2/p\,(x - py)}; \\ x - a_2 &= \frac{2\,x + 2\,pxy - r^2 + 1}{2\,(x + py)}, \quad y - b_2 = \frac{2\,y^2 + 2\,xy/p - r^2 + 1}{2/p\,(x + py)}. \end{aligned}\right\} \tag{9}$$

Now, eliminating λ_1 and λ_2 from (7) and (8), we have—

$$(x-a_1)\,(x-a_2) + (y-b_1)\,(y-b_2) = k\,(y-b_1)\,(x-a_2)\,(y-b_2)\,\,(x-a_1). \tag{10}$$

Substituting (9) in (10) and reducing,

$$\frac{(2\,x^2 - r^2 + 1)r^2 - 4\,p^2x^2y^2}{4\,(x^2 - p^2y^2)} + \frac{(2\,y^2 - r^2 + 1)^2 - 4\,x^2y^2p^{-2}}{4\,p^{-2}\,(x^2 - p^2y^2)}$$

$$= k\left\{\frac{(2\,y^2 - 2\,xyp^{-1} - r^2 + 1)\,(2\,x^2 + 2\,pxy - r^2 + 1)}{-4\,p^{-1}\,(x^2 - p^2y^2)}\right.$$

$$-\frac{(2\,x^2 - 2\,pxy - r^2 + 1)\,(2\,y^2 + 2\,xyp^{-1} - r^2 + 1)}{4\,p^{-1}\,(x^2 - p^2y^2)}. \qquad (11)$$

Cancelling $4\,(x^2 - p^2y^2)$, clearing of fractions, and changing to polar coördinates, we have (since $2\,x^2 - r^2 = r^2\,(2\,cos^2\varphi - 1) = r^2\,cos\,2\varphi$, and $2\,y^2 - r^2$ is similarly $-\,r^2\,cos\,2\,\varphi$, and $2\,xy = r^2\,sin\,2\,\varphi$),

$$(r^2\,cos\,2\,\varphi + 1)^2 - p^2r^4\,sin^2\,2\,\varphi - p^2\,(1 - r^2\,cos\,2\,\varphi)^2$$

$$+\,r^4\,sin^2\,2\,\varphi = pk\left[-\left(-\,r^2\,cos\,2\,\varphi - r^2\,\frac{sin\,2\,\varphi}{p}\right)\right.$$

$$(1 + r^2\,cos\,2\,\varphi + pr^2\,sin\,2\,\varphi) - (1 + r^2\,cos\,2\,\varphi - pr^2\,sin\,2\,\varphi)$$

$$\left.\left(1 - r^2\,cos\,2\,\varphi + \frac{r^2\,sin\,2\,\varphi}{p}\right]\right..$$

Arranging now according to powers of r, cancelling and putting 1 for $sin^2 + cos^2$—

$$r^4\,(1 - p^2) + 2\,r^2\,cos\,2\,\varphi\,(1 + p^2) - p^2 + 1 = 2\,pk\,(r^4 - 1)\,;$$

or—

$$r^4 + 2\,r^2\,cos\,2\,\varphi\,\frac{1 + p^2}{1 - p^2 - 2\,kp} + \frac{1 - p^2 + 2\,pk}{1 - p^2 - 2\,pk} = 0\,; \qquad (12)$$

but since $p = cot\,\frac{\alpha}{2}$, according to Chauvenet (Trig. Eq., 142)—

$$\frac{1 + p^2}{p} = 2\,csc\,\alpha\,, \frac{1 - p^2}{p} = -\,2\,cot\,\alpha. \qquad (13)$$

Dividing the numerator and denominator of the coëfficients in (12) by p and substituting from (13) we have—

$$r^4 + 2\,r^2\,cos\,2\,\varphi\,\frac{2\,csc\,\alpha}{-\,2\,cot\,\alpha - 2\,k} + \frac{-\,2\,cot\,\alpha + 2\,k}{-\,2\,cot\,\alpha - 2\,k} = 0.$$

From this, replacing k by $cot\,\beta$, we have (1).

For certain values of φ, equation (1) is much simplified, so that r and the location of certain points of these curves are quite easily found. In fact we have, if—

$$
\left.\begin{array}{ll}
\varphi = \pm \dfrac{\alpha}{2} & r^2 = \dfrac{\cot\,\alpha \pm \cot\beta}{\cot\,\alpha + \cot\beta} = \dfrac{\sin\,(\alpha - \beta)}{\sin\,(\alpha + \beta)}, \text{ or } 1\,; \\[2ex]
\varphi = 90^\circ \pm \dfrac{\alpha}{2} & r^2 = -\dfrac{\cot\,\alpha - \cot\beta}{\cot\,\alpha + \cot\beta} = -\dfrac{\sin\,(\alpha - \beta)}{\sin\,(\alpha + \beta)}\,; \\[2ex]
\varphi = 45^\circ & r^4 = -\dfrac{\cot\,\alpha - \cot\beta}{\cot\,\alpha + \cot\beta} = -\dfrac{\sin\,(\alpha - \beta)}{\sin\,(\alpha + \beta)}\,; \\[2ex]
\varphi = 0 & r^2 = \dfrac{\csc\,\alpha + \csc\beta}{\cot\,\alpha + \cot\beta} = \dfrac{\begin{smallmatrix}\cos\\ \sin\end{smallmatrix}\,\frac{1}{2}\,(\alpha - \beta)}{\begin{smallmatrix}\cos\\ \sin\end{smallmatrix}\,\frac{1}{2}\,(\alpha + \beta)}\,; \\[3ex]
\varphi = 90^\circ & r^2 = -\dfrac{\csc\,\alpha \pm \csc\beta}{\cot\,\alpha + \cot\beta} = \dfrac{\begin{smallmatrix}\cos\\ \sin\end{smallmatrix}\,\frac{1}{2}\,(\alpha - \beta)}{\begin{smallmatrix}\cos\\ \sin\end{smallmatrix}\,\frac{1}{2}\,(\alpha + \beta)}.
\end{array}\right\} \quad (14)
$$

Moreover, these curves cut the axes in general at right angles while they cut the primitive at an angle β; so that, when the points for the above radii are plotted, the curves are not difficult to sketch.

The projection used in figure 6 gives the highest degree of symmetry to the curves, and for the radii noted in (14) φ and β enter so symmetrically that solutions for one octant answer with slight modifications for other octants and interchanged α and β.

Probable Difference between solid Angles and their Traces.

§ 5. The probability that a given solid angle, P_1CP_2, will be cut to give a certain plane angle is indicated in figure 6 by the area between successive curves. Thus a glance at figure 6 gives us some idea of the various probabilities. We must remember, however, that the bounding planes of a mineral cannot be cut very obliquely if they give a well-defined and easily noticed outline. The same holds true of the development of cleavage cracks: but it does not hold true for twinning lines, since in this case sharp interference bands appear along the line of juxtaposition of two twins when they are placed between crossed Nicols.

The breadth of the border (b) made by a plane (P_1) depends on the thickness of the thin section (d) and on the angle at which it is cut (SP_1). The formula is—

$$b = d \cot SP_1.$$

A section of a mineral that has sharp, narrow lines of cleavage or of demarkation must therefore lie near to C (figure 6): that is to say, it must be nearly perpendicular to the planes whose traces the lines represent. Sections over 60° from C are uncommon. The range of probable sections is indicated by the dotted circle in figure 6. The angle traced by a solid angle in section will, accordingly, most likely differ about 5° from the solid angle, and will incline to be a trifle more acute if the solid angle is acute; yet it is far less likely to be much more acute than much more obtuse.

The fact that not all sections are equally frequent or likely to be noticed, and that from the breadth of their borders we can form some judgment as to their orientation, renders a mathematical investigation of the probable traced angle practically useless. It makes a pretty theoretical problem only.

Solution for Faces of one Zone.

§ 6. The equation (1) of § 4 and figure 6 may be used to find the position of a section if the three traces between which angles are measured are supposed to belong to faces of the same zone. We may combine or superpose two corresponding figures patterned after figure 6. The curves representing the loci of sections in which a given solid angle gives a certain traced angle have also a simple and easily found equation when the plane of projection is one of the sides of the solid angle. In figure 3 let $CP_1 = a$, $\angle C : S = \theta$, $\cot \angle SC : SP_1 = \cot \beta = m$, $\angle CP_1 : CS = \varphi$; then, substituting in the well-known trigonometric formula (Chauvenet, Trig. 10),

$$\cot a \sin b = \cos b \cos c + \sin c \cot A, \tag{1}$$

we have—

$$\cot a \sin \theta = \cos \theta \cos \varphi + \sin \varphi \, m. \tag{2}$$

Now, let $r = \tan \tfrac{1}{2} CS = \tan \tfrac{1}{2} \theta = \csc \theta - \cot \theta$. We have also $\frac{1}{r} = \csc \theta + \cot \theta$, and accordingly $\csc \theta = \frac{1}{2}\left(r + \frac{1}{r}\right)$ and $\cot \theta = \frac{1}{2}\left(\; - \frac{1}{r}\right)$. Substitute these values of $\csc \theta$ and $\cot \theta$ in (2), after dividing through by $\sin \theta$. Then—

$$\cot a = \tfrac{1}{2}\left(r + \frac{1}{r}\right) \cos \varphi + \tfrac{1}{2}\left(\frac{1}{r} - r\right) m \sin \varphi; \tag{3}$$

or—

$$2\, r \cot a = r^2 \cos \varphi + \cos \varphi + m \sin \varphi - r^2 m \sin \varphi.$$

The locus of S is therefore expressed in the following equation:

$$r^2 + \frac{2\, r \cot a}{m \sin \varphi - \cos \varphi} = \frac{m \sin \varphi + \cos \varphi}{m \sin \varphi - \cos \varphi}. \tag{4}$$

By writing $\varphi - \varphi_1$ for φ we can refer φ to any initial line, and if we have a similar equation derived from C, S, and P_2 we can eliminate r and have an equation of the fourth degree to determine φ. This I have already obtained.* If, in figure 3, φ is measured from O_3C, the bisectrix of P_1CP_2; if $a_1 = CP_1$, $a_2 = CP_2$, $\varphi_1 = \frac{1}{2} < P_1CP_2$, $n = cot < SC : SP_2$, and $m = cot < SC : SP_1$, then φ is determined by the following equations:

$$tan\ \varphi = -\frac{A\ cos\ \theta + B}{C\ cos\ \theta + D}, \text{ and } sin\ \theta = -\frac{E\ sin\ \varphi\ cos\ \varphi + F}{A\ cos\ \varphi + C\ sin\ \varphi}; \quad (5)$$

or—

$$tan^4\ \varphi\ (F^2 + D^2 - C^2) + tan^2\ \varphi\ (2\ F^2 + D^2 - C^2 + B^2 - A^2 + E^2) + B^2 - A^2 + F^2 + 2\ (tan^3\ \varphi + tan\ \varphi)\ (DB + EF - AC) = 0,$$

where—

$$\begin{aligned} A &= - cos\ \varphi_1\ (cot\ a_1 - cot\ a_2); \\ B &= - sin\ \varphi_1\ (n\ cot\ a_1 + m\ cot\ a_2); \\ C &= \quad sin\ \varphi_1\ (cot\ a_1 + cot\ a_2); \\ D &= - cos\ \varphi_1\ (n\ cot\ a_1 - m\ cot\ a_2); \\ E &= \quad m - n; \text{ and} \\ F &= - sin\ \varphi_1\ cos\ \varphi_1. \end{aligned}$$

Application to Augite, etc.

§ 7. There is one most frequent case that we may consider in detail: It arises when one of the three planes whose traces are supposed to be seen bisects the angle between the other two. This occurs in hornblende, augite, olivine, feldspar, titanite, pyrite and other minerals. It may be treated by either construction; and equation (5) of § 6 takes the much simpler form—

$$cos\ 2\ \varphi = a + b \pm \sqrt{(a + b + 1)^2 - 4\ b}, \quad (1)$$

where—

$$a = \left(\frac{n + m}{n - m} cot\ a\right)^2 \text{ and } b = \left(\frac{2}{n - m} cot\ a\right)^2.$$

We have also—

$$b\ (1 - cos\ 2\ \theta) = 1 + cos\ 2\ \varphi. \quad (2)$$

We derive (1) from (5) of § 6 as follows: $cos\ a_1 = 0$, $sin\ \varphi_1 = -1$, $cot\ \varphi^1 = cot\ a_2$; and we may drop the subscripts and write $cot\ a$ for both. Therefore,

* Tschermak's Min. u. Pet. Mitth., October, 1887, p. 207.

$A = D = F = 0$; $B = (n + m) \cot \alpha$; $C = -2 \cot \alpha$; and $E = m - n$. Hence, from § 6—

$$\tan \varphi = \frac{-B}{C \cos \theta}, \sin \theta = \frac{-E \cos \varphi}{C}. \tag{3}$$

Since $\sin^2 \theta + \cos^2 \theta = 1$, we have—

$$B^2 \cot^2 \varphi + E^2 \cos^2 \varphi = C^2. \tag{4}$$

Now we can put $a = \left(\frac{B}{E}\right)^2$ and $b = \left(\frac{C}{E}\right)^2$, and we may call $\cos^2 \varphi = x$, *i. e.*, $\cot^2 \varphi = \frac{x}{1 - x}$. Accordingly—

$$\frac{ax}{1 - x} + x = b; \tag{5}$$

whence—

$$x = \frac{a + b + 1}{2} \pm \sqrt{\left(\frac{a + b + 1}{2}\right)^2 - b}. \tag{6}$$

But as $x = \cos^2 \varphi = \frac{1 + \cos 2 \varphi}{2}$, equation (1) follows at once from (6). We may develop it into a rapidly converging series. Moreover, putting b in equation (3) we have $\sin^2 \theta = \frac{\cos^2 \varphi}{b}$. Substituting 2θ and 2φ for θ and φ, we obtain (2).

In number* 909, for example, there is an augite twin, quite obliquely cut, which is sketched in figure 2*a*. From it we have the following data: The trace of twinning (100) is parallel to the vertical cross-hair when the rotating stage is at 7°.1. Similarly for the trace of $(1\bar{1}0)$ we have 340.°9; for (110), 63°.1. Hence $n = \cot 26°.2 = -2.0323$, and $m = \cot 56°.0 = 0.6745$, and we have the following solution:

$\cot \alpha = \cot 46° 27'$; log. $\cot \alpha = 9.9780$
$m - n = 2.7068$; log. $m - n = 0.4324$

Subtract $9.5456 \times 2 = 9.0912$;

$m + n = -1.3578$; log. $m + n = n\ 0.1328$

Add to the above: $n\ 9.6784 \times 2 = 9.3568$.

Log.$^{-1}$ 9.0912 = 0.1234; log.$^{-1}$ 9.3568 = 0.2274 = a.
Multiply 0.1234 by 4, and we have 0.4936 = b.

* The numbers refer to sections in the collections of the Michigan State Geological Survey.

Hence—

$$a + b = 0.7210 \quad \log.\ a + b + 1 = 0.2358$$
$$2$$

$$\log.\ (a + b + 1)^2 = 0.4716.$$

$$a + b + 1^2 = 2.9621\ ;$$
Subtract $4b$ $\quad 1.9744$

$$0.9877.$$

Log. 0.9877 = 9.9946, and dividing by 2 we get the log. $\sqrt{(a + b + 1)^2 - 4\, b}$ = 9.9973, of which the antilog. is .9938. Therefore—

$$\cos 2\ \varphi = 0.7210 \pm 0.9938 = -\ 0.2728\ ;\ 2\ \varphi = 105.8\ \varphi = 52°.9\ ;\ \text{while}$$

$$\cos 2\ \theta = 1 - \frac{1 - 0.2728}{0.4936} = 0.4732\ ;\ 2\ \theta = 118°.2, \text{and}\ \theta = 59°.1.$$

Moreover, the direction of the + extinction in the one half (I) is 28°.6 ; in the other (II) it is 310°.5. The polarization color in I corresponds to a retardation of about mm. 0.000,48 ; in II, of about mm. 0.000,95. The hyperbolas close into a cross at 315°. This direction, therefore, is parallel or perpendicular to (010).

Figure 2 is the stereographic projection drawn with these data and illustrating the case figured in figure 2*a* and solved above. S is constructed with the above found (φ, θ). SC_4, SC_3, SC_2, etc., are the radii of the zone-circles SP_4, SP_3, SP_2, and are the directions of the traces of the corresponding faces and cleavages. SX_1 and SX_2 are the directions of the extinctions. Figure 2 and figure 2*a* harmonize well.

We may also check our solution by solving one of the spherical triangles, of which we have four parts given, as, for example, SP_1P_3. Here P_1P_3 = 46° 27′, SP_1 = 59°.2, and $\angle P_3SP_1$ = 26°.2. SP_1P_3 = 142°.9 by our previous solution, and by spherical trigonometry we have—

$$\log.\ \tan 26°.2 = 9.6920,\ \log.\ \cot 46°\ 27' = 9.9780$$
$$\log.\ \cos 59°.2 = 9.7106,\ \log.\ \tan\ 59°.1 = 0.2247$$

$$9.4026$$

$$\theta = 75°.9 \qquad \log.\ \cos\ \theta = 9.3892$$

$$\theta_1 = 67°.1 \qquad \log.\ \cot\ \theta_1 = 9.5901.$$

$SP_1P_3 = \theta + \theta_1 = 142°.9.$

A careful drawing is generally a sufficient check on the calculation and accurate as the measurements, and no numerical work is necessary but the finding of S.

Determination of optical Axes from a random Section.

§ 8. It is interesting to note that from such a random section we can theoretically determine the position of the optical axes, *i. e.*, α and V. Let $e = \angle m\,SB$, $f = \angle m\,SA$, $g = \angle m\,SB_1$, $h = \angle m\,SA_1$ ($CA = \alpha + V$, $CB = \alpha - V$), figure 2. Then, in a series of spherical right triangles, we have—

$$\begin{aligned} \tan e \sin Sm &= \tan (Cm - \overline{\alpha - V}), \\ \tan f \sin Sm &= \tan (Cm - \alpha + V), \\ \tan g \sin Sm &= \tan (Cm + \overline{\alpha - V}), \\ \tan h \sin Sm &= \tan (Cm + \overline{\alpha + V}); \end{aligned} \qquad (1)$$

and—

$$\begin{aligned} \sin e \sin SB &= \sin (Cm - \overline{\alpha - V}), \\ \sin f \sin SA &= \sin (Cm - \alpha + V), \\ \sin g \sin SB_1 &= \sin (Cm + \overline{\alpha - V}), \\ \sin h \sin SA_1 &= \sin (Cm + \overline{\alpha + V}). \end{aligned} \qquad (2)$$

Moreover—

$$\begin{aligned} \frac{e+f}{2} &= m\,SX_1 = x_1, \text{ and} \\ \frac{g+h}{2} &= m\,SX_2 = x_2, \end{aligned} \qquad (3)$$

where x_1 and x_2 are the extinction angles and may be determined by observation. Lastly, if $\gamma' - \alpha'$ is the retardation of one half and $\gamma'' - \alpha''$ that of the other half of the augite twin, their ratio, which may be determined by comparing polarization colors, is—

$$\frac{\gamma' - \alpha'}{\gamma'' - \alpha''} = \frac{\sin SA \;\; \sin SB}{\sin SA_1 \sin SB_1}. \qquad (4)$$

From equations (1) and (3) we can find $\tan 2x_1$ by clearing of fractions and expressing tangents in terms of sines and cosines in the form—

$$\tan 2x_1 = \sin Sm \times$$

$$\frac{\sin \overline{Cm - \alpha + V} \cos \overline{Cm - \alpha - V} + \sin \overline{Cm - \alpha - V} \cos \overline{Cm - \alpha + V}}{\sin^2 Sm \cos \overline{Cm - \alpha + V} \cos \overline{Cm - \alpha - V} - \sin \overline{Cm - \alpha + V} \sin \overline{Cm - \alpha - V}}. \qquad (5)$$

To this we can apply formulæ 105 to 108 of Chauvenet's Trigonometry, reducing it ultimately to the form—

$$tan\ 2x_1 = \frac{2\ sin\ Sm\ sin\ 2\,(Cm - a)}{cos\ 2\,(Cm - a)\,(1 + sin^2\ Sm) + cos\ 2\ V\,(sin^2\ Sm - 1)}. \qquad (6)$$

Similarly, for x_2—

$$tan\ 2\,x_2 = \frac{2\ sin\ Sm\ sin\ 2\,(Cm + a)}{cos\ 2\,(Cm + a)\,(1 + sin^2\ Sm) + cos\ 2\ V\,(sin^2\ Sm - 1)}. \qquad (7)$$

Again, eliminating SA, SB, SB_1, SA_1 from equations (4) and (2) we have—

$$\frac{\gamma' - a'}{\gamma'' - a''} = \frac{sin\,(Cm - a - V)\ sin\,(Cm - a + V)}{sin\,(Cm + a + V)\ sin\,(Cm + a - V)} \cdot \frac{sin\ g\ sin\ h}{sin\ e\ sin\ f}. \qquad (8)$$

From formula 119 of Chauvenet's Trigonometry, $sin\ e\ sin\ f = \frac{sin\,(e + f)}{cot\ e + cot\ f}$, so that, using equations (3) and (1), we have—

$$sin\ e\ sin\ f = \frac{sin\ 2\,x_1}{sin\ Sm} \cdot \frac{tan\ \overline{Cm - a + V}\ tan\ \overline{Cm - a - V}}{tan\ \overline{Cm - a - V} + tan\ \overline{Cm - a + V}}; \qquad (9)$$

and similarly—

$$sin\ g\ sin\ h = \frac{sin\,2\,x_2}{sin\ Sm} \cdot \frac{tan\ \overline{Cm + a + V}\ tan\ \overline{Cm + a - V}}{tan\ \overline{Cm + a - V} + tan\ \overline{Cm + a + V}}. \qquad (10)$$

Now, substituting (9) and (10) in (8) and reducing with the help of formulæ (105) to (108), as we did for (6), we finally get—

$$\frac{\gamma' - a'}{\gamma'' - a''} = \frac{sin\ 2\ x_2 .\ sin\ 2\,(Cm - a)}{sin\ 2\ x_1\ \ sin\ 2\,(Cm + a)}. \qquad (11)$$

Then (6), (7) and (11) may easily be transformed into the following equations:

$$cos^2\ Sm\ cos\ 2\ V$$

$$= -2 . \frac{sin\ Sm}{tan\ 2\,x_1}\,sin\,2\,(Cm - a) + (1 + sin^2 Sm)\ cos\ 2\ (Cm - a); \qquad (12)$$

$$= -2\,\frac{sin\ Sm}{tan\ 2\ x_2}\ sin\ 2\ (Cm + a) + (1 + sin^2\ Sm)\ cos\ 2\,(Cm + a); \quad (13)$$

$$\frac{tan\ 2\ Cm}{tan\ 2\ a} = \frac{\dfrac{sin\ 2\ x_2 .}{sin\ 2\ x_1}\,\dfrac{\gamma'' - a''}{\gamma' - a'} + 1}{\dfrac{sin\ 2\ x_2 .}{sin\ 2\ x_1}\,\dfrac{\gamma'' - a''}{\gamma' - a'} - 1}. \qquad (14)$$

If we have observed the extinction angles and determined the position of the section (S and therefore Cm and Sm), we can find $\alpha = < C\gamma$ and $V = \frac{1}{2} AB$ from (12) and (13). If we have determined the relative retardation $\frac{\gamma'' - \alpha''}{\gamma' - \alpha'}$, (14) may be used as a check; or we can determine α directly from (14) and use one of the others to determine V. We have then the remarkable result that a random section of an augite twin may be enough to determine both α and $2V$, unless it occurs in certain zones. Positions of the section near these zones will be unfavorable for finding one or the other. The case of figure 2 is unfavorable for finding $2V$, but α must be near 45°.

Solution in the Case in which the Section must be in a given Zone: Application to Tourmaline.

§ 9. The last case we take up is the common one in which we know at least approximately in what zone the section lies. Such knowledge is given us when twins have symmetrical extinctions, when long, slender prisms lie wholly in the thin section, when microliths are wholly in focus at the same time, etc. Then φ and θ, the coördinates of position of the section, are connected by a relation of the form $\cos\varphi = k \cot\theta$. We can, moreover, take the plane of projection in or perpendicular to the given zone, and thus make φ or θ 0° or 90°; so that our substitution in previous equations is quite simple. If we know, for example, from the extinction of hornblende or augite twins parallel to the twinning trace, that the section is in the zone of the orthodiagonal $(\bar{b})$, equation (3) of § 7 becomes—

$$\sin\theta = -\frac{E}{C}, \text{ and } B = 0;\ i.e.,\ n + m = 0.$$

Hence—

$$\sin\theta = \frac{m}{\cot\alpha}.$$

For the case of long prisms, we may assume that they lie at right angles to a face perpendicular to the prism axis, and that $\theta = 0$. Therefore, from equation (5) of § 6, $\tan\varphi = \frac{B}{D}$, and—

$$A\cos\varphi + C\sin\varphi = -E\sin\varphi\cos\varphi + F. \qquad (1)$$

Now, if $\tan\varphi = -B/D$, $\cos\varphi = -D/(B^2 + D^2)$, and $\sin\varphi = B/(B^2 + D^2)$; so that we have from (1)—

$$\frac{CB}{\sqrt{B^2 + D^2}} = \frac{EBD}{B^2 + D^2} + F; \qquad (2)$$

an equation of condition, which may be much simplified if $a_2 = a_1$, in which case we may drop the subscripts and write a; for then $A = 0$, $B = -(\sin \varphi_1) \cot a\ (n + m)$, $C = 2 \sin \varphi \cot a$, $D = - \cos \varphi_1 \cot a\ (n - m)$, $E = m - n$, and $F = - \sin \varphi_1 \cos \varphi_1 (n + m)$. Therefore—

$$B^2 + D^2 = \cot^2 a\ (n^2 + m^2 - 2 \cos 2 \varphi_1\ m\ n)\ ;$$
$$CB = -2 \sin^2 \varphi_1 \cot^2 a\ (n + m)\ ;\ \text{and}$$
$$EBD = \sin \varphi_1 \cos \varphi_1 \cot^2 a\ (n + m)\ (n - m)^2.$$

If we substitute these values in (2), and cancel and reduce and replace $(1 - \cos 2 \varphi_1)$ by $\sin^2 \varphi_1$, we shall have this formula, which connects m, n, φ_1 and a—

$$n^{-2} + m^{-2} - 2 \cos 2 \varphi_1 .\quad m^{-1}\, n^{-1} = \left(\frac{\sin 2 \varphi_1}{\cot a}\right)^2. \qquad (3)$$

This may also be derived directly from spherical triangles. If φ_1 and a, which depend on the terminal faces, are known, then m and n can vary only within certain limits. The point whose coördinates are $(m^{-1}\, n^{-1})$ will in fact be limited to an ellipse (figure 1) whose intercepts will be $(\pm \sin 2 \varphi_1 / \cot a, 0)$ and $(0, \pm \sin 2 \varphi_1 / \cot a)$. The extremities of its axes will be at the points $\left(\begin{matrix} - \tan \\ + \cot \end{matrix} \varphi_1 / \cot a,\ \begin{matrix} \tan \\ \cot \end{matrix} \varphi_1 / \cot a\right)$. A slight modification gives a similar ellipse connecting the apparent angles of termination of microliths, when it is their edges that we see instead of traces of their faces.

The use of this theory may be shown by the application of it to another example; and with this we close. A characteristic accessory of the slates and kindred rocks of northern Michigan is tourmaline. It occurs in small distinctly hemimorphic prisms. One end is inclined to be more bluish, and is terminated with the basal plane or else very bluntly. The other end is browner, and has a sharper termination. The most important, and therefore most likely to be observed, terminal faces are rhombohedra. The fundamental rhombohedron of Rosenbusch (R) has a basal edge angle of 133° 10′ and is Dana's $-\frac{1}{2}$. It is represented by $P_1 P_2 P_3$ of figure 3. The fundamental rhombohedron (R) of Dana is $O_1 O_2 O_3$. For the rhombohedron $q\, R$ equation (3) will become (since $\cos 2 \varphi_1$ will then be $\cos 120° = -\frac{1}{2}$, and $\sin 2 \varphi_1$ will equal $\sqrt{\frac{3}{4}}$, while $q\, c$ will, according to Dana's Textbook (page 72), be equal to $\sqrt{\frac{3}{4}} \tan a$)

$$n^{-2} + m^{-2} + m^{-1}\, n^{-1} = (q\, c)^2. \qquad (4)$$

Every value of q for different rhombohedra will give a different ellipse upon which the point (m^{-1}, n^{-1}) should lie. Now, we remember that m^{-1} is the tangent of the angle from the trace of the basis to the trace of P_2, or, which is the same thing, from the prism axis to the normal to the trace of P_2. The corresponding value for P_1 is n^{-1}. These values we may observe and, plotting them, see what ellipses they approach and what rhombohedra they indicate. Figure 7 shows the plotting of a number of such observations on tourmaline, together with the ellipses corresponding to R and $\pm \frac{1}{2}$ of Dana. We may derive an easily applied rough rule from the ellipses at once. We see, for example, that the greater angle from the trace of the basis to that of the rhombohedron should, for the fundamental rhombohedron, be between 42° and 47°. Allowing for variation on account of the section not being exactly prismatic, and on account of mistaking edges for the traces of faces, we see that R and $\pm \frac{1}{2}$ of Dana are doubtless the prevailing forms. The former is more common, and terminates the "antilogous" end, while the latter alternates with the basis on the "analogous" end.

Calcite and tourmaline are near enough in their parameters to permit the application of figure 7 to distinguish between the R cleavage and $-\frac{1}{2}$ pressure twinning of calcite.

Michigan Mining School, Houghton, Mich., *June* 18, 1890.

EXPLANATION OF PLATE 14.

FIGURE 1—An elevation illustrating the mode of making a stereographic projection.

FIGURE 2*a*—The sketch of a section of a twinned augite. (The two lines indicating the twinning should be parallel.)

FIGURE 2—A stereographic projection of the same section. SC_1 is taken parallel to the twinning line of 2*a*.

FIGURE 3—A stereographic projection of tourmaline, illustrating the section given in the lower left-hand part of the figure.

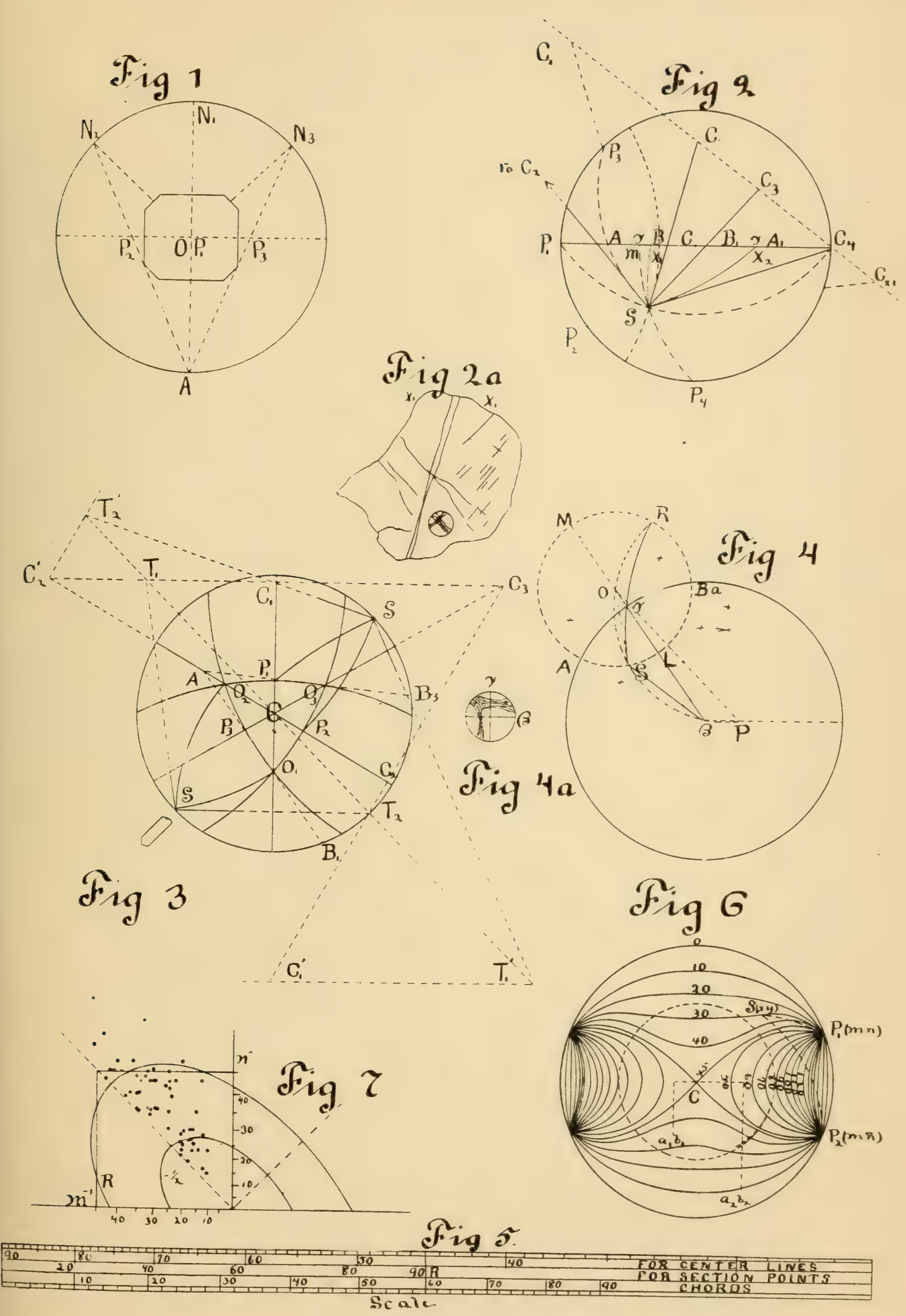
FIGURE 4*a*—An image in convergent light.

FIGURE 4—Diagram illustrating the determination of the position of the section which gives that image with the aid of the stereographic projection. It is located at *S*.

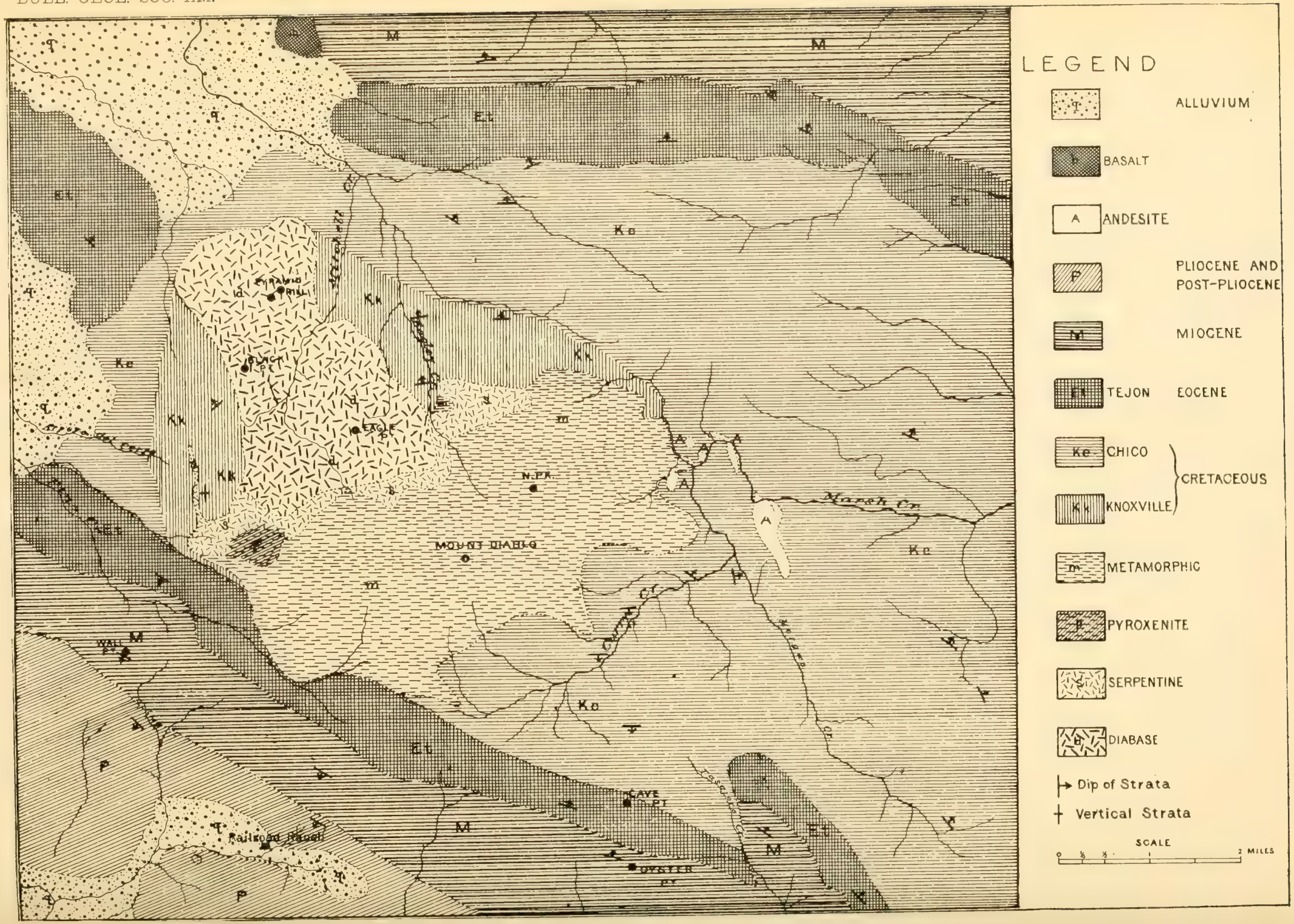
FIGURE 5—A scale to facilitate the use of the stereographic projection. The lower scale is of long chords.

FIGURE 6—Diagram showing the curves, any one of which is the locus of face-points of plane sections which cut a dihedral angle of 45°, so that the plane angle traced in them has the same value as that appended to the curve.

FIGURE 7—Diagram illustrating the connection which must exist between the apparent angles of termination of tourmaline rhombohedra in cross-section; also observations upon the same.



Diagrams used in identifying Mineral Crystals.



GEOLOGIC MAP OF THE VICINITY OF MOUNT DIABLO, CALIFORNIA.

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THE GEOLOGY OF MOUNT DIABLO, CALIFORNIA.

BY H. W. TURNER.

WITH A SUPPLEMENT ON

THE CHEMISTRY OF THE MOUNT DIABLO ROCKS.

BY W. H. MELVILLE.

(*Read before the Society December* 31, 1890.)

CONTENTS.

General Remarks.

Mount Diablo is an isolated peak of the Coast ranges of California, lying about 27 miles east-by-north of San Francisco. Although less than 4,000 feet high, it forms a prominent feature in the landscape, rising as it does from sea level, and is visible from all the main lines of railway leading to San Francisco. Owing to its isolation, the view from the summit is unusually fine, and it is frequently ascended by excursion parties.

Being easily accessible, it was selected by Professor Whitney as a field for detailed geological work when he first undertook the study of the Coast ranges. He there first obtained evidences of the Cretaceous age of the bulk of the metamorphic rocks of the range, having observed there the unaltered shales containing *Aucella mosquensis*, Von Buch, passing into silicified shales, or phthanites, about the head-waters of Bagley creek.* *Aucella mosquensis* † is a fossil common in and characteristic of the Knoxville (Neocomian) beds. These silicified shales are so intermingled with the other metamorphic rocks as to leave no doubt that all of them are of the same age.

In bulletin number 19 of the United States Geological Survey, Mr. G. F. Becker has further shown that the rocks of the lowest member of the Cretaceous (the Neocomian) only have been highly silicified, serpentinized, and otherwise altered.

Through the kindness of Mr. Becker I have been allowed to spend some months in geological field work at Mount Diablo. The work resulted in a geological map covering about 110 square miles, and in a collection of about 340 rocks. A reduced copy of this map forms the accompanying plate 15.

Dr. W. H. Melville, of the chemical division of the Geological Survey, was with me for a time at the mountain, and has made some interesting chemical studies, including quantitative analyses of several of the rocks. The results of his work accompany the present paper as a supplement.

Mr. Waldemar Lindgren was the first to detect the probably eruptive nature of part of the serpentine (peridotite and pyroxenite) at Mount Diablo, having found remains of olivines in some of it in Bagley cañon.

The Metamorphic Area.

The area of metamorphic rocks comprises the central mass of the mountain, including the main and northern peaks. It is only about ten square miles in extent; yet within it are found all or nearly all of the Neocomian meta-

* Geology of California. vol. I, 1865, p. 23.

† The name used by Professor Whitney is *Aucella piochii*, Gabb (Paleontology of California, vol. II, 1869, p. 194). This was later shown by Dr. White to be a synonym. See his paper on the genus *Aucella* in Becker's "Quicksilver Deposits," 1888, p. 226.

morphic rocks of the Coast ranges described as such by Mr. Becker in his monograph on quicksilver deposits. Phthanite, mica schist, glaucophane schist, diabase, amphibolite, with considerable metamorphic sandstone (in which the sand grains are plainly discernible), together with some small serpentine areas of uncertain origin on the southern slope of the mountain, form the metamorphic area. The metamorphic sandstones are much fractured, and are penetrated by numerous minute quartz veins. They contain also a large amount of calcite, largely in little bunches.

On the summit of the mountain there is a good deal of diabase, the origin of which is uncertain. Under the microscope it is found to contain som serpentine in thin streaks and patches, but also much augite, the feldspar being mostly decomposed.

Most of the rock of North peak appears to be a greatly decomposed diabase. It is, at all points examined, greatly crushed, and, like the meta morphic sandstone, contains veins of quartz and veins and bunches of calcite. This is true likewise of a good deal of the diabase found in patches, intermingled with silicified shale and metamorphic sandstone, in other portions of the metamorphic area.

The silicified calcareous shale (phthanite) is especially abundant on the southern and western slopes of the main peak. It occurs elsewhere, however, in patches at numerous points. Mica schist was found at one point only, two miles southeast of the main peak. Glaucophane schist is rather abundant, usually near serpentine. It occurs nowhere in any large body, forming only isolated croppings or narrow streaks. It may be seen on the ridge joining North peak and the main peak about one-half mile northeastward from the main peak.

About a mile and a half southwest of the main peak, near the edge of the metamorphic area and not far west of the road from the Railroad ranch to the Mountain house, there is some glaucophane schist so related (in part interbedded) with the shale about it as to lead one to suppose it to have been formed from the shale by the action of mineralizing solutions.

The Pre-Tertiary Igneous Rocks.

To the north of the metamorphic area there are two considerable areas of crystalline rocks thought to be of igneous origin. One of these is a diabase, and the other is a peridotite in some portions and pyroxenite at the other points, much of it having been altered to serpentine.

Diabase.—The larger and probably the older of these two areas is, in its most characteristic development, a typical diabase.

It forms an area of about four square miles lying north of the serpentine dike to be hereafter described, and embracing the points known on a map constructed by Charles Hoffmann as Pyramid hill (locally called Mount Zion), Black point and Eagle point.

It is believed to be of igneous origin from its being a holocrystalline rock, apparently indistinguishable from known eruptive diabases; from its nowhere exhibiting any trace of clastic structure; from its sharp contact with surrounding rocks, whether other crystalline rocks or unaltered sediments; and from its being practically uniform throughout in composition and microscopic structure, the main variation being a complete replacement of the augite by green fibrous hornblende in certain considerable portions of the area. No dikes have been seen, however, extending from it into the surrounding rocks.

In an unpublished paper on the Almaden quicksilver mine in Spain, Mr. G. F. Becker has traced a coincidence between the quantity of ilmenite in the diabase and the degree of fluidity which the phenomena indicate. He calls attention to the well-known fact that, in a blast furnace, slags are rendered practically infusible by a small percentage of titanium, and infers that this substance has a similar effect on rock magmas, rendering them less fluid and less likely to penetrate surrounding masses as narrow dikes. The abundance of titaniferous iron ore (ilmenite) in the Mount Diablo diabase may account for the lack of dikes.

The following description of the diabase is taken from slides numbered 43 and 143 of the series collected at Mount Diablo, now preserved in the laboratory of the United States Geological Survey in Washington.

Macroscopically, the rock is dark-greenish, compact, evidently crystalline, and of even texture.

Under the microscope it is seen to be a typical diabase, holocrystalline, ophitic in structure, composed of augite, plagioclase and ilmenite, with uralite and chlorite as secondary constituents.

The plagioclase is nearly all twinned after the albite law, the extinctions on the twinning plane *M* (010) being large (26°–25°, 30°–26°), suggesting labradorite. Zonal structure was noted in two plagioclases.

The augites, in many cases fresh, give large extinction angles (42°–54°) with characteristic cleavage, and are colorless in thin section. The augite is frequently twinned, sometimes more than once, as is shown by the different extinctions of different portions of the same mass; the different portions showing, as well, different directions of the dominant cleavage. In one individual an irregular middle portion extinguished differently from the remainder of the individual, although the dominant cleavage lines of the entire crystal were continuous. The interference colors of the augite are usually bright blue to green. Clear, doubly refracting grains in the centers of some of the augite individuals do not show interference colors. The presence of these grains in the augite may be related to the presence of chlorite in the interior of the uralite.

The uralite in these slides is largely light-brownish in color, with a slight greenish tinge, but is plainly dichroic or polychroic; it is distinctly and finely fibrous, and usually extinguishes a few degrees from the direction of the fibers. Cross-sections of the prisms show the crystal form of augite, and in places it is plainly seen to be derived from that mineral.

The color of the *C* ray of the uralite is pale greenish-brown, and that of the *A* ray pale brownish. The interference colors of the uralite are largely purplish. There is about as much uralite as augite. The frayed ends of the uralite prisms sometimes pass over into chlorite. Some of the uralite is stained with ferrotite.

The chlorite is plainly pleochroic, bluish-green when the fibres are parallel to the shorter diagonal of the polarizer, and pale brownish when at right angles. The polarization tints are deep-brown and indigo-blue, sometimes so dark that no light passes through. The chlorite is frequently derived from the uralite, but sometimes seems to be formed directly from the augite. In some cases it fills the spaces between the other constituents.

Ilmenite showing a grate-like structure occurs in much of the diabase. Considerable portions of the diabase area, however, contain no augite, the bisilicate being hornblende. Such portions, therefore, are practically diorite. The ridge of which Black point is a part is, from that peak southward to the serpentine dike, largely of this diorite. The rock of Eagle point ridge, immediately north of the same serpentine dike, is also largely hornblendic.

Number 307 is a typical example of this diorite. It comes from the southern slope of Black point. This rock, viewed macroscopically, is dark in color, very fresh looking, and of even texture. Other specimens have a much coarser texture, with more abundant feldspars, giving a grayish color, then more resembling ordinary eruptive diorite as to the macroscopic appearance. The hornblende of number 307 is fibrous, usually greenish, and contains numerous granules of iron oxide. No augite was noted in the slide. The plagioclase is fresh looking, polysynthetic and lath-like, largely imbedded in the hornblende.

In some other slides of the diorite there are no granules of iron oxide in the hornblende, and it is then indistinguishable from the light greenish-brown uralite of slides 43 and 143.

Slide number 283 shows some augites, minute scattered patches of which have been converted into uralite. Some of the hornblende of the slide is compact, all portions of the crystal extinguishing at once; and such prisms are not so evidently fibrous, but show prismatic cleavage plainly. Minute patches of some of this brown compact hornblende are decidedly bluish in color, suggesting glaucophane. Greenish fibrous hornblende is sometimes associated in the same prism with the brown compact variety, suggesting the formation of one from the other; in other prisms of the compact hornblende, irregular portions are nearly colorless, extinguishing, however, simultaneously with the brown parts.

Professor G. H. Williams * has described compact greenish hornblende from the Baltimore gabbro area, regarding it as a secondary product of the diallage, it being intimately associated with fibrous hornblende of undoubtedly secondary character. In another paper † he points out that it has long been recognized and experimentally proved by Mitscherlich and Berthier, G Rose, and Fouqué and Lévy that pyroxene and hornblende are two crystallographic forms for the same molecule, of which the former is stable at high and the latter at low temperatures; and he gives evidence of the alteration of hypersthene to compact brown hornblende.

Professor R. D. Irving concludes that the compact brown basaltic hornblende in certain hornblende-gabbro rocks of the Lake Superior region results from the alteration of pyroxene.

It may well be, therefore, that all of the hornblende of the diabase-diorite, even when compact and brown in color, is the result of paramorphism from pyroxene.

All of the slides described above exhibit the same ophitic structure, and the entire area is believed to have been originally diabase. Associated with the diabase-diorite there is an aphanitic black rock, found in small amount only. It has been collected on the southern flank of Black point and on the southeastern side of Pyramid hill. While one would infer from some hand specimens, showing the fine-grained rock and the diorite in contact, that it must occur as dikes in the diorite, a study of an exposure on the southeastern slope of Pyramid hill did not lead to this conclusion; the rock occurring there in small bunches and, apparently at least, grading into the coarser rock. Number 286 is a specimen of this aphanitic black rock. It is composed of lath-like plagioclase and flecks of fibrous green hornblende imbedded in a fine ground-mass of feldspar microlites and grains of magnetite. The latter is very abundant, and doubtless gives the black color to the rock. The feldspar phenocrysts are of notable size.

On page 412 of the supplement to this paper will be found two analyses of specimens from the diabase area by Dr. Melville. Number 44 is a diabase-diorite, and number 43 is one of the diabases above described. It will be observed that the two analyses are remarkably alike, and also that they do not differ materially from the analyses of Mr. Becker's pseudodiabase.‡ It may be noted that the composition of the glaucophane schist (supplement, page 413) is very similar to that of the diabase.

Peridotite and Pyroxenite.—Another large mass of crystalline rock, apparently also eruptive, lies south of the diabase area just described. It is

* Bulletin 28, U. S. Geol. Surv., 1886, pp. 40-42.
† Am. Jour. Sci., 3d ser., vol. XXVIII, 1884, p. 262.
‡ "Quicksilver Deposits," pp. 98, 99.

largely converted into serpentine, except in those portions where the rock is nearly pure pyroxene, and seems to answer very well to Professor G. H. Williams' rock pyroxenite, as set forth in an article on the "Non-feldspathic rocks of Maryland,"* in which he restricts the term to igneous masses composed only of pyroxene. Indeed the area, as a whole, has striking points of similarity to certain portions of the large gabbro-peridotite area near Baltimore so ably described by Professor Williams,† a certain small area, apparently genetically connected with the dike, containing plagioclase and forming a gabbro, other portions being unquestionable peridotites, while, as before stated, some portions of the area contain little else than pyroxene. The area is, as a whole, quite dike-like, the length being about five miles and the average width less than half a mile.

The dike has largely been converted into serpentine; but at several points in the serpentinized portions microscopic sections show remains of olivines and pyroxenes. It is likely that much of the rock, now serpentine, forming the bulk of the area originally contained considerable olivine, those portions composed of nearly pure pyroxene better resisting decomposing influences.

Both orthorhombic and monoclinic pyroxene occur in the peridotite, the latter in much larger amount. The rhombic pyroxene is slightly pleochroic, the *A* ray being perceptibly reddish. It is doubtless bronzite. The monoclinic pyroxene is mostly or entirely diallage.

In specimen number 322 the large diallages contain some granules of perfectly fresh olivine, and there is also considerable olivine between the large pyroxenes. This rock is practically a lherzolite.

Number 242 contains little or no olivine but both rhombic and monoclinic pyroxene, and answers very well to Professor Williams' websterite.‡ That portion of the serpentine dike two miles west of the main peak, indicated by inclined lines on the map forming plate 15, is nearly all pyroxenite.

In the supplement to this paper (page 406) Dr. Melville gives an analysis of pyroxenite (specimen number 242). It does not differ greatly in composition from the websterite of Williams. §

The following rocks represent decomposition products of the peridotite-pyroxenite dike (see analyses by Dr. Melville in supplement): 176 and 181, series II (page 406); 222 and 223, series III (page 408); and 235 and 239, series IV (page 409).

All of these serpentinous products contain less silica and less magnesia than the formula for serpentine given by E. S. Dana ‖ requires. They also contain alumina, which would be expected in a serpentine derived from a peridotite containing diallage and bronzite. That pure serpentines are

* American Geologist, vol. VI, 1890, pp. 35–49.
† Bulletin 28, 1886, U. S. Geol. Survey.
‡ American Geologist, vol. VI, 1890, p. 44.
§ Ibid., p. 41.
‖ Text Book of Mineralogy, 1884, p. 350.

comparatively rare may be seen by referring to J. D. Dana's "Manual of mineralogy."

The dike nature of this serpentine area is best shown on the western side of the mountain east of the eastern fork of Pine creek, where it is cut across by the Arroyo del Cerro and its branches. It is here from a few feet to about 150 feet in width, enclosed in dark, calcareous shales containing, at several points near the serpentine, *Aucella mosquensis*, Von Buch, a fossil characteristic of the Knoxville beds (lower Cretaceous); and near the northern end of this narrow dike both *Aucella* and *Belemnites* occur in limestone.

The strike and dip of the dike is in general about that of the enclosing shales, the strike being nearly north-and-south, and the dip about vertical. The serpentine of this narrow dike has an imperfect fissile structure, and at one point only did I find the dark bastitic variety.

The eruptive serpentine of Mount Diablo does not differ materially in chemical composition from the metamorphic serpentine described by Becker.* A specimen from one of the small serpentine areas on the southern slope of the mountain contains abundant remains of pyroxenes and olivines. The area is thought to have an origin similar to that of the large serpentine dike on the northern slope above described.†

As to the diabase and serpentine occurring in little patches throughout the metamorphic areas of the Coast ranges of California, and mixed in the most confusing manner with unquestionably clastic rocks of early Cretaceous age, it might be held by one seeking to prove their igneous origin that a molten magma injected into a mass of rocks so thoroughly and irregularly fractured as are the rocks of the metamorphic areas would on consolidation form irregular areas rather than definite areas and dikes, there being few regular fissures into which a molten magma could be injected. This is shown likewise in the irregular and generally non-continuous character of the quartz veins of the Coast ranges, giving positive testimony as to the character of the fissures which they have filled. Professor Whitney says: ‡

"The rocks of the Coast mountains are especially distinguished by the fact that the movements to which they have been subjected, and which have originated the complex of alternating elevations and depressions making up the system of chains known as the Coast ranges, have been apparently sudden and sharp, so that the result may be called a crushing and breaking rather than an uplifting and folding. * * * Often, and especially in the central and northern portions of the state, the rocks for long distances are so broken up that a recognition of their real structural relations is entirely impossible."

In marked contrast to these are the fissures of the Sierra Nevada, contin-

*Quicksilver Deposits, 1888, p. 110-111.

†Mr. G. P. Merrill has called my attention to a serpentine collected by himself at San Francisco (the area that extends out to Fort Point), in a slide of which pyroxenes and olivines are plainly to be noted.

‡Auriferous Gravels of the Sierra Nevada, 1880, p. 16.

uous often for many miles, as is evidenced by the frequent long and regular dikes and the quartz veins.

Gabbro.—In Bagley creek, north of the point where the serpentine dike crosses the creek, there is an exposure of a typical gabbro, containing a good deal of plagioclase (probably labradorite) and fresh diallage. In one crystal a regular narrow band of monochroic rhombic pyroxene extends through a diallage crystal, forming twins, such as are figured diagrammatically by Lévy.* This gabbro has associated with it a finer crystalline mass, apparently a part of the same magma, a slide of which shows the rock to be decomposed to an aggregate apparently largely quartz and feldspar, showing one quartz phenocryst with corroded borders, some plagioclase with twin lamellæ, and a little pyroxene. This finer grained material may be seen just south of the typical gabbro exposure in the bed of the creek. On the northern edge of the gabbro there is a sulphur spring. Here was obtained the series of specimens comprising series I of those described in Dr. Melville's supplement. Number 175 is the undecomposed gabbro; numbers 173 and 175 seem certainly merely weathered layers of the gabbro.

Between this gabbro and the serpentine lies a body of *Aucella*-bearing shale a few hundred feet thick; so that it has yet to be demonstrated that there is a genetic connection between the gabbro and the peridotite, a position which was at first taken and which still seems to me probable.

Mineral Deposits.

Precious Metals, etc.—Various metals occur in the mountain. Gold was found by Dr. Melville, associated with chalcopyrite and bornite, in a specimen of ore from a copper prospect in a ravine draining into Mitchell cañon. A considerable amount of work has been done in prospecting for copper in the vicinity of Eagle point, Black point, and Pyramid hill, but no large ore body was ever discovered. The copper ore seems always associated with diabase.

The so-called silver mine in the northern slope of Pyramid hill (Mount Zion) is said to contain some manganese. Cinnabar has been mined about one mile northeast of North peak. The ore is here directly associated with chromite. In proximity to the ore there is a ledge of the so-called quicksilver rock, largely opal, with some serpentine. In the ravine a little way below the mine there is a sulphur spring. Further down the slope, by the road that runs near the eastern base of the mountain, there is another spring that must have been very active in past times, as it has deposited a large amount of travertine. South of this spring deposit, by a branch of Marsh creek called Ferguson creek, there is a little butte of micaceous andesite.

* "Mineraux des Roches," 1888, p. 261.

Cinnabar occurs here, at the contact of the andesite with the adjacent unaltered shale. It is associated with chalcopyrite and calcite, some of the cinnabar being so intermingled with the calcite as to indicate contemporaneous deposition. There is no quartz at this place. Solfataric action is still going on in the old tunnel run in for cinnabar.

At a point about one mile south of the main peak there is a vein of quartz, much stained by ferric oxide. In samples of this, Dr. Melville found cinnabar in considerable quantity.

Coal.—Extensive beds of coal occur in strata of Tejon age, about five miles northeast of the main peak. These deposits have been successfully mined for many years. The coal is rather friable, and inferior to that of Bellingham bay and other more northern localities. On the dumps of some of the old mines (Black Diamond and others) there are abundant pieces of carbonized wood, usually containing pyrite.

There are also some coal seams, that will sooner or later be worked, about two and a half miles southwest of the main peak, by Pine creek, in strata of the Tejon, which is the usual coal-bearing formation of central California. Coal of a poor quality is obtained, however, from nearly horizontal beds of Pliocene age, at Ione, Amador county, California, and at some other points.

Numerous coal seams occur in the neighborhood of Corral hollow pass, southeast of Livermore. The strata are considerably faulted, and in consequence the miners find difficulty in following the coal seams. The seams dip at a high angle, and the coal is sometimes decomposed to a depth of fifty or more feet by the action of surface waters, the resulting material being a rust-colored spongy mass, which no one not familiar with coal prospecting would suppose to indicate the presence of coal seams.

According to Mr. J. Richards, who kindly showed me about the mines, the coal above water-level contains much gypsum, but below the water line the sulphate of lime is in solution in the water and the coal is in consequence of better quality. I myself noted some gypsum in the coal. At the time of my visit (1886) there were no producing mines, but the coal seams were well exposed at the Livermore, Richards and Coleman mines. At the latter mine there was exposed a vein about five feet thick, dipping 80° northwestward. Stratigraphically above the coal seam, in a shaly stratum, were numerous oyster shells.

In the Richards coal mine the coal seam, where observed, dips 35° northwestward, and the coal was decomposed down eighty feet, following the vein.

On the surface near the Richards mine, in sandstone, I collected Tejon fossils (*Turritella uvasana*, and others).

At the present time (1890) some of these coal deposits are worked.

Mineral Springs.—Besides the springs referred to in connection with the quicksilver mine, mineral waters issue at several points. A warm spring which I have not seen is said to exist in Mitchell cañon.

Sulphur springs in Eocene (Tejon) sandstone occur at the mouth of Pine cañon. There is also a sulphur spring about eight-tenths of a mile east of the main peak.

There are two large deposits of travertine associated with white Tejon sandstone, one about two miles and the other perhaps three miles northwest of Pyramid hill. The calcite of the travertine resembles stalactitic calcite as to color (a dirty white), and Professor Whitney states that some of it shows concentric lines of deposition.

Tertiary Eruptives.

Dikes of micaceous hornblende-andesite exist in the little altered Cretaceous strata east of the main mass of the mountain. Some shale taken at the contact of one of these dikes was found by Mr. Lindgren to contain some newly formed hornblende, while similar shale a few feet off showed no alteration.

About two miles west-by-north of Clayton there is a considerable area of basalt. It contains abundant olivine. Some of this rock is quarried and used for paving.

There is also considerable andesitic tufa and conglomerate in the neighborhood of Kirker pass, north of the mountain, associated with fossiliferous beds which have been referred by Professor Whitney to the Pliocene; and again by the Railroad ranch reservoir, south of the mountain, associated with fossil leaves, probably Pliocene.

The Sedimentary Terranes.

The General Section.—As may be seen by referring to Mr. Becker's paper on the "Stratigraphy of California," * and Dr. White's papers on the paleontology of the Pacific slope,† there have been recognized in the Coast ranges of California the following Cretaceous and later terranes:

Knoxville Beds—Neocomian. } Shasta Group.
Horsetown Beds—Gault. }
Wallala Beds—Middle Cretaceous.
Chico Beds—Upper Cretaceous.
Tejon Beds—Eocene.
Miocene.
Pliocene.
Post-Pliocene.

With the exception of the Horsetown and Wallala beds, all these formations are represented at Mount Diablo.

* Bulletin U. S. Geol. Surv., no. 19, 1885.
† Bulletins U. S. Geol. Surv., no. 15, 1885; no. 22, 1885; and no. 51, 1889.

The Knoxville Beds.—These beds are, as usual, associated with the metamorphic rocks, and the previously described pre-Tertiary igneous rocks are intruded in them. This statement may be taken with some reservation in regard to the diabase area, which is practically a *massif;* but the peridotite (serpentine) penetrates the Knoxville shales, forming a narrow dike a mile long.

The rocks of this age consist almost universally of dark shales with occasional arenaceous and calcareous layers. Each calcareous layer is rather a series of lenticular bodies than a continuous limestone stratum. This applies to the Sierra Nevada as well, only there the limestone masses are hundreds of feet in diameter. At Mount Diablo these lenticular masses do not exceed twenty feet in width, measuring across the strike. It is mostly in the calcareous strata that fossils are to be found. Besides the molluscan remains, they contain elasmobranch teeth and spines and numerous minute tests of foraminifera. These tests have in some cases undergone silicification. The most characteristic fossil of the Knoxville beds is *Aucella*. The slender variety, *Aucella mosquensis*, Von Buch, occurs, as before stated, in Bagley cañon, about two miles north of the main peak; also on the eastern side of the creek that heads east of Eagle point and eight-tenths of a mile northeast of that peak; also at several points in the neighborhood of the peridotite dike that lies two miles west of Eagle point; and about one-third of a mile and again one mile southwestward from the summit of Black point.

Belemnites occurs near the northern end of this peridotite dike in limestone, and also in a coarse sandstone just east of the limestone. In this sandstone there are calcareous pebble-like nodules, the *Belemnites* occurring in the sandstone itself.

I observed near the mining camp of Knoxville, in Napa county, California, some croppings similar to these, in which *Belemnites* is to be found in the sandy matrix, the included limestone pebbles containing *Aucella mosquensis*, Von Buch.

About one-third of a mile north of the *Belemnites* limestone I found in a single calcareous nodule *Aucella*, *Inoceramus*, and two small gasteropods. This is, I think, the first time that *Inoceramus* has been noted in the Knoxville beds in California.

In a limestone nodule in strata of the Knoxville group, about one and seven-tenths miles southwestward from Eagle point, just north of the serpentine dike, I collected a fragment of wood of which a thin section was made and referred to Mr. F. H. Knowlton, who states that it belongs to the genus *Cupressinoxylon*. This genus, I understand him to say, is regarded as the ancestor of the sequoias. Near the fossil wood I found a specimen of *Aucella mosquensis*.

The dip and strike of the Knoxville strata are usually quite variable, but the dip is universally great, and the strata are frequently vertical.

It is possible that some of the beds laid down as Knoxville on the geological map represent the Horsetown group, but no positive testimony on this point has been gathered. This is rendered likely, however, by the finding of *Aucella* and some other fossils associated with fossils of the Horsetown group at Riddles, Oregon;* so that the genus *Aucella* is not restricted to the Knoxville beds. It would, perhaps, be safer to use the old name, "Shasta group," for the lower Cretaceous beds at Mount Diablo.

The Chico Beds.—These deposits are mostly rust-colored sandstones, especially in the upper part of the series. Underlying the sandstones there are usually dark-colored shales with arenaceous and calcareous layers, indistinguishable lithologically from the strata of the Knoxville series; so that these dark-colored shales are characteristic rather of the Cretaceous as a whole than of any particular portion.

Chico fossils occur northeast, east, southeast and south of the mountain; but, except toward the south of Curry creek, they are not particularly abundant. Here, in the ravines that drain into the creek from the south (heading west of Cave point), there are to be found very finely preserved shells. The Chico beds contain, *Trigonia evansana*, Meek; *Arca breweriana*, Gabb; *Anchura californica*, Gabb; and numerous other characteristic fossils. *Inoceramus* is common in limestone nodules on the high ridge south of the main mountain. *Ammonites*, *Baculites*, fragments of crustaceans, tubes of *Serpula*, spines and teeth of elasmobranchs, foraminifera, and bits of fossil wood were found also.

Among the *Ammonites* was collected a large individual resembling *stolizckanus*, Gabb, of the Horsetown beds, but which Dr. White considers distinct and has named *Ammonites turneri*.†

Another new species described by Dr. White in the same bulletin, *Scobinella dilleri*, occurs also in the Chico beds south of Curry creek. A considerable amount of conglomerate is exposed in the ravines south of Curry creek. It contains numerous pebbles of metamorphic rocks and of quartz porphyrite. These last pebbles are probably derived from the Sierra Nevada. Quartz porphyrite occurs abundantly in the foot hills of Calaveras county. There are very few pebbles, however, of the red silicified shale of the Mount Diablo metamorphic area, which is so abundant. This would seem to indicate that the metamorphic rocks of the mountain were little exposed to erosion during the Chico epoch.

The Tejon Beds.—These beds are chiefly light-colored sandstones, sometimes nearly white, with some thinly bedded light-colored shales. To the west of Cave point there are fine exposures of Tejon sandstone with curiously formed cavities, apparently the effect largely of wind erosion. Characteristic fossils (*e. g.*, *Turritella uvasana*, Gabb, and *Meretrix uvasana*, Gabb)

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*This vol., pp. 201–208: G. F. Becker, "On the Early Cretaceous of California and Oregon."
†Bulletin U. S. Geol. Sur., no. 51, 1889, p. 26.

occur at numerous points. This is the coal-bearing formation of central California.

Miocene Beds.—These strata are largely coarse gray sandstones, containing *Ostrea titan*, Conrad, with pectens and echinoderms. The Miocene conglomerate in Pine cañon contains pebbles of quartz, quartzite, and various other rocks of the metamorphic series; and one pebble of rhyolite or quartz pophyry showing flow structure finely was noted. There are, however, no pebbles of hornblende or pyroxene andesite. I observed a few red phthanite pebbles in Miocene conglomerate by the road from the Mountain house to the Railroad ranch.

Pliocene Beds.—These beds contain fossil leaves, silicified wood, numerous shells, and hornblende-andesite tufa and pebbles.

There is some discrepancy in the paleontological evidence as to the age of these beds, and they are therefore treated rather fully. Some of the fossil leaves obtained from them have been referred to the Miocene and others to the Pliocene, by Professor Ward and Professor Lesquereux; but there is good evidence that the strata from which these different leaves came are of approximately the same age.

The shells, which are of marine origin, were considered Pliocene by Dr. Gabb of the former state geological survey of California, under Professor Whitney. There are three localities at which fossils have been collected. These are, Kirker pass to the north, the Railroad ranch reservoir to the south, and Corral hollow, some twenty-five miles to the southeast, of the mountain.

The Kirker pass locality has afforded the following marine shells as determined by Gabb:

Trophon ponderosum, Gabb;
Ranella californica, Hds.;
Purpura saxicola, Val.;
Lunatia lewisii, Gld.;
Littorina planaxis, Phil.;
" *remondii*, Gabb;
Crypta grandis, Midd.;
Standella falcata, Gld.;
Pseudocardium gabbii, Rémond;
Gari alata, Gabb;
Dosinia ponderosa, Gray;
Tapes staminea, Con.;
Cyrena californica, Gabb;
Liropecten crassicardo, Con.;
Ostræa bourgeosii, Rémond;
Astrodapsis whitneyi, Rémond.*

*Geology of California, vol. I, 1865, pp. 31-32. The list as printed is not altogether that of this reference, but is compiled from Gabb's later synopsis of "Tertiary Invertebrate Fossils of California:" Paleontology of California, vol. II, 1869, pp. 67-124.

Some shells collected by myself at Kirker pass were referred by Mr. Becker to Dr. Wm. H. Dall, who reports that he has identified the following species, all of which are probably still living:

Bittium asperum, Cpr.;
Tapes staleyi, Gabb;
Saxidomus squalibus, Desh.;
Solen, sp. und.;
Macoma, sp. und.

Marine organic remains are, I think, in general considered the most reliable indications of the age of strata, and this seems most reasonable, since the salt waters of the world are practically one body, in which physical conditions are more uniform than on the land or in the air, and marine forms are thus less subject to change by local influences than are those of the land or of fresh waters.

There are also in the finer layers at Kirker pass numerous fossil leaves, and much silicified wood is weathered out. In the proceedings of the United States National Museum* there is published by Lesquereux a short account of specimens collected by myself at Kirker pass. The species identified are as follows:

Diospyros virginiana, L., var. *turneri*, Lx.;
Magnolia californica, Lx.;
Laurus, cf. *canariensis*, Heer.;
Laurus, cf. *furstenbergi*, Heer.;
Viburnum, cf. *rugosus*, Pers.;
Vitis, sp. und.

These are considered to be probably Pliocene, although on page 11 of the work the same collection is referred to the Upper Miocene. But there is still other evidence of the Pliocene age of these beds in the character of the tufas and conglomerates. These are made up chiefly of detrital material of hornblende and pyroxene-andesite. So far as we know at present, the andesitic eruptions took place in Pliocene times, or perhaps accompanied the post-Miocene upheaval of the Coast ranges.†

The andesitic material at Kirker pass presumably was derived from the volcanic area to the north of San Pablo bay. The Railroad ranch reservoir beds also consist in part of andesitic conglomerate and tufa, with fine layers in which there are fossil leaves. The material is here more or less altered and penetrated by many small veins of chalcedony and calcite.

The Corral hollow beds are quite similar lithologically to those of the last two localities, containing much fine shale with fossil leaves and andesitic

* Vol. XI, 1889, p. 35.

† For evidence on this point, referring to the Coast ranges, see Becker, "Quicksilver Deposits:" Monograph XIII, U. S. Geological Survey, 1888, pp. 222–223; and, with reference to the latter range, Whitney's Auriferous Gravels of the Sierra Nevada, 1880, pp. 219–288.

tufas and conglomerates. The locality is on the northern side of Corral hollow, and was first investigated by the state geological survey,* whose officers collected here fossil leaves, supposed by Professor Whitney to be Pliocene.

Professor Lesquereux, in his " Cretaceous and Tertiary Floras," forming volume VIII of the monographs of the Hayden survey, gives the following species from Corral hollow, presumably collected by the California state survey:

Equisetum, sp. und.;
Sequoia angustifolia, Lx.;
Taxites olriki, Heer;
Alnus corrallina, Lx.;
Castanea ungeri, Heer;
Salix integra, Goepp;
Populus balsamoides, Goepp;
Plantanus dissecta, Lx.;
Laurus princeps, Heer;
" *grandis*, Lx.;
" *salicifolia*, Lx.;
" *californica*, Lx.;
Cinnamomum affine, Lx.;
Myrtus oregonensis, Lx.

These are, however, referred by Lesquereux to the Miocene, as also are the following, collected by myself: †

Laurus californica, Lx.;
" *resurgens*, Sap.;
" *furstenbergi*, Heer;
Persea pseudocarolinensis, Lx.;
" *punctulata*, Lx.;
Rhus henfleri, Heer.

It will be noted that two species of *Laurus* are common to the two localities, Corral hollow and Kirker pass.

The geological evidence that these beds (composed largely of andesitic detritus at the three localities named) are of the same age is so strong, and the evidence of the marine shells in favor of their Pliocene age is so definite, that it would seem most logical to regard them so, notwithstanding the Miocene aspect of the flora, of which one species (*Magnolia californica*, Lx.) has at another locality (Chalk Bluffs, Nevada county, California) been referred by Lesquereux himself to the Pliocene.

The four terranes just discussed, namely, the Chico, Tejon, Miocene, and

* Geology of California, vol. I, 1865, p. 38.
† Proc. U. S. Nat. Museum, vol. 11. 1889, p. 25.

Pliocene, are everywhere apparently conformable about Mount Diablo, and the series probably rests unconformably on the Knoxville shales and metamorphic rocks. Positive evidence of this non-conformity was, however, difficult to obtain, though the occurrence of metamorphic pebbles in the Chico and later terranes and the excellent evidence, both here and elsewhere, as to the highly metamorphic rocks being entirely of Neocomian (Knoxville) age makes this practically certain.

Post-Pliocene Beds.—The post-Pliocene deposits consist mostly of loose beds of sand and gravel. In the gravel are fragments and pebbles of red phthanite and other metamorphic rocks, of Pliocene shale, and of fossiliferous sandstone of probably Miocene age.

South of the mountain these beds are disturbed in one place, about a mile south of Wall point, where they dip southward at an angle of 45°. According to Professor Whitney,* the post-Pliocene beds north of the Pliocene at Kirker pass conformably overlie the Pliocene and dip toward the north.

The Epoch of Upheaval.

The main upheaval of the Coast ranges occurred in post-Miocene times. This was the result of a lateral stress that formed ranges having a northwest-and-southeast trend. The stress may have operated in the vicinity of Mount Diablo, forming, perhaps, a low ridge; but there is evidence that the main upheaval of the mountain occurred at the close of the Pliocene. From an examination of the geological map (plate 15) and the sections (figures 1, 2, and 3), it is plain that in the main the strata were thrown into their present positions by the elevation of the central metamorphic mass.

In a general way the strata north of the main peak dip northward, and those to the south of the main peak dip southward. The uplift was so vigorous that part of the strata to the south were actually reversed in position, and in places now dip northward at a high angle, the older strata overlying the younger. This reversal is greater at some points than at others. It is particularly observable west of Cave point and east of Tasajero creek. At the latter locality there is also a very evident fault, the horizontal throw of the strata being about one mile. This displacement is a conspicuous feature on the map forming plate 15.

The Pliocene rocks exposed by the Railroad ranch reservoir partake in this reversal, and it is likely that this is also the case with the Pliocene at Tasajero creek.

The strata immediately surrounding the metamorphic mass are, except for a space on the southwest, of Cretaceous age. Next to the Cretaceous, going away from the mountain in any direction, are Eocene (Tejon) strata;

* Geology of California, vol. I, 1865, p. 32.

and these are followed successively by Miocene, Pliocene, and post-Pliocene deposits.

The accompanying sections illustrate the general structure of the district.

The section figure 1, extending from Clayton to Oyster point, exhibits best the influence of the central metamorphic mass on the outlying later ter-

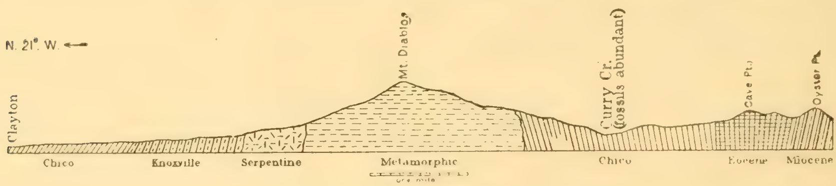

FIGURE 1.—*Section through Mount Diablo.*

ranes. The limit between the Chico and the Knoxville series is only claimed to be approximately located, and the strata to the south of the mountain between the metamorphic area and Curry creek are called Chico only because of this similarity to and conformity with the known Chico strata south of Curry creek. No fossils were obtained on the southern slope of the mountain north of Curry creek. The beds here are possibly of the Wallala epoch.

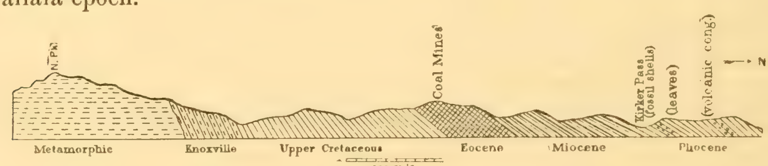

FIGURE 2.—*Section from North Peak to Kirker Pass.*

The section extending from North peak to Kirker pass shows an apparently conformable series from the Knoxville to the Pliocene; but, as before stated, there is no doubt that a considerable time elapsed between the close of the Knoxville epoch and the opening of the Chico epoch. It is also possible that some of the lower beds represented in this section as upper Cretaceous are really of the Wallala epoch. The beds represented as Miocene

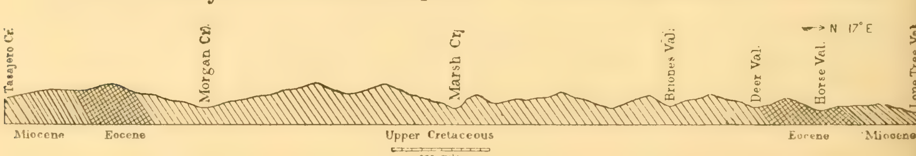

FIGURE 3.—*Section from Tasajero Creek to Lone Tree Valley.*

in the section are so considered on lithological and stratigraphical grounds, no fossils having been found in them at this particular point.

The section from Tasajero creek to Lone Tree valley shows the reversed strata east of Tasajero creek, where the Eocene and upper Cretaceous overlie the Miocene. It also shows a very great thickness of upper Cretaceous strata, all having substantially the same dip. Taking the horizontal distance of the lowermost Tejon beds east of Tasajero creek to the lowermost Tejon south of Lone Tree valley as six and a half miles and the average dip 40° from a horizontal, there must be here a thickness of four miles of beds, largely sandstones.

The upper Cretaceous strata north of the mountain (figure 2) have a horizontal thickness of about one and three-fourths miles and a thickness normal to dip of about one and one-eighth miles; and it is likely that this is not far from their maximum thickness. Consequently a single anticlinal fold will not account for the four miles of strata. It is more likely that two such folds exist here. In this case it would usually be expected to find some of the Tejon and Miocene beds infolded with the Chico, which is not the case. It is possible that these upper beds (Tejon and Miocene) were thrown into shallow folds only, over the double-folded Chico strata, and have since been entirely eroded.

The main peak of the mountain, especially its southern and southwestern slopes, is composed largely of red silicified shale. This rock occurs abundantly also at the head of Bagley cañon, and at numerous other points in the metamorphic area. It is a flinty rock, seemingly well adapted for preservation as pebbles; yet, although conglomerates exist in all the formations after the Neocomian that are to be found in the vicinity of the mountain, pebbles of this rock are very scarce till we come to the post-Pliocene, where they occur abundantly. Fragments of the red phthanite are to be found also scattered over the country, especially in creek beds for miles around; and, as it is many miles to any other metamorphic area, it is fair to assume that these post-Pliocene pebbles, as well as the angular fragments, came from the metamorphic mass of Mount Diablo.

The finding of very few pebbles of this rock in any formations preceding the post-Pliocene may be regarded as evidence that the metamorphic mass was little exposed to erosion before the close of the Pliocene.

The post-Pliocene strata north of Kirker pass, and probably everywhere in the north and northeast, appear to overlie conformably the Pliocene; but the underlying Pliocene, and the Miocene as well, dip at a comparatively small angle (40°) toward the north, and were evidently not so violently affected by the upheaval, being farther away from the center of disturbance, as were the strata south of the main peak. Sections of the strata north of the mountain apparently show continuous deposition from the Neocomian to the post-Pliocene, inclusive; but that this was not the case has been clearly shown by Mr. Becker * from geological evidence, and by Dr. White † from paleontological evidence.

* Bulletin U. S. Geol. Surv., no. 15, 1885.
† Bulletin U. S. Geol. Surv., no. 19, 1885.

The post-Pliocene beds south of the mountain are also disturbed, but to a much less extent than the Pliocene beds, dipping toward the south in some places at an angle of 45°, while farther away the dip is less; and my recollection is that the strata of sand and gravel by the road from Suñol to Livermore are nearly horizontal. When we consider that the Pliocene strata in this vicinity either dip toward the south at a very high angle (75° or more) or are actually reversed and dip toward the north, it would appear that the post-Pliocene deposits lie unconformably on the Pliocene.

It is probable that by the orographic disturbance attendant on the elevation of the central mountain mass all the strata that lie south of Suisun bay, west of the Sacramento valley, north of Livermore valley, and east of San Ramon valley were more or less affected.

In speaking of the elevation of the central mass, I do not mean to imply that it was pushed up bodily from below. The force may have been tangential.

NOTES ON

THE CHEMISTRY OF THE MOUNT DIABLO ROCKS.

BY W. H. MELVILLE.

(*Presented before the Society December* 31, 1890, *as a Supplement to the Memoir on the Geology of Mount Diablo, by H. W. Turner.*)

Introductory Note.—In the following notes, taken during the study of the altered and unaltered rocks in the Cretaceous series of Mount Diablo, the object was to ascertain the chemical changes by which certain of these rocks were brought into their present highly metamorphic condition, and to ascertain also to what chemical agencies the changes could be ascribed. To attain this end, analyses of a number of rocks, both altered and unaltered, and in some cases forming transitions, are compared.

The varieties of rocks which occur in the Mount Diablo district and of which types were analyzed are the following: Sandstones, shales, phthanite, glaucophane schists, diabase, pyroxenite, gabbro, and serpentines. The sandstones are grouped by themselves, while those specimens which illustrate transitions are arranged in series with appropriate descriptions, and with discussions of chemical composition.

Series I.—On the banks of the creek in Bagley cañon, and a few feet from the *Aucella*-bearing (calcareous) shale, a series of apparent transitions of shale into gabbro was found. Here sulphur waters ooze from the bank, and the odor of sulphuretted hydrogen is well marked. These waters have permeated the rocks, and the specimens were still wet when taken out. The sulphur was determined as sulphuric acid, the form in which it existed after exposure to the air and drying.

a. Shale, which exhibits a resinous luster, whereas in almost all shales in the metamorphic area a dull appearance is the rule; the color is brownish-black.

b. Shaly gabbro somewhat resembling serpentine; it is friable and contains carbonates and sulphates in some quantity. Apart from its being more friable than *a* as well as its light-green color, it bears considerable resemblance to that in luster and structure. It represents the exact contact between *a* and *c*, which follows.

c. Shaly gabbro, bearing carbonates and sulphates; it is friable, light green, resinous, and possesses a tendency to fibrous structure. Macroscopically, it looks like a true serpentine.

d. Crystalline gabbro, apparently eruptive, taken at the exact contact with the preceding specimen; it is hard, very compact; small pearly cleavage planes, with striations, are well marked; the color is dark green.

These specimens were taken within the space of a foot, and in the order tabulated.

Series I—Analyses of Shales and Gabbros from Bagley Cañon.

	*(9)	(173)	(174)	(175)
	a	*b*	*c*	*d*
H_2O at 105° C.	3.01	2.41	2.29	1.20
H_2O above 105°	5.92	2.74	2.47	1.83
CO_2	----	2.35	1.89	----
SO_3	0.93	0.24	0.43	----
SiO_2	56.66	45.43	45.69	47.49
P_2O_5	0.15	0.04	0.06	trace
Al_2O_3	17.64	12.55	13.30	15.81
Fe_2O_3	0.49	----	1.85	1.07
FeO	5.22	6.50	4.72	4.50
NiO	----	----	----	0.06
MnO	0.19	0.21	0.24	0.41
CaO	1.67	12.39	13.50	15.53
MgO	3.50	13.41	13.06	10.39
Na_2O	2.17	1.71	1.36	1.16
K_2O	2.27	0.11	trace	trace
Organic matter	little	little	---	----
	99.82	100.09	100.86	99.45

If these examples are to be regarded as illustrating the passage of one extreme of the series into the other, as there is some evidence, then the cause of this metamorphosis is to be found in the action of solfataric waters. The presence of sulphates and carbonates in specimens *a*, *b* and *c* becomes an important point, as tending to the confirmation of this assumption. The waters at present contain sulphates, carbonates and chlorides of the alkalies and of calcium and magnesium, together with a little silica, iron, carbonic acid and sulphuretted hydrogen. A less hydrated substance, the gabbro, is formed, and by the action of the heated waters calcium and magnesium oxides are added at the same time that a quantity of silica, alumina and alkalies are leached out. The sudden jump between specimens *a* and *b* in the contents of lime and magnesia must be explained on the supposition of a very rapid and

*Numbers in parentheses indicate the office labels of the working collection.

complete metathesis between the chemical substances in the mineral water and the constituents of the shale. Such a result might be expected under high pressure and at an elevated temperature. Mr. G. F. Becker has spoken* of metamorphic gabbro from this district in his study of the Coast ranges of California.

If, however, the gabbro is a crystalline igneous rock and forms an eruptive dike, it is equally possible to explain the intermediate specimens *b* and *c*. On this supposition *b* and *c* are merely shaly gabbros, whose composition has been slightly changed by the mineral water which has leached out a little silica, alumina and lime, while an increased percentage has been effected in the quantity of water, magnesia and alkalies. Furthermore, a small amount of phosphate, sulphate and carbonate has been added, the iron being wholly reduced in *b*.

The gap which exists between this shale and the three remaining rocks of the series is too great, it would seem, to admit other than the latter view of the case. For example, the sudden great decrease in silica and the increase in lime and magnesia in the passage from the shale to the shaly gabbro next in the series is scarcely admissible in a true transition. Field observations also are adverse to the view that the second and third specimens, *b* and *c*, possess any qualities of shale other than friability.

Series II.—The specimens (except 242 and 176) embraced in this series were taken from a ridge east of and above Bagley creek, at the northern edge of the serpentine dike described by Mr. Turner, and were selected so that each specimen would represent the composition of a vertical section a few inches from its neighbor.

a. Shale, friable, but not much altered and free from carbonates; slate-color; soft.

b. Shale, not so friable as *a*, but considerably altered and containing carbonates in seams; color more variegated.

c. Dark-colored serpentine, almost black, containing seams of secondary substance free from carbonate but ferruginous.

d. Serpentine, almost black, with greenish tinge; compact, with a somewhat bladed structure, breaking in irregular fractures; no carbonates nor chrysotile.

Specimen *c* occurs at the contact between *b* and *d*, and is, according to its external characters, an apparent transition between those specimens. The substance used for analysis in each case was freed from the seams of carbonates.

e. This analysis gives the composition of a bastite (number 176) which properly belongs to this series. It occurs in the same dike of serpentine

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*Geology of the Quicksilver Deposits: Monograph XIII, U. S. Geol. Surv., 1888, p. 101

from which the previous specimens came, and of which *d* is a typical specimen. It is a dark-green rock, with well developed cleavage surfaces, and contains fine seams of chrysotile. The cleavage planes are striated, and possess the very characteristic luster of bastite. In a strip of weathered material on the hand specimen pyroxenes are noticeable.

f. This specimen (number 242) is an example of fresh pyroxenite which occurs in the serpentine dike, and some distance west of the locality of the previous specimens of this series. It apparently contains a little olivine, while the principal constituents are bronzite and diallage. There is no trace of any variety of serpentine to be discovered in the sample.

The rock specimens from *a* to *d* inclusive contained some accidental organic matter. This was deducted from the analyses, which were then calculated on the basis of 100 per cent. for better comparison with *e* and *f*.

Series II—Analyses of Specimens from near Bagley Creek.

	(177) *a*	(178) *b*	(179) *c*	(181) *d*	(176) *e*	(242) *f*
H_2O at 105° C.	3.95	3.39	4.51	2.81	0.94	0.05
H_2O above 105° C.	4.57	6.97	9.56	10.94	12.43	0.24
SiO_2	53.65	49.14	38.53	40.50	36.57	53.25
P_2O_5	0.23	0.24	trace	trace	----	----
Cr_2O_3	----	----	trace	0.41	0.33	0.54
Al_2O_3	17.64	16.91	14.55	0.78	0.95	2.80
Fe_2O_3	4.06	4.39	2.65	4.01	7.29	0.69
FeO	3.72	3.82	4.01	2.04	0.37	5.93
NiO	trace	trace	trace	0.11	0.31	0.07
MnO	0.01	0.22	0.32	0.13	0.10	0.09
CaO	2.27	3.28	3.13	0.39	0.14	16.22
MgO	5.15	5.43	21.79	37.43	40.27	19.91
Na_2O	2.53	4.67	0.07	0.28	0.31	0.19
K_2O	2.22	1.53	0.88	0.16	trace	trace
	100.00	99.99	100.00	99.99	100.01	99.98

The best transition by far, from shale into serpentine, is shown in this table of percentage composition. Specimen marked *c* occupies an interesting position in the series, and although there exists between certain constituents great deviations on either hand, yet the tendency of the shale *b* and serpentine *d* to approach this mean is very striking. The most important constituent is magnesia, and it increases regularly by about 15 per cent., as it should, from *b* to *d*. Specimen *c* then partakes of the composition both of shale and serpentine.

There are two cases to consider in explanation of the product of change intermediate between the shale and serpentine: First, what would be the effect of those agents upon the shale which produced the conversion of the original rock of the dike into serpentine? The original rock may have been a pyroxenite, of which there are examples in the dike at some distance from the locality of the specimens under discussion, and an analysis of which is given under *f*. The large amount of iron in serpentines in general confirms the supposition of derivation of this class of rocks from ferro-magnesian silicates. The ferro-magnesian silicates are provided for in the bronzite and dillage of the pyroxenite, the latter constituent carrying considerable calcium oxide. The leaching out of considerable silica and almost all of the alumina and lime from the pyroxenite *f* by hot waters, which at the same time hydrate the residue, yields the serpentine *d*. Now all mineral waters contain a quantity of magnesia in solution, so that it might be assumed that some of the magnesia of the pyroxenite goes into solution. In this way, then, a transfer of magnesia to a portion of the shale *b* adjacent to *d* may be effected, while about 10 per cent. of silica is removed, as in the case of pyroxenite. The hydration goes on at this point also, by which about 4 per cent. water is added. The shale along the contact is thus converted into a more highly magnesian rock. The explanation of the loss of alkalies in *c* is found in the easy kaolinization of the feldspathic constituents of the shale under the assumed conditions. The high percentage of alumina shows without question that specimen *c* was originally shale. Hence it would seem that the process of metamorphism penetrated some distance into the shale before being arrested.

The second supposition, namely, that surface waters brought about the change in chemical composition along the contact of shale with the already-formed serpentine, seems to me not to carry with it that conviction which the first supposition does. For instance, the leaching out of about 10 per cent. of silica from *b* to yield that per centage in *c* would hardly take place undert he ordinary conditions which we witness to-day.

In precisely the same way as the serpentine (number 181), the bastite *e* (number 176), which possesses very nearly the same composition as the serpentine, can be regarded as produced from pyroxenite.

Series III.—The specimens of this series were found on the western slope of the mountain in a branch of the Arroyo del Cerro. The serpentines are from the dike described in Mr. Turner's notes, and the shales occur at the exact contact with this dike.

a. Slate-colored shale (1) in large lumps, friable, with a few very narrow and loose seams of a white substance marked *a* (2), which were all but removed from the shale before analysis. The composition both of the shale and of the material of the seams was determined by separate analyses. The white substance proved to be a carbonate and silicate of lime and alumina, probably clay and calcite.

b. Shale, very friable, occurring in small lumps about the size of a pea; the lumps were separated by calcite seams more abundant than in *a*, which were removed in great measure before the analysis was made.

c. Friable serpentine, apparently differing greatly from true serpentine.

d. A fair specimen of serpentine.

Series III—Analyses of Specimens from Arroyo del Cerro.

	(220)		(221)	(222)	(223)
	a (2)	*a* (1)	*b*	*c*	*d*
H_2O at 100° C.	1.44	3.41	9.19	2.16	1.67
H_2O above 100° C.	2.86	5.84	6.73	14.02	15.72
SiO_2	25.05	56.52	40.17	36.96	34.84
P_2O_5	0.08	0.11	0.08	0.02	0.04
CO_2	24.20	little	3.48	----	----
Cr_2O_3	----	----	----	0.78	0.68
Al_2O_3	8.28	17.65	12.76	0.39	0.42
Fe_2O_3	0.27	1.58	2.10	5.00	6.08
FeO	2.41	5.25	3.56	2.34	1.85
NiO	trace	trace	trace	trace	trace
MnO	4.11	0.32	0.16	0.09	0.01
CaO	27.87	1.09	4.24	3.81	7.02
MgO	2.61	3.97	15.42	33.84	30.74
Na_2O	undet.	2.14	0.57	0.34	0.42
K_2O	undet.	2.36	1.36	0.14	0.07
	99.18	100.24	99.82	99.89	99.56

The same processes of leaching and substitution which are discussed in series II appear to have acted at the contact *b*. The shale *b* still possesses all the characters of a true shale. Its composition shows a great increase of water and magnesia, the latter by no means to be accounted for as carbonate, while there is a large decrease in silica and a small loss in alumina. There has also been a later secondary action of surface waters or mineral springs by which calcite and clay have resulted. Mineral springs similar to those in Bagley cañon might have existed formerly, but there is no indication of their existence at present.

Series IV.—To the east of the Arroyo del Cerro are found the fossils *Belemnites* and *Aucella*. This region comprises a portion of the metamorphic area, and in it there is a good exposure of strata of shale and serpentine which extends for about a hundred feet. A series of typical specimens were collected from points in this exposure a few feet apart, of which the analyses are given below.

a. Shale, altered considerably, light-brown and friable. Carbonates in small quantity form a part of the mass of the rock. This shale is Neocomian.

b. Serpentine, very much weathered, interwoven with seams of quartz and calcite; darker colored than *a*; fibrous tendency slight.

c. Limestone, weathered, very friable, light slate-colored.

d. Calcareous shale, next to the same serpentine dike mentioned in connection with series III. It is hard, compact, dark-colored; it contains seams of calcite, but the analysis was made on material from which this secondary carbonate had been almost completely removed. In the quartz seams a zeolite (natrolite) occurs, and sparingly distributed small particles of pyrite are to be found. The shale is very much altered, particularly at the contact.

e. A yellowish-green talc-like rock, forming a part of the serpentine dike at this point and containing considerable chromite. It has a resinous luster, and a tendency to fibrous structure. Limestone intervenes between this rock and the calcareous shale *d*.

Specimens *c*, *d*, and *e* properly belong to a separate series, of which *c* and *e* are extremes. They are grouped here for convenience.

Series IV—Analyses of Specimens from near Arroyo del Cerro.

	(233)	(235)	(236)	(238)	(239)
	a	*b*	*c*	*d*	*e*
H_2O at 100° C.	8.74	3.32	0.76	1.41	0.44
H_2O above 100° C.		12.51	2.33	6.24	12.40
SiO_2	45.64	41.52	21.19	44.56	32.27
CO_2	4.59	----	26.84	17.62	----
P_2O_5	0.27	----	2.55	0.16	trace
Cr_2O_3	0.12	----	----	----	5.19
Al_2O_3	15.42	1.57	0.39	3.12	11.45
Fe_2O_3	3.40	3.50	1.52	1.27	trace
FeO	3.73	1.07	undet.	5.21	5.05
NiO	----	----	----	----	0.19
MnO	0.33	0.29	3.61	trace	trace
MgO	4.62	36.84	1.39	3.39	33.30
CaO	8.11	0.44	35.61	12.70	0.41
Na_2O	3.13	----	undet.	3.09	trace
K_2O	1.86	----	undet.	0.88	trace
	99.96	101.06	96.19	99.65	100.70

Series IV shows a contact of shale *a* with serpentine *b*, the analyses of which are given in the above table. A transition is also given of limestone *c*, calcareous shale *d*, and a peculiar rock *e*, which may be considered an unusual form of serpentine. The high percentage of alumina, however, gives a ratio of basis to silica very different from that of serpentine. These analyses are interesting in that they show the composition of the same species of rocks, which have been previously discussed, in the extreme northwestern part of the serpentine dike.

The following analyses of shale *a* was made with a view of ascertaining its mineral composition. Shale *a* will be found to contain albite, for the final residue in the scheme below is almost identical with the composition of this feldspar. The shale fuses to a brown-black glass, so also after the removal of the carbonates, and the final residue fuses to a light-colored glass at about the same number on the scale of fusibility. A slide of this rock showed the presence of albite. Information as to the other constituents is wanting.

Analysis of Neocomian Shale.

			Per cent.
Removed by dilute hydrochloric acid (ascertained by difference)			24.53
Removed by strong hydrochloric acid:	SiO_2	0.03	
	Al_2O_3	6.02	
	Fe_2O_3	6.00	
	FeO	0.40	
	MnO	trace	16.88
	CaO	0.58	
	MgO	3.17	
	Na_2O	0.36	
	K_2O	0.32	
Removed by sodium carbonate solution:	SiO_2	18.26	18.26
Final residue:	SiO_2	27.77	
	Al_2O_3	8.00	
	Fe_2O_3	0.41	
	MnO	0.05	
	CaO	trace	40.33
	MgO	0.25	
	Na_2O	2.75	
	K_2O	1.10	
			100.00

Series V.—This series consists of two specimens from a locality at the head of Bagley creek in the metamorphic area, and represents the passage of the common red shale into silicified shale or phthanite. The great mass of these deposits in Mount Diablo is exceedingly folded and distorted, yet shows the alternating layers of the two components, a phenomenon quite usual in this class of rocks in the Coast ranges. This rock is very friable, and the phthanite can be readily separated from the shale. In most cases the color is brownish red, as in the samples analyzed; but often greens and grays are represented, the latter especially when white granular quartz intermingles with these. Throughout this phthanite, quartz seams a few millimeters wide intersect each other in a kind of network, and sometimes crystals of quartz are noticed. Likewise the red shale exhibits the same amount of quartz. In the analyses the shale was freed from quartz, an easy matter, and also the purest fragments of phthanite were selected for analysis.

Series V—Analyses of Shales from the Head of Bagley Creek.

	(186) *a*	(185) *b*
Loss at 100° C.	1.03	0.21
Loss above 100° C.	2.92	0.72
SiO_2	69.98	93.54
P_2O_5	0.05	----
Al_2O_3	11.69	2.26
Fe_2O_3	6.23	0.48
FeO	1.08	0.79
MnO	0.49	0.23
CaO	0.38	0.09
MgO	1.29	0.66
K_2O	3.72	0.51
Na_2O	0.73	0.37
	99.59	99.86

Series VI.—This series consists of four sandstones, two of which are from the metamorphic area.

a. Upper Cretaceous, Chico sandstone; light brown, fine granular, rather soft; clastic grains of mica and feldspar observed.

b. Lower Cretaceous, Neocomian sandstone; from the head-waters of Bagley creek; hard, granular, greenish.

c. Miocene sandstone from near Wall point; granular, small light-brown and black particles evenly distributed; very friable.

d. Chico sandstone with fossil, *Trigonia evansana;* compact crystalline; color greenish-gray.

Analyses of these sandstones were made in order to give an account complete as possible of the varieties of rocks in the region which was studied, quite as well as for the sake of comparing their composition. They have no bearing upon the points which are discussed in the previous pages.

Series VI—Analyses of Tertiary and Cretaceous Sandstones.

	(11) *a*	(187) *b*	(59) *c*	(33) *d*
H_2O at 100° C.	1.06	1.45	1.43	0.57
H_2O above 100° C.	2.60	3.34	2.25	3.45
CO_2	none	5.10	7.76	*11.30
SiO_2	73.71	56.84	44.54	36.93
P_2O_5	none	0.10	0.29	0.16
Al_2O_3	10.40	11.37	12.63	7.22
Fe_2O_3	3.89	1.46	2.50	1.59
FeO	1.88	4.95	3.08	2.95
MnO	0.17	0.22	0.44	0.57
CaO	0.96	7.62	14.65	29.34
MgO	1.62	3.10	5.55	2.34
Na_2O	3.48	3.26	3.35	2.94
K_2O	0.99	0.86	1.37	0.64
	100.77	99.67	99.84	100.00

Series VII.—From the diabase area in Mitchell cañon, north of the serpentine dike, two specimens were selected. Specimen *a* was fresh, but specimen *b* was somewhat altered and partly uralitic. The analyses show but slight differences in composition. In this diabase serpentine is absent, and it is not found to yield this hydrous magnesian silicate. It would be necessary to substitute a magnesian silicate for the plagioclase, which has been shown before in the case of shales a difficult and an imperfect operation. Field observations show no relations between the diabase and the serpentine of Mount Diablo as they have shown between the pyroxenite and serpentine.

Series VII—Analyses of Diabase from Mitchell Cañon.

	(43) *a*	(44) *b*
Loss at 105° C.	0.59	0.34
Loss above 105° C.	2.90	2.67
SiO_2	52.06	51.58
P_2O_5	0.13	0.24
TiO_2	0.47	1.05
Al_2O_3	14.34	14.99
Fe_2O_3	2.11	2.04
FeO	7.74	8.36
MnO	trace	trace
CaO	8.05	8.59
MgO	9.26	6.51
Na_2O	1.74	3.08
K_2O	0.73	0.31
	100.12	99.76

* CO_2 by difference. Organic matter in very small quantity exists in all four sandstones, but it was not determined.

Glaucophane Schist.—Glaucophane schist is found in Pine cañon on the road to the summit of the mountain. A fragment from a bowlder out of place in the bed of the creek was analyzed. Its color is that of the well-known species, bluish with streaks of green. Its schistose structure was well marked, while innumerable cinnamon-colored garnets were distributed throughout the mass. Often garnets are wanting in glaucophane schist. So also calcite may or may not be found in these schists.

Analysis of Glaucophane Schist from Pine Cañon.

	(272)
H_2O at 100° C.	0.17
H_2O above 100° C.	1.81
SiO_2	47.84
P_2O_5	0.14
Al_2O_3	16.88
Fe_2O_3	4.99
FeO	5.56
MnO	0.56
CaO	11.15
MgO	7.89
K_2O	0.46
Na_2O	3.20
	100.65

Peculiar Serpentine.—A serpentine or talc of peculiar character was found in a bowlder out of place in the bed of the creek in Ferguson ravine. It appeared peculiar because it possessed the characters both of serpentine and talc. Its olive color, waxy luster, crystalline structure, and absence of fibers, apart from the well-developed cleavage planes which were apparent, led me to believe it a talc.

White seams traverse the specimen in all directions, and carry chromite. This white mineral appeared in part much like chrysotile, from its hardness and fibrous character. Some sulphuric acid was found in it; hence it is probable that sulphate of lime forms a small portion of the white material.

It appears to me that this rock is a serpentine. The analysis shows it to contain an extraordinary amount of water. Its composition is as follows:

Analysis of a Peculiar Serpentine.

	(164)
Loss at 100° C.	0.39
Loss above 100° C.	20.43
SiO_2	30.98
Cr_2O_3	0.34
Al_2O_3	1.04
Fe_2O_3	4.88
FeO	2,01
MnO	0.42
CaO	0.22
MgO	38.44
Na_2O	0.40
K_2O	0.16
SO_3	0.44
P_2O_5	trace
	100.15

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TWO BELTS OF FOSSILIFEROUS BLACK SHALE IN THE TRIASSIC FORMATION OF CONNECTICUT.*

BY W. M. DAVIS AND S. WARD LOPER.

(*Read before the Society December* 31, 1890.)

CONTENTS.

I. INTRODUCTORY STATEMENT: BY W. M. DAVIS.

PREVIOUS STUDIES.

For a number of years past I have given some of my spare time in the summer, generally with the assistance of Mr. C. L. Whittle, of the United States Geological Survey, to the study of the Triassic formation of Connecticut, especially in the neighborhood of Meriden. The peculiar structure of the formation is well shown there, and it makes an excellent problem for field teaching; for that reason Meriden has been chosen for several seasons

* Communicated by permission of the Director of the U. S. Geological Survey.

as one of the districts to be visited by the Harvard Summer School of Geology. The following papers have been published during the progress of my study:

"Brief Notice of Observations on the Triassic Trap Rocks of Massachusetts, Connecticut and New Jersey:" Amer. Journ. Sci., 3d ser., vol. XXIV, 1882, pp. 345–349.

"The Structural Value of the Trap Ridges of the Connecticut Valley:" Proc. Bost. Soc. Nat. Hist., vol. XXII, 1882, pp. 116–124.

"The Relations of the Triassic Traps and Sandstones of the Eastern United States:" Bull. Mus. Comp. Zoöl. at Harv. Coll., geol. series i, 1883, pp. 249–309, with three folded plates.

"Mechanical Origin of the Triassic Monoclinal in the Connecticut Valley:" Proc. Amer. Assoc., vol. XXXV, 1886, pp. 224–227.

"The Structure of the Triassic Formation of the Connecticut Valley:" Amer. Journ. Sci., 3d ser., vol. XXII, 1886, pp. 342–352.

"The Structure of the Triassic Formation of the Connecticut Valley:" 7th Annual Rep. U. S. Geol. Surv., 1888, pp. 461–490, with one plate.

"The Ash Bed at Meriden and its Structural Relations:" Proc. Meriden Scient. Assoc., III, 1889, pp. 23–30.

"Topographic Development of the Triassic Formation of the Connecticut Valley:" Amer. Journ. Sci., 3d ser., vol. XXXVII, 1889, pp. 423–434.

"The Faults in the Triassic Formation near Meriden, Connecticut; a week's work in the Harvard Summer School of Geology:" Bull. Mus. Comp. Zoöl., geol. series ii, 1889, pp. 61–87, with five plates.

"The Intrusive and Extrusive Triassic Trap Sheets of the Connecticut Valley;" By W. M. Davis and C. L. Whittle: *Ibid.*, pp. 99–138, with five plates.

Structure of the Triassic Formation about Meriden.

Origin of the Deposits.—As at present understood, the structure of the formation may be described as follows: The Triassic strata were deposited in a body of water formed by the submergence of a peneplain of crystalline schists and gneisses; detritus was washed down from the unsubmerged portions of the region on either side, east and west. The pre-Triassic surface is spoken of as a peneplain because it is, in the first place, manifestly a surface of deep erosion on strongly deformed schists; and second, because the line of contact of this deeply eroded surface with the Triassic beds along the under or western margin of the formation is at present so nearly straight. If the pre-Triassic surface had been very uneven, as it must have been for much of the time during its deep erosion, the unevenness should now make itself manifest in a very irregular boundary along the base of the formation; but, as stated above, this is not the case: the base of the formation appears to rest on a relatively even foundation, an ancient peneplain. In a small way, this is best shown in a ravine west of Southington, where a sandy basal conglomerate is seen lying directly on the evenly eroded surface of the tilted crystallines.

The original extent of the complete formation beyond its present boundaries is not known. It may have been many miles broader than it now is, but there is no good evidence now in hand on this question.

Formation of the Trap Sheets.—During the period of deposition there were outflows of lava at several dates. The sheets formed by outbursts at three of these dates are now well correlated; the first of them is relatively thin and vesicular or amygdaloidal; the second is much thicker and more massive, and at some places it appears as a double flow, one sheet of lava lying on another without a noticeable accumulation of sediments between them; the third is again thin like the first. The outcropping edge of the massive middle sheet now forms a series of strong ridges; hence it was called the "main" trap sheet by Percival, while the lower and upper were called the

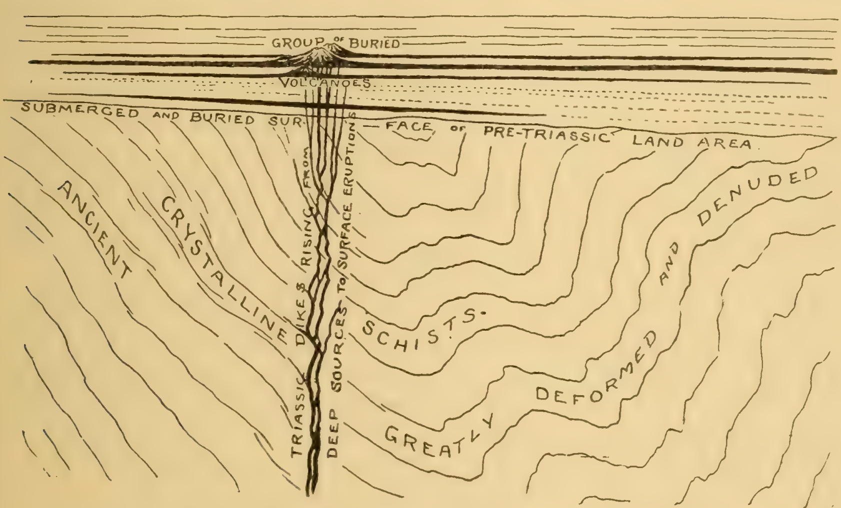

FIGURE 1—*A Portion of the completed Triassic Formation lying on the denuded Crystallines.*

The lower lava bed, spreading out from the dikes near the bottom of the Triassic strata, is the intrusive sheet. The three upper sheets, spreading out from the volcanic cones, are the overflows, called respectively the anterior, main and posterior.

"anterior" and "posterior" sheets respectively, although he did not recognize that these names, which he used to indicate relative topographic positions, would indicate relative time of outflow as well.

In addition to these great overflows, there is at least one great intrusive sheet* and, apparently, several smaller ones. The large one occurs close to the base of the formation, and hence is now seen near its western margin, because the present structure is, as a whole, an eastward-dipping monocline. The date of this intrusion is not definitely fixed, although it appears that

* Professor Newberry has misquoted me (Monograph XIV, U. S. Geol. Survey, 1888, p. 7) as saying that all the trap sheets were overflows. The intrusive nature of the West rock and palisade sheets was recognized in my first essay, and I have never found reason to regard it as of other origin.

good reasons can be shown for provisionally regarding it as of earlier date than the tilting and faulting of the formation, and hence of roughly synchronous date with the overflows. Besides various minor sheets and dikes of undetermined relations, there is a great mass of dikes in Mount Carmel which may be plausibly regarded as marking the vent through which the lava of the sheets rose to the surface. All of this inferred original structure is illustrated in figure 1.

Deformation.—The time of deposition appears to have been terminated by an upheaval, accompanied by tilting and faulting. The tilting is generally to the eastward, or somewhat south of eastward. The faulting has not been well made out except in the neighborhood of Meriden, where the lines of fracture run northeastward or east-northeastward with much regularity. As this direction corresponds with the strike of the underlying schists, where they are seen beyond the limits of the Triassic beds toward the southwest and toward the northeast, it may be supposed that the trend of the faults was determined by the strike of the schists; *i. e.*, that the forces by which the formation was disturbed reached deep below the foundation of the Triassic beds and moved the schists as well, and the latter slipping and faulting along or nearly along their planes of foliation, the overlying Triassic beds broke in the same direction, the dislocations of the smaller superficial mass being guided by those of the greater underlying mass, as has been suggested for the origin of the Great Basin ranges by Gilbert.*

Be this as it may, it is clearly determined that the whole sequence of aqueous and igneous beds has been tilted and strongly faulted, the entire mass being thus divided into a number of long narrow blocks from an eighth of a mile to a mile or more in width, and separated from one another by dislocations, varying from a few tens of feet up well toward two thousand feet. In nearly all cases the heave or upthrow is on the southeastern side of the fracture, and the amount of heave is in a rough way proportionate to the width of the next block toward the southeast; and this seems to be strongly confirmatory of the theory above stated concerning the cause of the faulting.

In the southeastern corner of the present Triassic area the strata were gently folded, or dished, as well as faulted; and here the ridges formed on the harder trap sheets are consequently curved.

If the deformation thus described went on with ordinary geological rapidity, the constructional form of the country produced by it must have been peculiar, to say the least. The nearest existing likeness to it that I have found is in southern Oregon, in the region of the tilted and faulted blocks of lava so well described by Russell; † but there the breaking of the originally even mass into blocks is not so orderly as it was in Connecticut, or at least about Meriden.

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* Wheeler's Surveys West of the 100th Meridian, vol. III, 1875, p. 62.
† Fourth Annual Report, U. S. Geol. Survey, 1884, p. 443 *et seq.*

Subsequent Degradation.—At present, the Triassic formation presents no trace of its ancient constructional topography; that was completely obliterated in the long period of erosion that followed the post-Triassic tilting. From evidence found in New Jersey,* it may be said with a good degree of probability that the period of erosion ran through Jurassic and into Cretaceous time, and that it endured long enough to reduce the broken constructional surface of the Triassic area and of the adjacent crystallines, which shared in the post-Triassic disturbance to a greater or less degree, to a surface of moderate relief and low altitude; that is, to a peneplain: a peneplain of much later date than that on which the Triassic beds lie. The same peneplain may be traced far and wide along our Atlantic border, and for an unknown distance inland.† In New Jersey and further south, the denudation of the peneplain was succeeded by a time of moderate depression, when the ocean advanced over the lowland; the waste then received from the interior, not at that time submerged, constitutes the Cretaceous strata of the Atlantic slope. Whether these strata ever reached over southern New England has not been determined, but their appearance in Long island makes such an extension eminently possible; and when the map of Connecticut is completed and the relation of topography to structure is well studied, it may be possible to say something more on this point by means of the location of the rivers, inferring an inland extension of the Cretaceous if the preglacial valleys are generally discordant with the structure.

The Cretaceous peneplain or lowland of denudation is no longer a lowland; it was elevated about the beginning of Tertiary time to a greater altitude inland than near the coast, thus forming a gently sloping plateau; and since then the streams and the processes of subaërial decay have been at work dissecting it. On the crystalline areas they have made but little advance, and here the valleys are still narrow; but on the softer Triassic rocks a broad lowland has again been opened out at a lower level. The preservation of distinct traces of the old Cretaceous lowland, now a highland, on the hard crystalline rocks, while the weaker Triassic beds have already been reduced to a second peneplain close to the newer and lower base-level, is an interesting example of the strong difference in the rates of topographic development of masses of different resistance.

Topographic Expression of Structure.—The trap sheets of the Triassic formation, being much harder than the adjacent sandstones and shales, have resisted erosion more successfully; and the main trap sheet still retains a good measure of the height to which the old Cretaceous peneplain was lifted.

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*The Geographic Development of Northern New Jersey; by W. M. Davis and J. W. Wood, Jr.: Proc. Bost. Soc. Nat. Hist., vol. XXIV, 1889, p. 385.

† W J McGee. Three Formations of the Middle Atlantic Slope: Amer. Journ. Sci., 3d series, vol. XXXV, 1889, p. 35.
B. Willis. Round about Asheville: Nat. Geogr. Mag., vol. I, 1889, pp. 299-300.
W. M. Davis. Rivers and Valleys of Pennsylvania. Ibid., p. 15.

Standing on one of its summits, such as Chauncey peak or Higby mountain, three miles northeast of Meriden, one may see the crest-lines of the main ridge in the various blocks toward the northwest and southeast, all reaching about the same height, and this common height closely like that of the remarkably even sky-line of the crystalline plateau by which the Triassic lowland valley is enclosed on the east and west. The gradual descent of the highland to the south is also apparent from this point of view. Another notable feature seen at the same time is Mount Carmel, apparently in the same block with Higby, but some ten miles toward the southwest, rising somewhat above the sky-line of the crystalline highland, and, therefore, to be regarded as having been a low hill on the old peneplain in Cretaceous time.

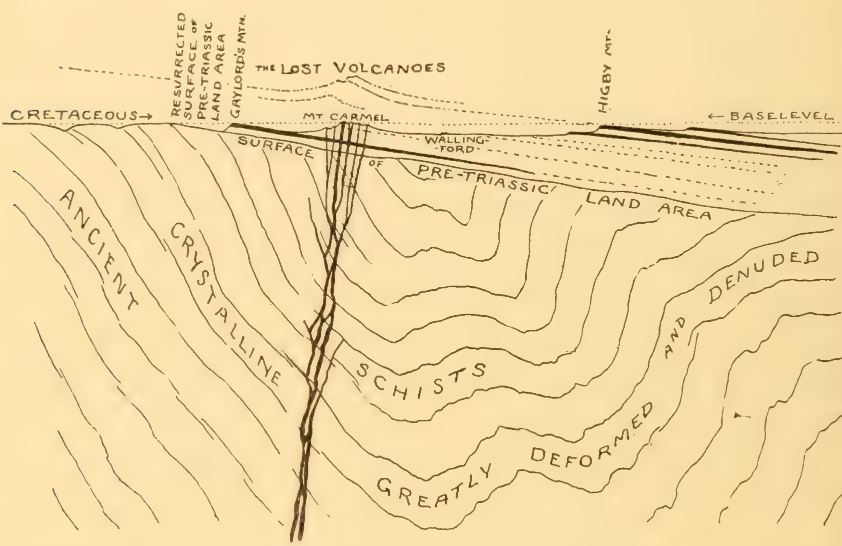


FIGURE 2—*A Portion of the Triassic Formation, after tilting into the monoclinal Attitude and deep Erosion.*

The volcanic cones inferred to have been formed where the lavas rose to the surface and supplied the overflows are now all destroyed, and Mount Carmel is supposed stand beneath their ancient site, where the feeding dikes now outcrop. No faults are shown in this figure, because the section line is supposed to run between the enclosing faults of a single block; and no cross-faults are yet known.

It has been stated above that as Mount Carmel is composed of numerous dikes, many of large size, it may be regarded as the locus of the volcanic pipes up through which rose the lavas now seen in the extrusive and intrusive sheets. No direct evidence of this correlation can be obtained at present; for the intrusive sheet near the base of the formation would intersect the Mount Carmel dikes below the actual surface of the country, and the extrusive sheets would rise far above Mount Carmel, if prolonged in its direction towards their hypothetical volcanic centers of eruption; but the interpretation here suggested is very satisfying when on the ground with the whole district spread out before the observer, as is illustrated in figure 2.

Let the observer climb to the crest of Higby mountain or to any of the other summits near Meriden. It is manifest from these fine points of observation that the lava sheet of which the ridge is formed once continued upward on the plane of its dip into the air, as it still continues downward under ground. The main sheet may be traced forty or fifty miles along its outcrop; it may reasonably be supposed to have had a breadth of a quarter or half of this measure. Its great volume suggests a vent of good size from which the lavas were poured out. The association of ashes and lava blocks with the anterior sheet indicates violent explosive action and the building of volcanic cones at the center of eruption. Not a trace of these cones can now be found. They may still be buried in the lower part of the eastern half of the monocline; but we have no means of testing this supposition. They may have been eroded from the uplifted part of the western half of the monocline; and this supposition is strongly supported by the occurrence of the great irregular "neck" or network of dikes in Mount Carmel. There is no demonstration of connection between these volcanic roots and the outflowering surface sheets; but the two parts correspond so well that the supposition of their genetic connection is eminently satisfactory, even though it involves the wholesale destruction of the uplifted volcanoes in Jurassic time.

Objection may of course be made on the ground of the great erosion that this supposition involves. Certainly a great amount of material has been denuded if the section is here drawn correctly; but, in spite of that, this is still the best interpretation that I can offer.

Verification of Inferences as to Structure.

It is manifest that the correctness of the interpretation here briefly sketched depends in large measure on the certainty with which the faults in the formation are demonstrated. I have therefore given particular attention to the evidence on which their recognition depends, and have made it the main theme of the exercises in the seven-day halt of the Harvard summer school in the Meriden district, as mentioned above. It seems to me to reach an absolute demonstration.

The character of the evidence is as follows: In the first place, an examination of the lava sheets of the district shows them to be extrusive, because they are vesicular and slaggy at the upper surfaces; because they are associated with beds of ashes; because their fragments, large and small and more or less water-worn, occur in the overlying sandstone; and because the bedding of the overlying sandstones conforms to the inequalities of the lava sheet, even filling the small crevices and open vesicles at the surface. Under the microscope, minute fragments of trap are seen to be mixed with the sand grains in the filling of the vesicles. Being extrusive, the lava sheets may be regarded as conformable members of the bedded series; being resistant, they form ridges and are easily traced; hence much of the stratigraphic study of the region is based upon them. In the second place, when the region is examined on several northeasterly lines parallel to one another, the sequence of beds on each line is found to be essentially constant, namely, lower sandstones and conglomerates, a vesicular lava sheet (the anterior), shales, a heavy lava sheet (the main), shales, a thin lava sheet (the posterior), and finally an upper series of shales and sandstones. This repetition of so complicated a sequence of beds is not thought to be possible as an accidental occurrence; hence the hypothesis of faulting is introduced, and the fault lines are searched out. These, in the third place, are found by tracing the ridge-making members of the series until they end, and drawing lines to connect their terminations. The lines thus drawn are found to run systematically northeast-and-southwest; bands of breccia are found at several points along them; local disturbances of the generally uniform dip of the beds occur along the lines, and always acoordant with the drag of the supposed faults; the heave of the faults is, with one exception, systematically on the eastern slide of the line of fracture. In the fourth place, the peculiarly intricate relations of the ridges, by which they are offset from one another and their ends overlapped—the "advancing" and "receding order" of Percival,—find a simple geometrical explanation, susceptible of trigonometrical formulation, by means of the theory of faulting; and the prevalence of abrupt bluffs at the southern ends of the ridges, while the northern ends fall away gradually (a very marked feature of the Meriden district) follows necessarily from the degradation of monoclinal lava sheets cut by oblique faults, the bluffs being formed where the strike of the sheets and the trend of the faults make an acute angle.

When evidence so varied and so complete is repeated over and over again in the most systematic order, the conclusion to which it leads cannot be gainsaid.

But even though the faults are seemingly demonstrated fully by general structural evidence, additional evidence is always in order; and for that reason I have endeavored during the past summer to discover whether the fossils of the formation would bear on the question.

If a fossil-bearing horizon is found in one of the blocks into which the formation is divided, it evidently might be expected to occur in the same position relative to the trap sheets in the adjoining blocks, and so on for a considerable distance from the place of its original discovery, as indicated in figure 3. A correct knowledge of the location and throw of the various faults should thus enable one to define with considerable accuracy the localities where outcrops of any fossiliferous bed might be looked for in the several blocks.

With this thesis in mind, I secured the assistance of Mr. S. Ward Loper, of Middletown, formerly of Durham, Connecticut, where he had made explorations of certain fossil-bearing beds of black shale, and from which he had obtained a large collection of Triassic fishes and plants. Many of the fishes described in Professor Newberry's monograph were of his collecting. It was clear that two of his localities were simply different outcrops of a single bed of black shale in the Totoket block, about a quarter way from the anterior trap sheet up through the anterior shales to the main trap sheet. This will be called the anterior black shale. Search for the same shale bed was then

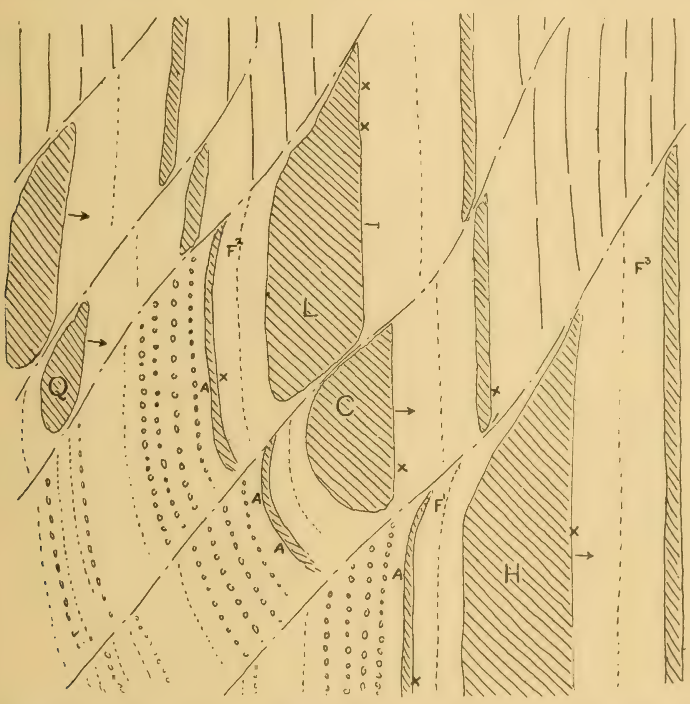


Figure 3—*Sketch Map of about ten Square Miles Area to illustrate the Monocline near Meriden, Connecticut.*

Showing parts of the Higby (H), Chauncey (C), Lamentation (L) and Quarry (Q) blocks. The known localities of the fossiliferous anterior shales in this area are at the northern edge of the Higby block (F^1) and northern part of the Lamentation block (F^2); and of the posterior, near the northern side of the Higby block (F^3). Beds of ashes and bombs are found in the anterior trap at A, and contacts of the trap sheets with the overlying sandstones at X.

begun in the blocks next toward the northwest, and, although much embarrassed by the drift that so generally occupies the anterior valley in which the black shale crops out, we were successful in finding it at three other points, and in securing fossils from it by digging to a moderate depth. It occupies essentially the same position in the stratified series at all these points. The extreme points now identified in this bed are about fifteen miles apart, and ten well proved faults occur between them.

Another bed of dark shales with impressions of fish and plants has been known for many years in a small brook north of the village of Westfield, Connecticut, and about half a mile southwest from the station of that name on the Berlin-Middletown branch of the New York, New Haven and Hartford railroad. This lies about one hundred and fifty feet below the posterior trap sheet, or about a quarter way from the posterior to the main sheet. It will be referred to as the posterior black shale. Outcrops of what seems to be the same bed have been opened at four different places, the distance between the extreme points being about fifty miles, including twelve or more faults. Its position is everywhere two or three hundred feet above the main trap sheet.

A more precise statement of the location of the fossiliferous strata and a provisional list of the fossils found in them is presented by Mr. Loper.

On examining the tables of species as made out by Mr. Loper, there appears to be good reason for concluding that different outcrops of the two beds of shale might be distinguished as belonging to two horizons on paleontological grounds alone; but it should be borne in mind that there is still much possibility of finding various species, now known only from one of the beds, in the other. The large number of species from the old Durham locality means in part good conditions for their preservation, but it means also that this locality has been more carefully worked and for a longer time than any other. It may also be suggested that while the stratigraphic correspondence of the several outcrops of the anterior and posterior shales was very satisfactory, so far as determination by rough pacing measures would determine, it is quite possible that they do not represent precisely equivalent horizons, although they are certainly as nearly equivalent as the so-called geological horizons commonly are. It is not unlikely that there may be several fossiliferous layers at slightly different horizons of the anterior and posterior shales, and that our openings touch one of them at one point and a second at another. Indeed, it may be that there are various fossiliferous black shales scattered through the formation, yet not visible owing to their weakness and the heavy drift cover that so effectively blankets over the surface; but the main question of the repetition of certain fossiliferous beds at definite positions in the various faulted blocks seems to be settled. The occurrence of the two shales at predicted localities and the correspondence in the fossils of each horizon at various localities so fully conform to the requirements of the theory of the faulted monocline that this structure may now be regarded as established for Connecticut on paleontological as well as on structural evidence.

HARVARD COLLEGE, CAMBRIDGE, MASS., *December*, 1890.

FOSSILS OF THE ANTERIOR AND POSTERIOR SHALES: BY S. WARD LOPER.

The Area examined.

In accordance with instructions received from Professor Davis last June, I have endeavored to test the continuity of the anterior and posterior fossiliferous shales associated with the trap ranges of the Triassic formation of the lower Connecticut valley. I have examined carefully the shale outcrops lying between the anterior and main trap ridges for nearly the whole distance across the state (about 50 miles), and have also looked for the posterior shales over a considerable part of this distance.

Although the work assigned me is not fully completed, I am able to report much that is of a satisfactory nature. Openings have been made along both the anterior and the posterior shales in several of the faulted blocks of the formation, and the beds thus disclosed, as well as the fossils obtained from them, show an indisputable correspondence in the stratigraphy.

About 450 specimens have been collected, exclusive of many hundred fossils which have been taken during the past twenty years from the shale beds of Durham and vicinity. About twenty-four species of fishes and plants, some hitherto undescribed, are now known from these localities. A comparison of the species from the different localities of the anterior and the posterior shales shows a correspondence in the fauna and flora, clearly sustaining the theory of the original continuity of the horizons through all the now faulted blocks of the Triassic formation.

Along the middle and southern ranges there has not been much difficulty in finding available points for making openings; but toward the northern line of the state, above the gap of the Farmington river at Tarriffville, the shales have been generally inaccessible on account of the great amount of drift by which they are buried. The red sandy beds and the blue shales associated with the black shales, are, however, traceable entirely across the state; and with sufficient time for closer search at certain points, there is little reason to doubt that the fossiliferous shales might be uncovered in the northern area.

The method of searching for the shales has been to walk over all the strip of country between the anterior and main trap ridges, and also, so far as has been possible in a single season, between the main and posterior ridges, making a thorough examination for outcrops of the fossiliferous beds in their appropriate positions. Several new localities yielding many valuable fossils have thus been discovered. The anterior shales were found at one point in the Lamentation block by excavating where there were no outcroppings, but where it was judged the fossiliferous beds ought to occur.

The Localities explored.

Anterior Shales: 1. Durham.—The anterior black shales are found in a stream bed on the western slope of Totoket mountain, near its northern curve in the southern limit of the town of Durham, where I have worked them for the past twenty years. The shales are now difficult to reach on account of water that fills the pits, and no search has been made here this year. The species heretofore found at this point have, however, been included in the tabular list given below. They are described as from "Durham" in Professor Newberry's monograph.

2. Bluff Head.—This is another outcrop in the same Totoket block and of the same bed as the preceding, but about two miles east of it, and north of the bold northeastern end of the main trap ridge, known as Bluff head. It lies near the northern line of Guilford. I found this bed about two years ago by following up a stream in which a boy had picked up a fossil fish. The shales are much decomposed and need careful handling, but the specimens are in good form. They closely resemble those from Durham.

3. Higby.—Black shales with fish scales were found by Professor Davis and myself last June in a ravine between the anterior and main trap ridges at the northern end of Higby mountain, about half a mile south of Highland station, on the Meriden, Waterbury and Connecticut River railroad. This was the first point at which discovery of fossils rewarded our search on a predicted horizon in the formation. An excavation in the bank secured a number of fragmentary specimens of fishes and plants. Large foot-prints were found in an associated sandstone.

4. Berlin.—No natural outcrops of black shales were found in the Lamentation block; but an excavation made at their expected horizon, about fifty feet above the anterior trap sheet, resulted in finding them, although of small thickness. This was in the southern part of Berlin, east of the Berlin-Meriden road, on land belonging to Mr. George Hall, near the house of Mr. Robert Hurlburt. The specimens were few in number and of poor condition, but sufficed to identify the shales.

5. Southington.—An old cement quarry on the back of the anterior trap ridge in the Ragged Mountain block (called South High rock in Professor Davis' paper on the faults near Meriden) contains some dark shales in which a number of plants were found. Fossil fishes are said to have been found here years ago. One specimen was discovered last summer by Mr. J. B. Woodworth, of the United States Geological Survey.

Besides these localities, there is good opportunity for opening the shales in the proper horizon above the back of the anterior trap sheet in the Bradley mountain block, at the outlet of the Plainfield reservoir; and dark shales were found by digging above the anterior ridge on the western slope of Rattlesnake mountain, near Farmington, though no fossils were secured here. These and other localities further north may be examined at a later date.

Posterior Shales: 1. East Haven.—Mr. E. O. Hovey, while at work on the geology of the New Haven topographic map sheet last summer, found an outcrop of fossiliferous black shales in a stream running into Saltonstall pond from the east near its southern end. The bed lies a hundred feet or more beneath the posterior trap sheet, and belongs in the Pond mountain block. A number of good specimens were secured by digging into it.

2. North Guilford.—Several years ago I found some fish scales in black shales exposed in a stream near the posterior trap sheet of the Totoket block. No opening has yet been made in these shales, but they may be provisionally referred to the posterior series.

3. Stevens.—An old locality, posterior to Paug mountain, near a shaft sunk for coal, on land belonging to S. G. Stevens, in the town of Durham. No work was done here last summer, but the species previously secured are entered in the list.

4. Westfield.—The posterior shales are exposed in a stream bed, a quarter of a mile northwest of Westfield village and half a mile southwest of Westfield station on the Berlin and Middletown railroad. These belong in the Higby block, near the fault that cuts it on the northwest. They lie about 100 feet below the posterior trap. The locality has been known for many years; a representative collection was secured from it last summer.

5. South Bloomfield.—Black shales were found at Gillett's Mills, lying posterior to the Talcott mountain range of the main trap sheet, but fossils are not yet discovered here.

6. North Bloomfield.—One mile east of Tarriffville, an extensive bed of black and blue shales was discovered, about 100 feet under the posterior trap, in the bed of a small stream, sixty rods south of its junction with the Farmington river, just above the Bloomfield and Winsor bridge. Many plant impressions were found here, but no fish remains.

The long distance from Westfield to South Bloomfield has not as yet yielded any posterior black shales.

There are black shales, sometimes fossiliferous, seen or reported at Little Falls, south of Middletown reservoir, in Middlefield, at Zoar, and in Middletown, Rocky Hill and Glastonbury. Some of these appear to constitute a second or higher horizon on the posterior; but their position is not yet well determined.

Species collected.—All the specimens collected last summer have lately been arranged according to localities and species at the Museum in Cambridge, Massachusetts, and provisionally determined by comparison with figures in Newberry's and Fontaine's monographs. The accompanying table presents the results thus obtained.

Provisional Table of Species of Fishes and Plants from the Anterior and Posterior Shales.

Species.	Anterior Shales.						Posterior Shales.				
	Durham.	Bluff Head.	Higby.	Lamentation.	Southington.	Anterior localities.	Posterior localities.	East Haven.	Stevens.	Westfield.	North Bloomfield.
Fishes.											
Diplurus longicaudatus, Newb.	+	0	0	0	0	1	1 (?)	0	0	(?)	0
Ptycholepis marshii, Newb.	+	+	0	0	0	2	0	0	0	0	0
Catopterus redfieldi, Egerton	+	+	0	0	0	2	2 (?)	+	0	(?)	0
" *gracilis*, J. H. R.	+	+	+	+	+	5	3	+	+	+	0
" *anguiliformis*, W. C. R	+	(?)	0	0	0	2 (?)	0	0	0	0	0
" *minor*, Newb.	+	0	0	0	0	1	0	0	0	0	0
" *ornatus*, Newb.	+	(?)	+	0	0	3 (?)	0	0	0	0	0
Ischypterus fultus, Ag.	+	(?)	0	0	0	2 (?)	0	0	0	0	0
" *micropterus*, Newb.	+	+	+	+	0	4	3	+	+	+	0
" *minutus*, Newb.	+	0	0	0	0	1	0	0	0	0	0
" *gigas*, Newb.	0	0	0	0	0	0	2	0	+	+	0
Undetermined ovate form	+	+	0	0	0	2	1	+	0	0	0
Plants.											
Pachyphyllum simile, Newb.	+	0	+	+	+	4	0	0	0	0	0
" *brevifolium*, Newb.	+	0	+	0	+	3	0	0	0	0	0
Otozamites latior, Sap.	+	0	0	0	+	2	1	0	0	0	+
" *brevifolius*, F. Br.	+	0	0	0	0	1	1 (?)	0	0	0	(?)
Clathropteris platyphylla, Bg.	+	0	0	0	0	1	0	0	0	0	0
Loperia simplex, Newb.	+	+	+	0	+	4	3	+	+	+	0
Cycadinocarpus chapini, Newb.	+	0	+	0	+	3	1	0	0	+	0
Equisetum rogersi (?), Sch.	0	0	0	0	0	0	4	+	+	+	+
" sp. und.	0	0	+	+	+	3	3	+	+	0	+
Baiera münsteriana, Ung.	+	+	+	+	+	5	0	0	0	0	0
Ctenophyllum braunianum, Sch.	0	0	0	0	0	0	1	0	0	0	+
Calamite-like stems, with head	+	0	+	+	0	3	0	0	0	0	0
Undetermined stem, with spines	+	0	0	0	+	2	0	0	0	0	0

Distribution of Species.

It appears from the table that the following five species of fish and five species of plants are common to both the anterior and posterior shales, as represented in the collections from the localities here considered:

Fishes . .
- *Diplurus longicaudatus*, Newb. (doubtful in posterior).
- *Catopterus redfieldi*, Egerton.
- *Catopterus gracilis*, J. H. Redfield.
- *Ischypterus micropterus*, Newb.
- Undetermined ovate form.

Plants . .
- *Otozamites latior*, Sap.
- *Otozamites brevifolius*, F. Br. (doubtful in posterior).
- *Loperia simplex*, Newb.
- *Cycadinocarpus chapini*, Newb.
- A small undetermined *Equisetum* (?).

The anterior shales alone have afforded the following six species each of fish and plants:

Fishes . .
- *Ptycholepis marshii*, Newb.
- *Catopterus anguilliformis*, W. C. Redfield.
- *Catopterus minor*, Newb.
- *Catopterus ornatus*, Newb.
- *Ischypterus fultus*, Ag.
- *Ischypterus minutus*, Newb.

Plants . .
- *Pachyphyllum simile*, Newb.
- *Pachyphyllum brevifolium*, Newb.
- *Clathropteris platyphylla*, Brong.
- *Baiera münsteriana*, Ung.
- Calamite-like stems, with head.
- Undetermined stem, with spines.

The posterior shales have produced the following single species of fish and two species of plants, not yet found in the various openings on the anterior shales:

Fishes . . *Ischypterus gigas*, Newb.

Plants . .
- *Equisetum rogersi*, Sch.
- *Ctenophyllum braunianum*, Sch.

The most marked features of this comparison are the absence of *Ischypterus gigas* from the anterior shales, where so many other species of fish are found, and the limitation of several species of plants to the anterior shales, although the flora of the posterior shales embraces a number of species common to both.

Results.

The work has, therefore, been not only clearly confirmatory of the theory of a faulted monocline, but it has also secured many fine specimens for the National Museum, and it has shown that systematic exploration may yet reveal much of interest where it was supposed that but little remained to be discovered.

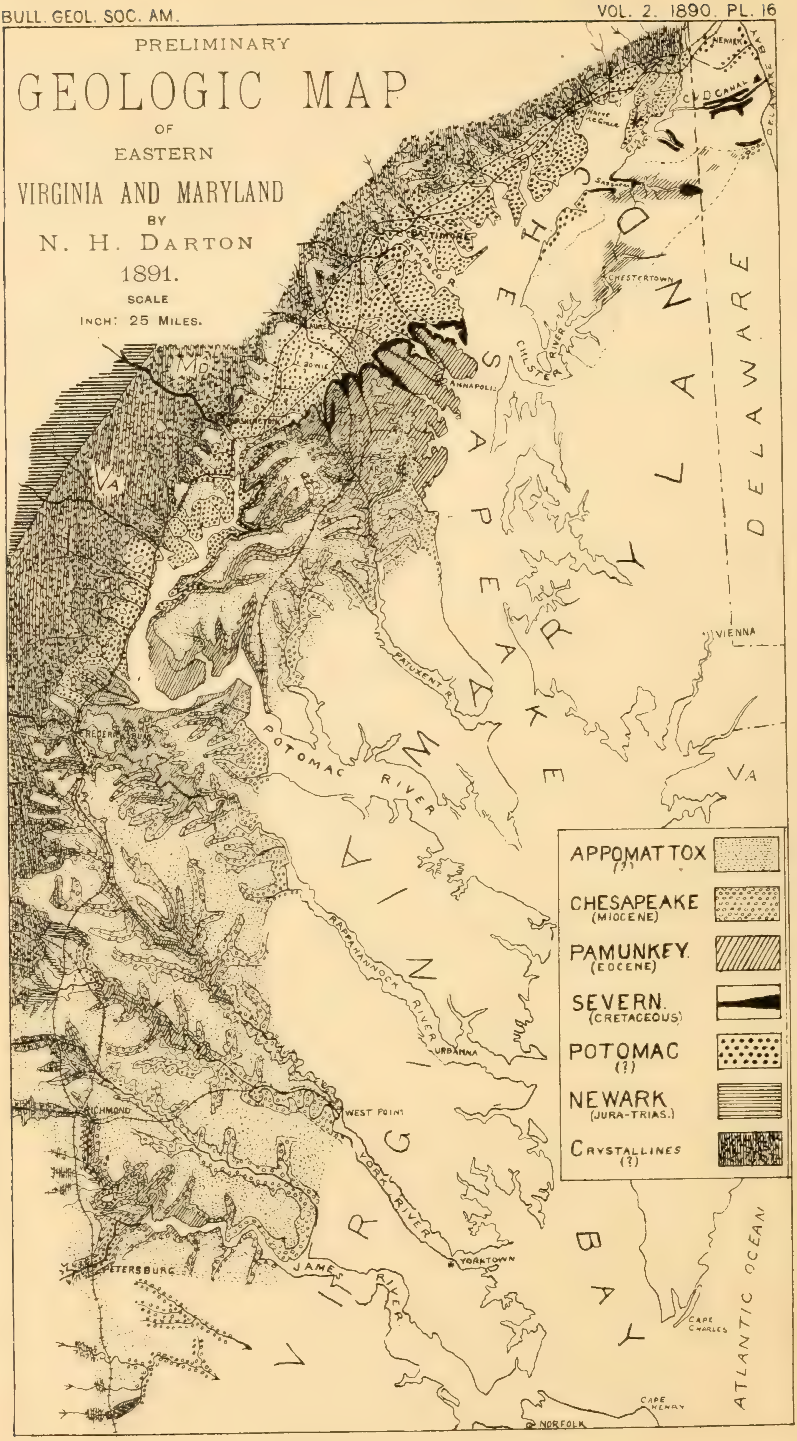
Washington, D. C., *December*, 1890.

DISCUSSION.

Professor C. H. Hitchcock: Being greatly interested in the facts of this paper, I desire to ask Professor Davis where, judging from his conclusions as to Connecticut, we should expect to find the fish beds in connection with the Holyoke-Tom range in Massachusetts?

Professor W. M. Davis: The location of the belts of shale in Massachusetts will depend on the correlation of the trap ridges of Connecticut and Massachusetts. Without being able at present to settle the question, I am inclined to believe that the anterior sheet in Connecticut thickens northward and becomes the main sheet north of the state line, while the main sheet of Connecticut thins and becomes a subordinate posterior further northward. If this is correct we should look for the anterior shales of Connecticut on the back of the Mount Tom-Holyoke range; and the Bear's Hole locality, a mile or two north of the Westfield river, appears to confirm this suggestion. The posterior shales of Connecticut should lie further east, but they are not yet identified.

Professor B. K. Emerson: Further northward, in Massachusetts, a band of black shale occupies the same horizon above the Holyoke traps, but has furnished only plant remains. In northern Massachusetts the Sunderland and Turners Falls fish beds also occur just above the Deerfield trap sheet.


PRELIMINARY
GEOLOGIC MAP
OF
EASTERN
VIRGINIA AND MARYLAND
BY
N. H. DARTON
1891.
SCALE
INCH: 25 MILES.
APPOMATTOX (?)
CHESAPEAKE (MIOCENE)
PAMUNKEY (EOCENE)
SEVERN (CRETACEOUS)
POTOMAC (?)
NEWARK (JURA-TRIAS.)
CRYSTALLINES (?)
CHESAPEAKE BAY
MARYLAND
DELAWARE
VIRGINIA
VA
MD
BALTIMORE
ANNAPOLIS
CHESTERTOWN
CHESTER RIVER
VIENNA
PATUXENT R.
POTOMAC RIVER
RAPPAHANNOCK RIVER
URBANNA
WEST POINT
YORK RIVER
YORKTOWN
JAMES RIVER
RICHMOND
PETERSBURG
NORFOLK
CAPE HENRY
CAPE CHARLES
ATLANTIC OCEAN
NEWARK
C. & D. CANAL
DELAWARE BAY

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MESOZOIC AND CENOZOIC FORMATIONS OF EASTERN VIRGINIA AND MARYLAND.

BY N. H. DARTON, U. S. GEOLOGICAL SURVEY.

(*Read before the Society December* 30, 1890.)

CONTENTS.

Introductory.

The crystalline rocks of the Piedmont region in Virginia and Maryland are flanked eastward by an overlapping series of deposits of later Mesozoic and Cenozoic age, which extend thence to the Atlantic ocean, a distance averaging one hundred miles. This district has been designated the "coastal plain," and is in general terms the continuation of the Piedmont plains which, with gradually decreasing elevation, finally pass beneath sea-level.

The eastward inclination of the crystalline rock-surface on which the coastal plain deposits lie is slight, and the width of the zone of overlap from the feather edges and outliers of the formations to the final disappearance of this floor below tide-level usually averages about ten miles.

The irregular western terminations of the various formations usually do not give rise to notable topographic features, and in the larger drainage depressions the crystalline rocks finally disappear below the clastics, generally at a considerable distance below the head of tide-water.

Excepting the most recent member, which often forms low terraces, the formations of the coastal plain series constitute a succession of thin sheets, inclined gently seaward and gradually thickening in that direction. Normally their outcrops are from below upward, from west to east; but there is considerable overlapping westward, and the sequence and extent of their relations vary greatly in different parts of the region.

The formations constituting the coastal plain series are as follows: The Potomac of McGee; the southern extension and termination of a portion of the New Jersey Cretaceous greensand series, which I shall designate *Severn*, from typical exposures, described by Clark, on the Severn river near Annapolis; a representative of the Eocene, restricted to Maryland and Virginia, for which the term *Pamunkey* is appropriate on account of the typical nature and extent of the exposures on the Pamunkey river, as described by Rogers; the Miocene formations, which I shall comprise under the group name *Chesapeake* from Chesapeake, bay, adjacent to which the formation attains its greatest development; and the Appomattox and the Columbia of McGee.

Previous writers on the geology of the coastal plain region of Virginia and Maryland comprise Conrad, W. B. Rogers, McGee, Fontaine, Uhler, and W. B. Clark, together with a few others whose observations have been less extended.

It does not seem desirable at present to give an exhaustive account of the contributions of these observers, and only a brief sketch is here offered: The formation now known as Potomac was described by Rogers* in Virginia, and McGee † and Fontaine ‡ have studied it both in Virginia and Maryland. The extension of the Cretaceous through the western shore of Maryland was established by W. B. Clark, § and Uhler || has also described some of its features. The Eocene and Miocene formations have been considered at greater or less length in the paleontologic writings of Conrad, by Rogers in reports on geological surveys of Virginia, and in parts of eastern Maryland by Uhler in the paper above referred to.

The Appomattox south of the Fredericksburg region was differentiated by McGee,¶ and to this observer we are also indebted for the separation and study of the Columbia formation.**

While these various investigations have afforded a most valuable basis for the elucidation of coastal plain geology, especially in certain type areas where the relations are more obvious, the greater part of the region is left involved in geologic questions of very great intricacy. This is especially the case in the many districts in which there are complex overlap relations, intergradations and similarity of deposits, weathering, shore phenomena and inter-geologic terracings, which, in soft materials with unsatisfactory exposures, are often exceedingly puzzling.

During the past two years the writer has been engaged in almost continuous field-work in this region; and in this memoir it is proposed to give a brief general abstract of the more noteworthy results, as a preliminary contribution to coastal plain geology. The investigation is still actively in progress, and more extensive reports of results and methods will appear later.

The Formations.

THE GEOLOGIC COLUMN.

The components of the geologic column of the coastal plain region of Virginia and Maryland are as follows:

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* Report of Progress of Geological Survey of Virginia for 1840, chap. III.

† "Three Formations of the Middle Atlantic Slope:" Am. Jour. Sci., 3d ser., vol. XXXV, 1888, pp. 121–143.

‡ "The Potomac or Younger Mesozoic Flora:" Monographs U. S. Geol. Survey, vol. XV, 1889, pp. 1–62.

§ Johns Hopkins University Circulars, vol. 8, no. 69, 1889, pp. 20–21.

|| Proc. Maryland Acad. Science, vol. 1, 1888, pp. 11 34, 45-98.

¶ Loc. cit., pp. 328–330.

** Loc. cit., pp. 367–388, 448–466; and in "The Geology of the head of Chesapeake Bay:" 7th Annual Report of the Director U. S. Geol. Survey, 1885–'86, pp. 537–646.

Representative.	*Age.*
Columbia formation.	Pliestocene (early).
Erosion interval.	———.
Appomattox formation.	Pliocene (?).
Erosion interval.	———.
Chesapeake formation.	Miocene.
Erosion interval.	———.
Pamunkey formation.	Eocene.
Erosion interval.	———.
Severn formation.	Cretaceous.
Erosion interval.	Cretaceous.
Potomac formation.	Cretaceous (?).
Erosion interval.	Jurassic (?).
Newark formation.	Jura-Trias.
Erosion interval.	Early Mesozoic.
Crystallines.	(?).

GENERAL DISTRIBUTION AND STRUCTURE.

The accompanying map (plate 16) is a generalized reduction, in the main, of large scale sheets mapped in detail during the past year. On account of the thinness of the formations, especially in their feather edges, and the intricacy of the boundary lines, great difficulty has been experienced in producing a small scale map in black and white, and the result is not altogether effective. Careful examination should, however, afford all data of general interest concerning the distribution of the formations in the explored belt.

The cross-sections in figure 1 illustrate, at intervals, the structural relations and the general configuration of the mass of each formation above tide-level.

The Columbia formation is omitted from both the map and the sections to avoid the greatly increased complexity which its representation would introduce. In the western part of the region this formation is confined to the lower terraces along the great transverse drainage depressions and for a short distance up some of the side drainage lines. In the low coasts eastward it fringes the shores for a considerable distance, and in the aggregate covers wide areas.

The Potomac formation lies directly on an irregular surface of the old crystalline rocks excepting in a small area north of Richmond, where an outlying mass of the Newark formation intervenes. Southward from Fredericksburg it is overlapped by succeeding formations, and only appears in the larger depressions toward the head of tide-water.

The Severn formation lies on the irregular surface of Potomac sands or clays, and thins out and disappears a short distance south of Washington. Opposite Washington its edge is locally cut off by the overlap of succeeding formations.

The Pamunkey formation lies on a slightly irregular surface of the Severn formation in Maryland and directly on the Potomac sands southward through Virginia. Opposite Washington its western edge is also cut off locally by the next succeeding formation, and for the greater part of its area above tide-level it is so deeply buried under later deposits that it only appears in the deeper depressions.

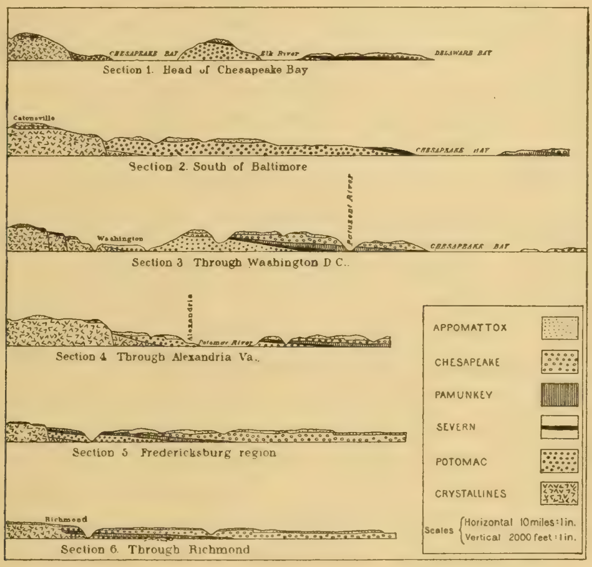


FIGURE 1—*Sections through the Cenozoic and Mesozoic Formations and the Crystalline Rocks of eastern Virginia and central Maryland.*

The Chesapeake formation rises above tide-level for nearly the entire area of the coastal plain region. It lies on a gently eastward dipping plane of unconformity on the Pamunkey formation, but overlaps westward to the Potomac formation at Washington, and to a greater or less degree to the crystalline rocks in the region southward from Fredericksburg into the Carolinas.

The Appomattox formation is a wide-spread, high-level terrace capping, which lies upon and overlaps all of the other formations. Southward from Fredericksburg it is an almost continuous cap on the high lands from the crystalline rocks to the sea, but northward it is confined to the higher levels and is more widely eroded.

POTOMAC FORMATION.

Distribution.—The areal distribution of the Potomac formation in Virginia and Maryland is represented on the map, and its characteristics and relations have been described by McGee in his memoir on "Three formations of the middle Atlantic slope." There are, however, a number of special questions respecting its distribution, relations and stratigraphy which merit brief discussion.

Stratigraphy.—It has been suggested by McGee and held by Fontaine that the argillaceous member of the formation is superior to the arenaceous member and perhaps separated by a stratigraphic break. A study of this question has, however, led me to believe that while the relative positions of the two members are in the main as above stated, there is both a lateral and vertical intergradation. In Virginia the arenaceous member occupies the entire width of the outcrop belt. Along the Potomac river and northward the argillaceous member is first seen at the top of the formation; but by a gradual lateral intergradation it appears to extend lower and lower in horizon, finally to the exclusion of the arenaceous beds. Vertical intergradation is well exposed in the Washington region, but evidence of the lateral change is fragmental and less decisive. Northward from Washington to Baltimore and beyond, the formation consists of clays, mainly of red and buff tints, with intercalated sand streaks. This is the iron-bearing clay of Tyson, the variegated clays of Fontaine, and the Baltimorean of Uhler.

The evidence offered by Fontaine to prove the stratigraphic break in the formation is in the clay belt at Hanover station and at Federal hill in Baltimore, where the variegated clays are underlain by sands. I have studied these localities and many others of the same character, and have become convinced that the sands are only lenses inclosed in the clay series; a very common occurrence in the Baltimore region. A boring made in the Federal hill exposures passed through the sands into clays below, and in the Hanover district and northward the clays are often exposed lying directly on the crystalline rocks, both at high and at low levels.

There can be little doubt that the Raritan clays of New Jersey are the northern extension of the Potomac clays, for the outcrops are practically continuous, the relations are precisely the same, and there is no evidence of stratigraphic break or overlap.

The "Albirupean."—In 1888, Uhler* announced the discovery of a formation lying unconformably between the Potomac and Severn formations, for which the name "Albirupean" was suggested.

* Proc. American Phil. Soc., vol. XXV, pp. 42–53.

Regarding this formation I have to report adversely, for it is found to consist of certain local sand beds occurring at several horizons in the Potomac clay series. In Uhler's typical section along the banks of the Severn river above Round bay, the "Albirupean" sands graduate above and laterally into typical iron-bearing clays of the Potomac formation. Other "Albirupean" sands were found to be *included* in the clays along the Patapsco and elsewhere in the Baltimore region. Usually these sands are sharply demarked from clays below by sharp unconformities, but above and laterally they become argillaceous and gradually merge into pure clays. There can be no doubt in regard to the wide vertical distribution of these sand streaks in the formation, and they cannot consistently be grouped as a separate formation.

Shore Deposits.—The shore deposits at the western edge of the Potomac formation often lack the distinctive features of the beds further eastward, and some errors have been made in their identification. In Maryland the pure clays sometimes lie directly on the crystalline rocks, but usually they become sandy and gravelly, and in some cases are represented solely by coarse materials. In Virginia the arenaceous beds are usually overlapped by later formations, but a few basal contacts are exposed in which the sands, with clay pebbles and quartz pebbles, lie directly on the crystalline schists. Both in Virginia and Maryland there are regions in which the western margin of the formation is represented by fringes and outliers of coarser shore deposits, usually capped by a protecting mantle of the less destructible Appomattox gravels. The Appomattox formation in these regions consists largely of rearranged Potomac gravels, and this has led them formerly to be mistaken for undisturbed Potomac sediments, but it is almost always possible to discriminate the two formations. In the terraces west of Alexandria, Washington, and Baltimore, notably at Tennallytown and Catonsville, this joint occurrence is especially notable.

In the Sassafras river region I find that McGee* has included a portion of the dark Cretaceous (Severn) beds in the Potomac, and in Maulden's mountain excluded as Cretaceous some gray and brown sands really belonging to the Potomac.

Stratigraphic Position.—The Potomac formation, as originally defined by McGee, is a stratigraphic unit lying between the Newark formation and the New Jersey Cretaceous greensand series and separated from both by structural breaks representing long time gaps. Its upper part or entire thickness in the north may extend more or less above the horizon of the beds in the James and Potomac regions, but the formation represents continuous deposition throughout.

* Geology of Head of Chesapeake Bay; U. S. Geol. Survey, Report of Director, 1885-'86, pp. 585, 587, 590, 613.

The erosion epoch between the Potomac formation and the Cretaceous greensand is one of considerable moment, but the gap between the Potomac and Newark represents one of the great periods of uplift and erosion which is second only to the gap between the Paleozoics and the Newark formation.

SEVERN FORMATION.

Distribution and Characteristics.—In 1888, Clark identified the Cretaceous formation on the "western shore" of Maryland by the discovery of typical molluscan casts at Round bay on the Severn river, on Magothy river, at Millersville and Collington, and at Fort Washington, and so set at rest any question in regard to the southward extension of the formation, at least through Maryland. The writer has found that the formation is a continuous sheet, clearly defined in its stratigraphic relations, and finally disappearing near the latitude of Marshall Hall, on the Potomac river, south of Washington.

The formation consists throughout almost entirely of fine black sand, more or less flecked with scales of mica, very sparingly but irregularly glauconitic, and usually containing considerable carbonaceous materials. The finest exposures are in the high cliffs at Round bay, on the Severn river, a locality to which Clark and Uhler have paid considerable attention. There it is exposed lying on an irregular surface of a local coarse gray sand bed in the Potomac formation; and back from the river, on some of the higher lands, it is in turn capped by weathered beds of the Pamunkey formation, beneath which it also disappears down the river toward Annapolis. Southward there are frequent exposures in road, railroad and stream cuts, in a narrow belt which extends continuously nearly to Washington; thence its edge is cut out for a few miles by an overlap of the Chesapeake formation, but it comes out again opposite Alexandria and is exposed in considerable force in the gullies along the face of the terrace fronting the Potomac and in some of the side drainage ways. At Fort Washington it is exposed in the "bluff," lying on gray lignitic clays of the Potomac formation, and capped by a few feet of weathered Pamunkey deposits.

At every exposure organic remains are found, commonly in the forms of casts or impressions. At several localities east and southeast of Washington and a short distance from the city I have found fossil shells occurring abundantly in the formation, notably *Exogyra costata* and a large *Cyprimeria*, like *densata*.

Northward from Round bay the formation is exposed in the lower Magothy river for the last time on the "western shore." On the eastern side of Chesapeake bay the black carbonaceous sands are again exposed, lying on the Potomac sands and clays at Howell's point, and thence occupying the high banks of the lower Sassafras river, finally sinking beneath the Pamunkey formation near Lloyd's creek. On the northern side of the Sassafras, again near its head, and in the Bohemia creek depression, the formation is also exposed at intervals. In Delaware the exposures in the Chesapeake and Delaware canal cuts are well known, and in this region the formation comprises a series of more or less distinctly separable beds, which, by Chester, have been correlated with the various members of the New Jersey greensand series.

The thickness of the formation gradually decreases southward; in the lower Sassafras and Round bay regions it is nearly 100 feet; northeast of Washington, 10 to 30 feet; opposite Alexandria, 25 feet; along Henson creek, 20 feet; and in the Fort Washington bluff, 18 feet.

Stratigraphic Relations and Equivalency.—The Severn formation is frequently exposed in contact with the Potomac clays, and lies on an unconformity always sharply defined by great contrast in material and considerable local irregularity of surface. It is in turn unconformably overlain by the Pamunkey formation, from which it is widely separated structurally and faunally.

The Severn formation is the continuous southern extension of the New Jersey Cretaceous greensand series, but whether it represents all or part of these members is not as yet determined. In Maryland it is a stratigraphic unit, distinctly separable from the New Jersey series as a whole by its homogeneity of constitution; and it is with this restriction that the term "Severn" is applied.

PAMUNKEY FORMATION.

Distribution and Characteristics: General Features.—This formation occupies a belt of considerable width extending through Maryland and Virginia above tide-level with a length of about 200 miles. The greater part of its area is buried beneath younger formations, but it is exposed extensively in each of the larger depressions, where it is a conspicuous member of the coastal plain series.

The formation consists of a homogeneous sheet of fine-grained materials, glauconitic sands mainly, usually profusely fossiliferous. Excepting a few local beds of clay, secondary limestones, and some gravels at its base, the formation does not comprise stratigraphic components. Wherever the formation has been bared of overlying formations its glauconitic constituent is either weathered out, leaving fine light-colored sands, or decomposed and the iron redeposited as a red or brown stain and in crusts and concretions. This weathered phase is general in the northern part of the region beyond the edge of the overlying Chesapeake formation, along the western margin in Virginia, and in all old outcrops.

In describing the distribution and noteworthy exposures of the formation it will be convenient to briefly consider each general area separately.

Nottoway River.—The southernmost exposure of the Pamunkey formation is a small outcrop near Bollings bridge, which I have not visited.

Appomattox River.—At Petersburg the formation is represented by a few feet of slightly glauconitic black sands containing casts of Eocene mollusca. This is exposed lying on the Potomac gravels just northwest of the city, and again in the depression at the city water-works, where it is capped by Chesapeake beds.

James River.—In the James river depression and up its side branches the Pamunkey formation is extensively exposed. At Richmond the thin edge of the formation consists of black sands similar to those at Petersburg, and it is exposed lying between Chesapeake and Potomac beds in the Shockoe creek depression.

Descending the James, for several miles the edge of the formation lies some distance back from the river bluffs, and is more or less overlapped by the Appomattox. From a short distance below Dutch gap to Coggins point the formation, with its gentle easterly inclination, gradually crosses tide-level and the river bluff exposures are frequent, and at some points particularly fine, notably at Tar bay. The beds consists mainly of richly glauconitic marls, highly fossiliferous, which are worked to some extent for fertilizers. The overlying Chesapeake beds become prominent in the bluffs below City Point, and in this region there is a thin local bed of white clay in the Pamunkey formation near its summit.

Chickahominy River.—This stream was not explored, but the Pamunkey formation is probably reached by the river channel for a greater or less distance in the district opposite the James river exposures.

Pamunkey River.—The exposures in this depression begin just about Hanover Court-House, and thence for many miles down the river they constitute an almost continuous section. Rogers considered this section typical, and described some of the outcrops in considerable detail. Glauconitic sands predominate, and fossils are abundant.

Mattaponi River.—Exposures are frequent on the Mattaponi, but are not especially noteworthy. Argillaceous materials enter largely into the components of the formation.

Rappahannock River.—In this basin the outcrops of the formation occupy a considerable area. West and northwest of Fredericksburg the beds of buff sand lying on the Potomac formation are found to be Pamunkey in age, representing beds from which the glauconite has been weathered out. Farther eastward the glauconitic marls are seen in many excellent exposures in river bluffs and side drainage depressions, capped usually by the Chesapeake beds.

Potomac River.—The formation occupies the western side of this basin from near Washington to Pope's creek, and the eastern side from Acquia creek to Mathias point. The finest exposures are in the high bluffs that extend eastward along the river from the mouth of Acquia creek. About 100 feet of Pamunkey beds are exhibited, consisting mainly of glauconitic marls and sands, with several limestone beds, and, near the top, a few feet of light-colored sandy clays. Fossils are abundant, and very nearly the entire Pamunkey fauna is represented. West of this region the weathered phase of the formation predominates, and its soft buff sands are conspicuous toward Stafford Court-House, in one area including a thick fossiliferous limestone stratum.

On the eastern side of the Potomac, Port Tobacco river, and Mattawoman, Piscataway and Henson creeks and their branches give frequent exposures of fossiliferous glauconitic marls, and there are outcrops along the Potomac river at Pope's creek, at Clifton Beach and in the bluff at Fort Washington.

Opposite Washington (as shown in figure 1, page 435) the western edge of the formation is cut out and replaced by the Chesapeake formation. This condition prevails in the high ridge lying just east of the Anacostia river; but farther eastward and southward the edge of the formation is exposed again, and its fossiliferous marls are found in every drainage way to within about five miles of the capital.

Patuxent River.—In this valley the formation emerges from beneath the Chesapeake beds at tide-level a few miles below Nottingham, and, rapidly widening in area northward, finally extends around past Marlboro to the drainage of the Anacostia and northeastward to the shores of Chesapeake bay. In the southern part of the area, dark-colored glauconitic marls prevail; but in districts where the Chesapeake mantle has been removed the red sands of the weathered phase occupy the surface. These red sands contain abundant casts and impressions of Eocene species, and there can be no doubt as to their stratigraphic equivalency with the dark beds southward.

Chesapeake Bay.—In the Annapolis region and along the South and Severn rivers the weathered phase attains the greatest development, and red sands with ferruginous crusts, concretions and sandstone layers occupy a wide area. The opposite or "eastern shore" of Maryland is heavily mantled by sands and gravels of undetermined age, and outcrops of the subterrane are infrequent; but I have studied the river banks and traced the Pamunkey formation up the Chester river past Chestertown and up the Sassafras river past Georgetown into Delaware nearly to Nockimixon pond, where it thins out and the Severn and Chesapeake formations come together.

In the "eastern shore" exposures the weathered phase was found to prevail; but casts and impressions of *Cardita planicosta* and *Dociniopsis meekii* occur in every outcrop. On the Sassafras river the Severn formation occurs for some distance near its mouth, and again, I believe, at its head; but there is a wide intermediate belt occupied by Pamunkey beds, which are especially well exhibited at Georgetown and Fredericktown. The Pamunkey area on the "eastern shore" is indicated on the map (plate 16) by a broken line, which, I should add, is only approximately accurate.

Thickness.—The thickness of the Pamunkey formation along its southeastern outcrops is about 150 feet from the South river to James river, and is apparently quite uniform throughout. Northwestward the thickness diminishes to a mere feather edge lying on the Potomac formation and usually overlapped by the Chesapeake or Appomattox formation.

Stratigraphic Relations.—North of the Potomac river the Pamunkey formation lies between the black sands of the Severn formation and the diatomous beds of the Chesapeake formation, separated in each case by a wide structural and paleontologic gap. Exposures of unconformity with the Severn formation are not abundant, and, owing to close similarity and intermingling of materials at the contact, are not always distinct. Along some of the headwaters of the Northwest branch of the Patuxent and again in the bluff at Fort Washington the weathered red beds of the Pamunkey are at several points exposed lying on a slightly irregular surface of the unchanged black sands of the Severn formation, and contacts are also occasionally observed on the South, Severn and Magothy rivers. A fine exposure of the contact is displayed in a road cutting a few hundred yards south of Buena Vista, Prince George county, Maryland.

At Glymont, Maryland, and thence southward through Virginia, the Pamunkey formation lies directly on an irregular surface of the Potomac formation, usually including more or less numerous Potomac pebbles in its lower beds. In the vicinity of Acquia creek, exposures of contacts are frequent, and along the railroad a few rods south of the bridge there is an exposure, referred to by McGee, in which the base of the Pamunkey formation is seen occupying an old ravine in the Potomac surface. At many points near Fredericksburg and Brooke station, as well as at Richmond and Deep Bottom on the James, and at Petersburg and Bollings bridge, the basal pebble bed of the Pamunkey and the contact with the Potomac are exposed with uniform relations throughout.

The unconformable superposition of the Chesapeake on the Pamunkey formation was frequently referred to by Rogers, and I have traced it through hundreds of exposures in Virginia and through Maryland.

The surface is usually relatively smooth, but there is a sharp contrast in materials and usually a streak of pebbles of quartz or of Eocene fossil casts in the overlying beds.

Along the western border of the coastal plain region at some localities, and in the higher river terraces, the Appomattox formation lies directly on the Pamunkey formation, and in the lower river terraces the latter is overlain by the Columbia deposits.

Taxonomy.—The paleontologic evidence in regard to the age of the Pamunkey formation establishes its equivalency with the Eocene as recognized by Rogers and Conrad half a century ago. It is not possible as yet to definitely state its precise relative position in the Eocene, or to correlate it with other North American deposits. It is not known whether its basal and surface planes are approximately parallel throughout, either to each other or to the bedding of the formation.

CHESAPEAKE FORMATION.

Distribution and Characteristics.—This formation occupies a belt comprising nearly the entire width of the coastal plain region in Virginia and a wide area in southeastern Maryland. All of the water-courses of the region cut more or less deeply into the formation, and it frequently constitutes high bluffs along the larger streams. In Maryland it lies east of the Potomac river, and on the "western shore" its northern termination is in a series of outliers midway on a line connecting Washington and Annapolis. Its northern limit on the "eastern shore" is indicated approximately by the dotted line on the map (plate 16), but the details of its distribution in that region are not yet determined.

The formation is diverse in composition, consisting of sands, clays, marls, diatomaceous beds, and shell fragments, in all several hundred feet in thickness. The lower beds consist mainly of dark-colored clays and fine, mealy sands containing the extensive and well-known diatomaceous deposits. These are succeeded by lighter-colored clays and sands, with occasional local inclusions of blue marl. The upper beds are coarser-grained, and consist chiefly of white beach sands containing shells and deposits of shell fragments, and occasional argillaceous members. These three series intergrade in zones, which vary somewhat in stratigraphic position and vertical extent, and all the members rapidly thicken seaward, apparently reaching a thickness of nearly 1,000 feet at Fort Monroe.

The lower beds of the formation occupy a broad, irregular belt extending through Virginia into Maryland along the western part of the coastal plain region. Its finest exposures are at Richmond, at Petersburg, on the Rappahannock river below Fredericksburg, on the Potomac river at Pope's creek (Maryland), on the Patuxent river near Nottingham, and at Herring bay on Chesapeake bay. On the "eastern shore" it is seen near Wye Mills (Maryland), and on Little Duck creek, south of Clayton (Delaware); and it is found in the deep artesian wells at Atlantic City, New Jersey. On the "western shore" of Maryland I have found that it extends northwestward to Washington, being conspicuous in the high terraces overlooking the city from the east, and represented by an isolated patch lying on the Potomac sands and crystallines just outside of West Washington.

In Virginia, southward from Fredericksburg, it extends far westward on all of the divides, but with gentle seaward inclination follows down the drainage eastward. The diatomaceous deposits are variable in size and purity, and are irregularly scattered through the clays without restriction to any definite stratum.

The medial clays and marls are relatively thin, but they occupy a considerable area in Virginia. The finest exposures are on the James river near Claremont, near Hanover Court-House, in the Bowling Green region, in Nomini cliffs on the Potomac river, on the lower St. Mary's river, and near West Point on the York river.

A well-known exposure of the upper beds of the Chesapeake formation is found in the cliffs at Yorktown; and other fine exposures are at Grove wharf, Smithfield and Claremont on James river, at Suffolk on Nansemond river, at Lanexa on the Chickahominy, at Urbana on the Rappahannock, along the lower Patuxent river and the adjoining shores of Chesapeake bay, and near Easton as well as elsewhere on the Choptank river. At all these points the Yorktown fauna is well represented, and the remains occur in great abundance, Claremont on James river being an especially noteworthy locality, although less known than some of the others.

Stratigraphic Relations.—For the greater part of its area, the clays of the Chesapeake formation lie directly on the eroded surface of the Pamunkey greensands. Westward at some points it overlaps for short distances on the Potomac formation and crystalline rocks. On James river below City Point the medial portion of the formation lies on Pamunkey greensands, indicating an island or local shore bluff in the early Chesapeake seas. Elsewhere the stratigraphic position of the base of the formation appears to be constant, and the basal plane is a smooth surface inclined eastward very uniformly at the rate of about ten feet to the mile.

In the Washington section the base of the Chesapeake formation locally cuts across the thin edges of the Pamunkey and Severn formations, and lies directly on the Potomac formation. At Good Hope hill, in this region, occur the Eocene fossils mentioned by McGee,* but they are found to be casts mixed with casts of Cretaceous species, both imbedded in sands containing impressions of Miocene mollusca. This occurrence of pebbles, in part consisting of fossil casts, is quite common at the base of the Chesapeake formation, notably at Herring bay and on the Pamunkey river. In Maryland, especially near Nottingham and on Pope's creek, the base of the formation consists locally of a thin, hard silicified stratum filled with Miocene molluscan impressions.

The Chesapeake formation is unconformably overlain by the Appomattox formation, and along the bay shores and stream depressions by the Columbia formation.

*"Three Formations of the Middle Atlantic Slope:" Am. Jour. Sci., 3d ser., vol. XXXV, p. 136.

Taxonomy.—The Chesapeake formation is abundantly fossiliferous throughout, and the Miocene age of the fauna was recognized by Rogers and Conrad half a century ago.

It has been shown by Heilprin that the fauna of the upper part of the formation differs materially from that of the lower, but I find that there is less difference than is indicated by Conrad's lists, and that the transition is a very gradual one. The formation can hardly, on these grounds, be separated into Marylandian and Virginian, as proposed; and there is every reason to believe that the beds in Virginia in their entirety are of precisely the same age as their extension into Maryland. The paleontologic evidence is fully in accord with this, at least in a general way, and the structural evidence indicates complete continuity.

APPOMATTOX FORMATION.

Distribution and Characteristics.—The differentiation of the Appomattox formation in the southern states by McGee is one of the most valuable contributions ever made to American geologic science. The great extent and prominence of the formation and its significant bearing on the geologic history of North America give it an importance second to that of no other formation on the Atlantic slope.

The northern termination of the deposits was supposed to be near Potomac creek, a few miles north of Fredericksburg; but I have found that while there is a break in its continuity in the region east of the Potomac river, it soon begins again and thence continues northward probably through Maryland, and in attenuated scattered outcrops, through Delaware and into Pennsylvania and New Jersey.

It is displayed in the high terraces about Washington, and it caps nearly all the higher terrace levels of the "western shore" of Maryland northward to the latitude of Baltimore. Still farther northward it is confined to outliers on the divides along the western margin of the coastal plain region; but at the head of Chesapeake bay it extends farther eastward and, in the high Elk ridge, caps the Cretaceous and Potomac formations over a considerable area.

The formation was no doubt originally continuous throughout the Atlantic coastal plain, but it has suffered great erosion. Southward it caps all the high terraces, but northward from the Mattaponi the drainage ways have invaded it more widely until north of the latitude of Washington its remaining areas are relatively small isolated outliers.

The Appomattox formation in eastern Virginia consists of light-colored loams of buff and orange tints, containing streaks and beds of pebbles and coarse sand in varying proportions and irregular deposition. Northward in Maryland coarser materials gradually increase in amount, and in the Washington-Baltimore region and northward gravel beds predominate. On Good Hope hill, east of Washington, the high terrace is capped for some distance by beds consisting mainly of large pebbles and sand, with a buff loam matrix. Farther eastward the proportion of loam increases and the pebbles decrease in size and number. In the high terraces extending westward from Alexandria, in the outliers west of Washington and Baltimore, in the high terraces southeast of Baltimore, and generally along the crystalline border in Maryland and Delaware, the formation consists mainly of iron-stained pebbles in a matrix of more or less sandy orange or buff loam. Thin layers and lenses of ferruginous conglomerates are of frequent occurrence in the northern Maryland belt, in the capping on Elk neck, and in the Pennsylvania and New Jersey outliers. In some cases the formation contains somewhat coarser materials adjacent to the larger drainage depressions, especially on the Potomac river, where the pebble beds are particularly noteworthy.

The thickness of the formation is variable, but it averages between 20 and 30 feet. In Maryland it is generally under 25 feet, but in Virginia it is usually somewhat thicker than this.

Stratigraphic Relations.—The Appomattox formation lies on a terraced surface comprising in various regions all the preceding formations of the coastal plain series. In Virginia and the southern part of the "western shore" of Maryland it lies on the Chesapeake formation over an area of several thousand square miles. It overlaps upon the Pamunkey formation in the Fredericksburg region, northeast of Washington, and in the James, Pamunkey, Mattaponi, Rappahannock and Potomac depressions. In several isolated knobs on Elk neck it lies directly on the Cretaceous greensand series. It lies on the Potomac formation in the Hanover Junction region, about Fredericksburg, in the wide terraces west and south of Alexandria and Washington, in the Baltimore region, and thence northward in Maryland and probably in Delaware. In the Richmond coal field and about Hanover Junction it lies on the Newark formation, and all along the western edge of the coastal plain region it overlaps for a greater or less distance upon the crystalline rocks in Virginia, Maryland and Delaware.

Generally the base of the formation is sharply demarked, but frequently it is composed of local materials which merge more or less gradually into the surface of the underlying formation. This is particularly the case in some contacts with the lower Chesapeake, Pamunkey and Potomac formations, which have furnished much of the Appomattox materials.

The surface on which the Appomattox formation was deposited is a series of gently rolling plains, separated by gentle slopes and low local terrace scarps. These terraces and slopes descend successively eastward with varying intervals and amounts, and the plains have also a very gentle eastward inclination. There is also a series of similar transverse pre-Appomattox terraces and slopes along the great transverse drainage depressions, which add complexity to the contour of the basal surface, but at the same time throw much light on the geologic history of the region.

In the first place, as all these shallow terraced basins appear to be pre-Appomattox in age, their existence records the interesting fact that the transverse depressions of the coastal plain region were first excavated by the retreating waters which carved the longitudinal terraces during the interval between the deposition of the Chesapeake and Appomattox formations; for the pre-Appomattox formations bear no records of the presence of transverse drainage. In the second place, it is found that these terraces present evidence of a post-Appomattox deformation in their extension to progressively lower minimum levels from north to south from Maryland to North Carolina. In the Roanoke basin the Appomattox is brought down to tide-level at some points by the terraces, but northward the minimum elevation of its base gradually increases finally to an altitude of 250 feet at the head of Chesapeake bay. As it is altogether improbable that there was longitudinal inclination to the floor on which the Appomattox formation was deposited, this gradual northward slope indicates an uplift approximating 250 feet in amount distributed through the interval of about 250 miles.

The origin of the oblique southward deflection of the rivers across the western part of the coastal plain does not appear to be related to this longitudinal uplift. It is probably due either to a shallow pre-Appomattox flexing along the Piedmont shore or to shallow channels just off the mouths of the pre-Appomattox streams. In either case the result would be a southward deflection of the drainage into these lines when emergence took place.

As I have not yet studied the seaward extension of the Appomattox formation, I have not observed its overlap by the Columbia formation; but the two formations are separated by a great uplift and erosion interval. This epoch differed from its base-leveling predecessors by greater relative emergence and consequent stream action which developed the greater part of the present physiography of the region. This erosion deepened and greatly widened the transverse drainage depressions, trenched the side drainage depressions, and cut into the edges of the terraces to an extent gradually increasing northward from North Carolina, and in northern Maryland resulting in the removal of wide areas of the coastal plain formations, especially the Chesapeake and Appomattox.

Taxonomy.—No fossils have yet been discovered in the Appomattox formation in the Virginia-Maryland region, but the structural evidence above presented definitely places its stratigraphic position between the Chesapeake and Columbia formations, and widely separated from both by long erosion intervals. Its precise age is unknown.

COLUMBIA FORMATION.

In regard to this formation I have at present but little of general interest to add to the statements of McGee. I do not find the interfluvial phase so widespread as was originally supposed, and do find that certain high level gravels and terraces of the Washington region are of Appomattox age.

The Columbia terraces border the coastal plain rivers from the fall line region to their mouths, and extend over wide areas in the low regions adjoining Chesapeake bay. The formation lies on terrace planes cut in the various subterranes near tide-level and ranging in position from a few feet above to a moderate distance below.

The altitude of the terraces decreases eastward, and, as shown by McGee, gradually increases northward through Virginia and Maryland. This increase of altitude northward is similar to that of the Appomattox formation, but less in amount, and probably indicates that part of the deformation is of post-Columbia age.

Following Columbia deposition came increased emergence, slightly greater northward, and cutting of the present river channels to depths considerably below present tide-level. Then followed submergence, which buried the great river channels and the eastern edge of the coastal plain under tidewater and ushered in the present epoch.

THE DISPLACEMENT.

Course and Relations.—In studying the physiography of the head of Chesapeake bay McGee found evidence of the existence of a longitudinal displacement, which has depressed the level of the coastal plain considerably below that of the Piedmont region. The line of dislocation is marked by steep slopes along the margin of the Piedmont region, and was traced for several miles along the side of the head of the bay. It was suggested that this displacement probably extended from the Hudson river region southward along the border of the coastal plain, following down the Anacostia river east of Washington, and finally merging into a flexure in the Acquia creek region.

I have found, however, in studying the border zone between the Piedmont and coastal plain regions, that there is a line of dislocation some miles west of this course which is practically continuous from at least as far north as Newark, Delaware, to south of Fredericksburg, and has had a more complicated history than was at first supposed. The details of this history are not as yet fully worked out, and at this time it is possible to give only a brief general account of the more prominent consequences of the displacement.

The dislocation traverses the crystalline rocks and Newark, Potomac, Pamunkey, Chesapeake (?), Appomattox and Columbia formations, but the Potomac, Appomattox and adjoining crystallines are the formations in which the relations of the actual fault line are mostly exhibited. The displacement, as a whole, appears to be continuous throughout, but its amount varies, and in some areas the effects of dislocation become indistinct through diminution in amount, distribution through a zone, or merging into a flexure.

South of Baltimore, near Relay, the relations of the dislocation are particularly well exhibited, and the amount of displacement is fully 250 feet. The relations in this region are shown in section 2, figure 1, page 435. At the exposures in this vicinity, clay caps the bare steep slope of the crystalline fault scarp, and at the base, on the downthrown block, a greater or less thickness of clay abuts against it. This relationship is general for some miles south from Baltimore, and west of the city it is exhibited in diminished amount near Loudon Park cemetery, beyond which evidence of the dislocation is lost for some distance.

Northeastward from Baltimore the effects of the dislocation soon become prominent, and its line is marked by a steep scarp in the crystallines, which extends with varying heights and degrees of distinctness through northern Maryland into Delaware and beyond. Usually the Potomac and Appomattox materials are either eroded back from the summit of the scarp for some distance or entirely removed, and in the larger depressions the drainage has cut through a greater or less thickness of Potomac materials on the downthrown side, exposing the crystalline floor for a mile or two eastward.

At Washington a dislocation traverses the thin outlying feather edges of the Potomac formation and its Appomattox cap just west of Georgetown, and crosses the Potomac river just below the fall line. Thence through northern Virginia the dislocation gives rise to a prominent scarp on each divide, which is more or less continuous and distinct for many miles. At first it dislocates the Appomattox, together with, at some points, a feather edge of the Potomac; but in the region between Occoquan and Fredericksburg its amount increases greatly and it traverses a considerable thickness of the Potomac, at one point the western edge of the Pamunkey, and in most cases the Appomattox, with a throw of from 150 to 300 feet, as shown in sections 3 and 4, figure 1 (page 435).

This dislocation crosses the Rappahannock a mile above Fredericksburg, and its relations are there well exposed. It has not been definitely traced southward, but there is evidence of displacement near Richmond and Petersburg, which may be along a continuation of this same dislocation.

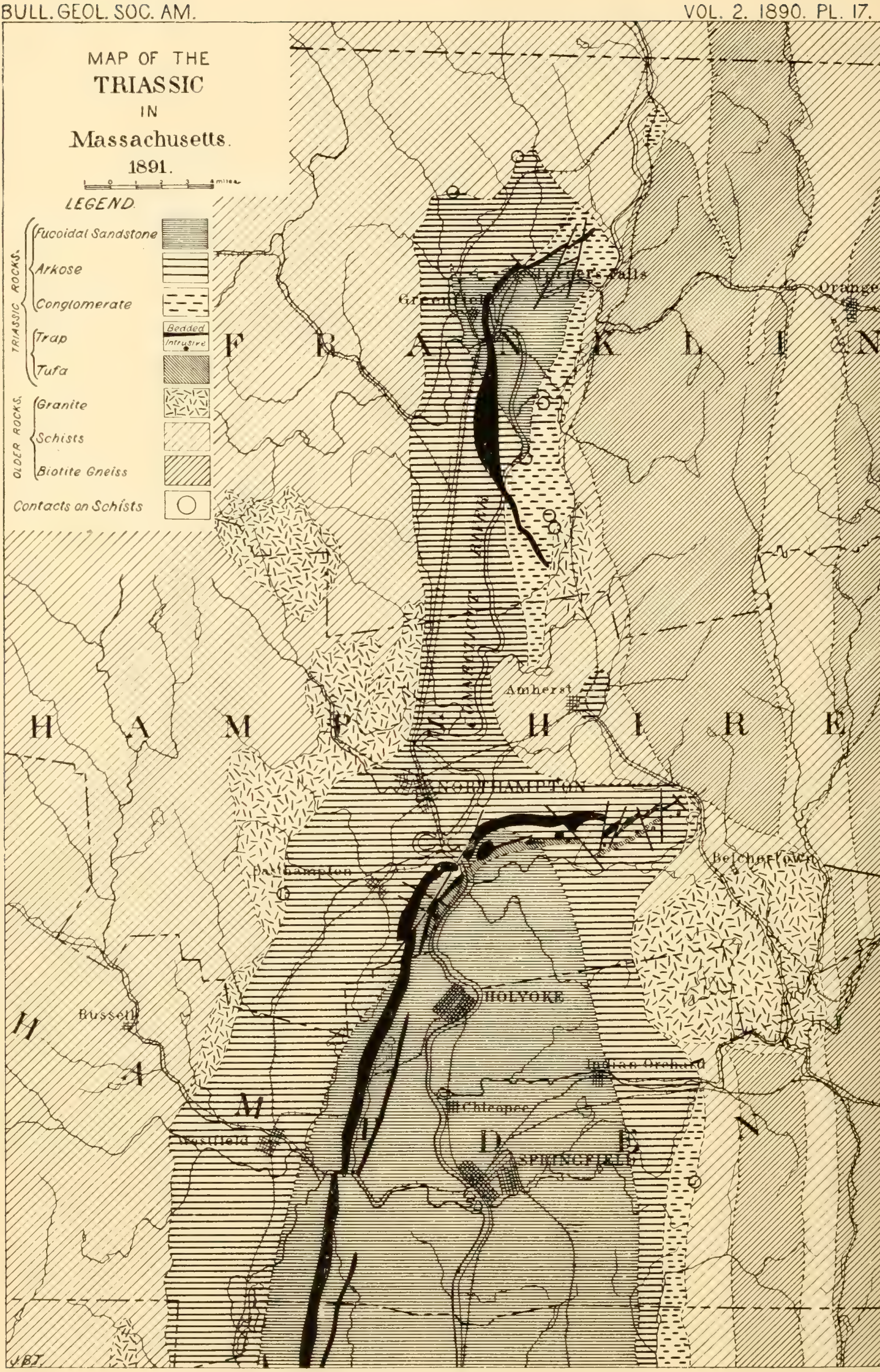
Date.—The date of the displacement is in the main post-Appomattox, but there is some evidence that a series of local movements occurred before the epoch of Appomattox deposition. The greater part of the displacement was effected between Appomattox and Columbia times, apparently just before Columbia deposition. In the gorge of the Potomac river a narrow Columbia terrace extends for some miles above the line of dislocation, and the relative altitude of this terrace and the Columbia terraces eastward about Washington suggests some displacement in post-Columbia or intra-Columbia times. Since Appomattox times the scarp west of the displacement has been cut down in the drainage depressions, and in the larger streams has given rise to a special series of gradually receding rapids, of which the Great falls of the Potomac is an example.

Geologic History.

The principal events in the history of the coastal plain region, so far as now determined, are as follows:

1. Irregular surface and shore line of crystalline rocks, overlapped in certain areas by the Newark formation.
2. Submergence and deposition of the Potomac formation.
3. Emergence; degradation of the Potomac to an unknown extent.
4. Submergence; deposition of Cretaceous greensand series, including the Severn deposits.
5. Emergence; degradation of the Cretaceous and, toward the south, of the Potomac to an unknown extent.
6. Submergence; deposition of the Pamunkey formation on the Severn and Potomac surfaces.
7. Emergence; degradation of the Pamunkey and its shores westward.
8. Submergence; deposition of the Chesapeake formation.
9. Emergence; terracing and cutting of basins now occupied by the estuaries.
10. Submergence; deposition of the Appomattox formation, overlapping far upon the Piedmont region.
11. Emergence; tilting northward; subaërial development of the outlines of the present topographic configuration; widespread lateral degradation, increasing in amount northward; displacement along the great dislocation.
12. Submergence and deposition of the Columbia materials.
13. Emergence somewhat greater in amount than the submergence of 12; land tilted gently southward; excavation of channels in the Columbia and underlying beds in greater part to somewhat below present tide-level.
14. Slight submergence; marsh, silt and shore formations of recent age.

Of course, this list really comprises only the headings of chapters, which record a vast number of minor events and complications of geologic history, only to be ravelled by a great amount of careful study. At present it would be premature to discuss the events in greater detail, for the data at hand are incomplete and in large part unsatisfactory. In the continuation of the investigation, however, it is hoped that there may be attained a full elucidation of geologic history and relations in the coastal plain region.


MAP OF THE
TRIASSIC
IN
Massachusetts.
1891.
LEGEND.
TRIASSIC ROCKS.
Fucoidal Sandstone
Arkose
Conglomerate
Trap
Bedded
Intrusive
Tufa
OLDER ROCKS.
Granite
Schists
Biotite Gneiss
Contacts on Schists
FRANKLIN
HAMPSHIRE
HAMPDEN
Greenfield
Orange
Amherst
NORTHAMPTON
Belchertown
HOLYOKE
Russell
Indian Orchard
Chicopee
Westfield
SPRINGFIELD
J.B.T.

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ON THE TRIASSIC OF MASSACHUSETTS.

BY BENJAMIN K. EMERSON.

(*Read before the Society December* 31, 1890.)

CONTENTS.

INTRODUCTION.

Difficulties in the Way of Correlation.—The sudden and irregular transitions from the coarsest to the finest sediments, the derivation of many of the coarse beds from rocks not known in place among the crystallines of the surrounding region, and the prevailing easterly dips have made the correlation and explanation of the Triassic deposits of Massachusetts somewhat uncertain.

They have been explained as in whole or in part of glacial origin; and, by assuming the prevalent easterly dips to represent the true status, a vertical column has been constructed having the following members, beginning with the lowest: (1) Coarse sandstones below the trap; (2) Trap; (3) Sandstones above the trap; (4) The coarse conglomerates of Mount Toby. Thus very improbable thicknesses have been assigned to the series.

The Problem attacked in a new Way.—As my knowledge of the crystalline rocks of the adjoining country became so intimate that I had no longer any hope of finding there the peculiar rocks found among the pebbles of the conglomerates; as my attention was attracted anew to the subject by the fruitful discussions of Professor Davis concerning monoclinal faulting in the adjoining region in Connecticut; and as I had gained all the information I could from the trap sheets and the tufa bed (the only persistent and easily traced members of the series), I determined to attack the problem from another side, and, for the time disregarding dip and strike, to map the area, making such lithological distinctions as my previous knowledge indicated as most promising, especially in respect to persistence and distinguishability in the field.

Lithological Distinctions.—In carrying out my plan of work I chose six distinctions, to which I have given names, as follows:

1. The Sugarloaf arkose, or the felspathic sandstone and conglomerate;
2. The Mount Toby conglomerate, or the coarse schist and quartzite conglomerate;
3. The Longmeadow brownstone, or the fucoidal sandstone;
4. The Chicopee shale, or the calcareous red shale;
5. The Granby tufa, or the diabase tufa;
6. The Holyoke and Deerfield diabase beds.

The third and fourth of these distinctions proved less important than the others, and they are merged on the map.

Structural Relations.—The Triassic basin is a "graben"—a fault-bounded block sunk, at least in places, more than three thousand feet below sea-level, and more than four thousand feet below the plateaus on either side, with the newest pre-Triassic rocks of the region in its bottom.

On the western bordering plateau, measuring from the southern line of the state, coarse muscovitic granites are largely developed half across the state, and these are followed by coarse dark mica-schists, dark phyllites and the Bernardston series of Devonian quartzites, and mica and hornblende schists, in order as one proceeds to the Vermont line.

Currents indicated by the Deposits.

The Arkose.—Beginning at the southwestern corner of the Triassic basin, strong northward-moving currents have spread the coarse felspathic and muscovitic material, rudely comminuted and sorted and little rounded (quite coarsely conglomeratic near the shore, and still a very coarse sandstone several miles from shore), all along against the granites in the southern half the state, from which this material was derived, and have carried the same northward for twenty miles, past the shores of dark schists, quartzites and phyllites, and at the very northern apex, in the village of Bernardston, the crumbling arkose bleaches white from the abundance of the half-kaolinized feldspar. The arkose is in great mass; artesian wells 700 to 3,000 feet deep fail to reach its bottom.

Where the exact boundary can be seen, as south of the Bernardston limestone bed and at Leyden glen, a local conglomerate of quartz pebbles from the schists rests on the crystalline rock; but is only a few inches thick, and in many places large, well rounded pebbles of vein quartz from the schists appear in the arkose, carried out from the shore by the undertow and mingled with the granitic material brought from farther southward.

The Conglomerate.—A current of still greater force swept southward along the eastern border of the valley, carrying much coarse material derived from the peculiar schists which form the eastern plateau in Northfield, and forming a conglomerate with blocks often two to four feet long and with everything less than two inches long washed out of it.

The boundary between these two deposits, the arkose and the coarse conglomerate, is a narrow band rather than a line, but can be followed very sharply across Gill. It is the interlocking boundary of two contemporaneous deposits shifted in vertical section from east to west as the two opposing currents varied in strength.

Buried Peaks.—On following the coarse Mount Toby conglomerate further southward into the mountain from which its name has been taken, a series of very gratifying and surprising discoveries was made, which at once cleared up the question of the origin of the problematical rocks and strengthened the proof of the current system here being explained.

At Whitmore's ferry, on the Connecticut at the northern line of Sunderland, fishes have long been found in the black Triassic shales. These occur at the water's edge and dip eastward beneath Mount Toby, the place being the western foot of the mountain in the center of the Triassic basin. In the bluff just above, and in apparent conformity, appear fine-grained black rocks, which are made difficult of access by the waters of a brook coming down over them in a pretty waterfall.

Examining these rocks at the top of the bluff and just south of the mill-pond, on the edge of the latter, I was surprised to find three *rôches moutonées* of quartzite and hornblende schist rising in the midst of the conglomerate, where I should have said the Triassic must be at least a thousand feet thick. The ice-smoothed surface showed clearly that the schist was much jointed; a little south the blocks were slightly moved, then a little red sand was filtered into the fissures, and then the blocks were gradually moved out of place so that they could be only partly refitted, and soon foreign material (granite and vein quartz) appeared as pebbles among the other constituents. This was effected in three rods of fine ice-polished surface, and fragments from these peculiar quartzites and hornblende schists appeared in the conglomerate in abundance for miles southward.

A similar outcrop was found later on the northern spur of the high hill that rises west of Montague. Here a peculiar porphyritic granite appears in the midst of the conglomerate and repeats all the conditions described above, and was another of the unknown rocks of the conglomerates. This reinforced the conclusions here advanced as to the current system and showed the local origin of the conglomerate and the improbability of its glacial origin. The outcrops form also beautiful sections of transition from the Triassic into the disintegrated crystalline rocks in strong contrast to the usual sections, where quartz conglomerates, concentrated from the wear of a large quantity of rock and often transported a considerable distance, form distinctly unconformable contacts. They indicate that the disintegration of the crystallines was so deep and the transgression of the water so rapid that this area was not eroded down to the firm rock. I think, from all the circumstances, that this erosion was performed by submarine currents and not by strictly shore action.

Further, if subjected to slight metamorphism, such contacts would be wholly obliterated. Thus in several ways they throw light on the difficult contacts among the altered rocks of the Berkshire hills. This furnishes an illustration of the effects of secular disintegration conjoined with rapid transgression, as discussed by Professor Pumpelly in another paper in this volume.*

The conglomerate materials found about Mount Toby are carried down the eastern side of the valley for several miles beyond where schists form the border of the basin, and across the eastern area of the pegmatites; but these gradually supply their place, and the resulting arkose is carried down the eastern side of the valley and, in the center of the state, blends with that already described on the west.

The Sandstone and Shale.—At Turner's Falls, and again in the southern third of the state, the basin widens, and, as the coarse shoreward beds retain their width, a central area of sandstones—the Longmeadow brownstone—was accumulated in the quieter situation; while in the southern area, which is also the more extensive, the bay widened so greatly that in its middle fine silts and marls gathered, forming the Chicopee shale.

While the two first (shoreward) rocks, the arkose and the conglomerate, are marked by coarse rippling and cross-bedding (directed northward on the western side), the central rocks are filled with problematical tubular markings (sand tubes, one-eighth inch to one-half inch in diameter and one inch to eight inches long, which I have called fucoids, but which my paleobotanical friends hesitate to acknowledge as plant remains), "bird tracks," mud cracks, rain drops, curdled drying surfaces, and every indication of frequent immersion and emersion.

Conditions of Deposition.

I believe the region to have been a narrow bay, with tides of the Bay of Fundy type (reinforced on the east by the prevalent strong westerly winds),

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* Pp. 209–224.

which swept up the western and down the eastern side and left the center of broad shallow mud flats at a considerably higher level than the shoreward portion, so that they alone were regularly abandoned by the water at low tide. It follows from all this that the deposits named above were contemporaneous, and this is neatly shown by the trap sheets. The Holyoke sheet came up through a fissure in the shale and flowed westward out over the brownstone and the arkose; but for miles, while resting on these latter rocks, its basal portion is full of fragments of shale and limestone, picked up while flowing over the mud beds. The Deerfield bed rests at its northern and southern ends on the Mount Toby conglomerate, in its middle upon the sandstones and shales, and beneath the lookout tower east of Greenfield it plainly flowed with a thickened crust, which unrolled before it and became deeply fissured as it came to lie beneath the thick mass, so that by hydraulic pressure the red mud was forced five or six feet up into the fissures of the porous trap from below; while, immediately above, the same fissures are filled for another six feet by an aphanitic trap, which oozed down from the still melted mass above, cementing the porous blocks. The great thickening of the Holyoke bed in its western portion, Mount Toby, may be due to its flowing westward into the deeper channel.

The Monoclinal Faulting.

Having made out in general the distribution of the different varieties distinguished above, the boundaries were studied with more care, with fuller consideration of dip and strike and with special reference to the question of monoclinal faulting. The only part of the area suitable by the character of the outcrops and the direction of the boundaries was the northern portion of the Turner's Falls sandstone area, where the boundary runs east and west; and northward of and parallel to it is the outcrop of a trap sheet to repeat any faults which might be found in it. This boundary was, in fact, sharply serrate, and at least four nearly parallel north-and-south faults are indicated, three of them also cutting the trap, all with upthrow on the east of the fault.

Description of the Map.

On the western side of the map (plate 17), the large number of extensive granite areas will be noted near the valley border in the southern half of the state; and within these limits a vast number of smaller granite dikes occur, which are wanting further northward and westward. The arkose, above four miles wide, adjoins and was derived from this granite from Southwick past Northampton, where it was bored into to a depth of 3,000 feet, and where, at "the oxbow," it is a fine, feldspathic conglomerate. This arkose then continues toward the north end of the basin, skirting an area on the west wholly free from feldspathic rocks. On the eastern side the Northfield schists appear in the conglomerate in Northfield and down past Miller's Falls; that is, southward beyond their place of occurrence in the shoreward hills.

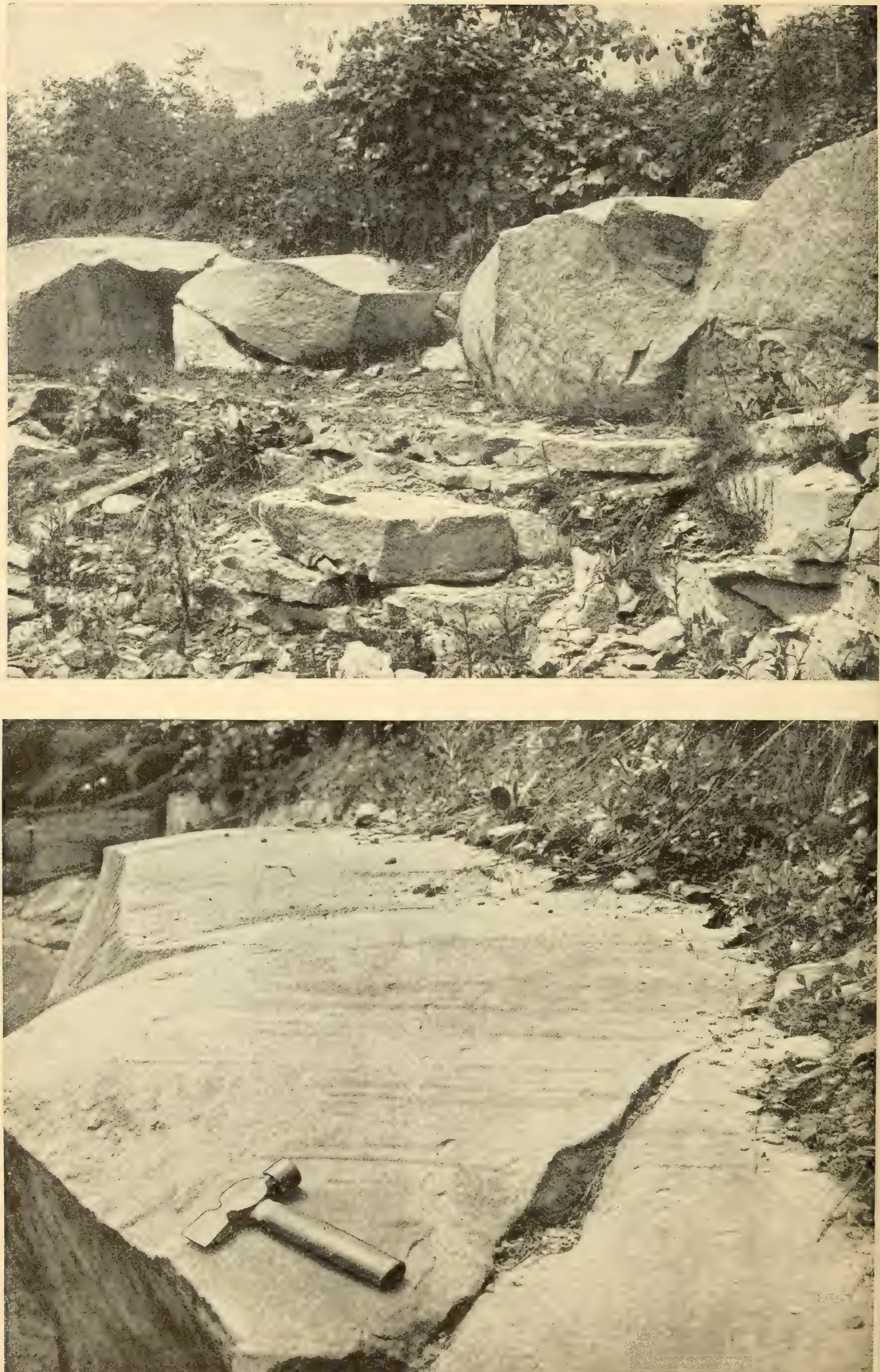
Then the porphyritic granite projects through the conglomerate, as represented on the map at the center of the small circle drawn just south of the southernmost point of the railway between Miller's Falls and Greenfield. Its contributions are trailed off southward a long way, as are those of the Whitmore's Ferry schists represented by the center of the circle next south on the river. The area of schist around Amherst is crowded with granite veins, and the schist and quartzite conglomerate is carried southward over this for about four miles before the feldspathic material becomes predominant, and an arkose results which is then carried southward, blending for a distance with the arkose from the western side.

All the boundaries between the three classes of sediments here discussed are boundaries between practically contemporaneous deposits, and so are bands rather than lines; and, with the thick coating of Pleistocene beds, they can be traced only approximately.

The contemporaneous trap sheets and the tufa beds rest on all the three kinds of rock at once, showing that they are facies of a single formation.

A similar line might have been drawn, starting at Holyoke and running parallel with the trap ridge on the west, and through Chicopee Falls and Springfield on the east to the southern line of the state, about four miles east of the Connecticut river, which should include the black-and-red shales with concretionary limestones.

Although foreign to the subject of this paper, I may call attention to the interesting series of volcanic plugs which run parallel to and about a mile south of the greatly faulted Holyoke trap bed.



GLACIATED SURFACES NEAR THE DRIFT MARGIN, ROCK POINT, PA.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 457-464, PL. 18 APRIL 27, 1891

GLACIAL GROOVES AT THE SOUTHERN MARGIN OF THE DRIFT.

BY P. MAX FOSHAY AND RICHARD R. HICE.

(*Read before the Society December* 30, 1890.)

CONTENTS.

Introductory Note.

In a preliminary paper in the American Naturalist for September, 1890,* there was a brief sketch of the phenomena herein described in greater detail and illustrated by photographs reproduced mechanically (plate 18). These phenomena, consisting of grooves, striæ and potholes, were discovered by the writers in the course of a survey of the Pleistocene formations of the valley of the Beaver river. The description of the particular phenomena in which we are interested is here prefaced by a short account of some of the features and the geological history of this portion of western Pennsylvania.

Physiography of the Beaver Valley.

The Beaver river is formed at Lawrence Junction, on the Pittsburgh, Youngstown and Azhtabula railroad, by the confluence of Mahoning and Shenango rivers, and, after a course of about twenty-one miles in a southerly

* Vol. XXIV, p. 816.

direction, terminates by emptying into the Ohio river at Beaver. In its course it receives but one large tributary, the Connoquenessing, which enters it from the east at a point about thirteen miles from its mouth, and which ordinarily carries about one-fourth the volume of water of the Beaver above its point of meeting with the Connoquenessing. A more interesting region, for its extent, to the student of Pleistocene geology can hardly be found. Throughout its whole course the river flows in a valley deeply excavated in the rocks of the Lower Productive Coal Measures and the Conglomerate series (XII). For the first three miles of its course it lies wholly within the drift-covered region, as do its parent streams. In the next two or three miles it passes through the drift margin. The remainder of its course lies in the driftless region, though the Pleistocene terraces are well developed in many places along this latter portion.

In topography the valley consists of a base-level plain, a mile or more in width, bounded by slowly rising and rounded hills, and of a rock gorge, 200 yards in width, cut to a depth of about 350 feet in the floor of the upper and wider valley, as shown in figure 1. The base-level plain is 250 feet above

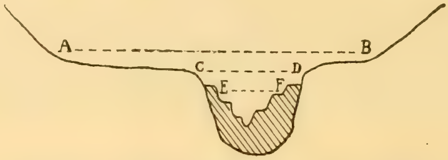


FIGURE 1.—*Ideal Cross-Section of Beaver Valley.*

A, B = Base-level plain; *C, D* = Rock gorge; *E, F* = Inner gorge; shaded portion represents drift material and Pleistocene terraces.

the river at its mouth and about 100 feet above water-level at Lawrence Junction, a difference of about 100 feet, while the level of the river has risen somewhat less than 100 feet, so that the plain slopes slightly to the northward. The plain is covered by a deposit of clay, sand and gravel, the first-mentioned member being most characteristic, with a maximum observed thickness of twenty feet. This deposit is older than the terminal moraine and the kames of the second glacial epoch, as it is found underlying a large kame at the mouth of the Connoquenessing. It probably represents the slack-water sediments of the continental depression accompanying the first glacial epoch—the Columbia period of McGee.

The rock gorge for the eleven miles between Wampum and Beaver Falls has almost perpendicular walls, and so forms a veritable cañon, the precipitous sides being due to the remarkable development of the Homewood sandstone, which forms the top member of the cañon walls as also of the Conglomerate series (XII) and is a very massive sandrock from 75 to 150 feet in thickness for the whole distance.

The gorge is completely filled with drift material for more than sixty feet of its depth at the river mouth, while at Lawrence Junction there is nearly or quite two hundred feet of such filling. One of the writers of this paper has elsewhere* presented facts to prove that in preglacial times the stream occupying this deep and now partially filled cañon flowed toward the north and was tributary to the Erian river of Spencer, which then occupied the central valley in the present basin of Lake Erie. Thus the Beaver river exhibits the phenomena of reversed drainage, and conforms to the system of reversed drainage worked out by Professor John F. Carll in the upper Allegheny region of Pennsylvania.

Wherever the distance between the walls of the rock gorge is sufficient to have preserved them from stream erosion, we find the Pleistocene terraces covering the walls to a greater or less height. They are best developed for the first two or three miles of the river's course above the terminal moraine; also on the parent streams for a considerable distance, and more especially for the last five miles of its course. The intervening portion is so narrowly inclosed that the terraces have for the most part been entirely removed by erosion, only fragments remaining.

The Glacial Phenomena.

Glacial Deposits.—In the vicinity of Wampum (five miles from the head of Beaver river and immediately across from Chewton, mentioned below) the terminal moraine has been described by Lewis and Wright† as crossing the river. From their report we extract the following description of the point of crossing:

"The Beaver river is crossed by the moraine at Chewton, eight miles south of Newcastle, and is here filled with immense accumulations of stratified drift several miles in length. Chewton stands upon a high and broad terrace more than 150 feet deep, which forms a level plain at its southern termination, but which develops northward into ridges and conical hills, inclosing large kettle-holes and having all the typical features of a glacial deposit. This conspicuous accumulation extends for nearly two miles up the river, and is heaped up into still higher knolls and ridges as the river is ascended. It passes into till upon the higher ground on each side of the river. While the water issuing from under the glacier in this river valley has stratified the materials of the moraine and, with the aid of ice, has heaped up the sand and gravel into the peculiar knolls and ridges so characteristic of a glacial region, no evidence appears that the glacier extended any tongue of ice down the river. There is no sign of drift deposits in the valley of the Beaver south of the moraine other than those formed by the action of water."

The terrace 150 feet in depth, mentioned in the above quotation as underlying the village of Chewton, is the old base-level plain (as is clearly seen

*P. M. Foshay, Am. Journ. Sci., vol. XL, 1890, p. 397.
† Report Z, Second Geol. Survey of Pennsylvania, by H. C. Lewis and G. F. Wright, 1884, p. 194.

from the other side of the river), having its escarpment mostly concealed by the Pleistocene terrace deposit; while the grooves and striæ described below show that the ice extended at least two miles below Chewton, provided land ice is the only agent capable of forming such grooves in solid rock.

At the mouth of the Connoquenessing, where is situated a summer resort and picnic grounds (Rock Point), the base-level plain of the Beaver is mostly on the western side of the river, and continues so for several miles in both directions. Toward the north the plain bears upon its surface a large L-shaped kame, a mile in length, which reaches down to a point about one-half mile above Rock Point. This kame is composed of stratified gravel and sand, and has a hummocky and irregular outline. Several kettle-holes are to be seen upon its surface. The direction of the long arm of the kame is north-and-south, or parallel to the valley of the base-level plain here, while the short arm lies nearly at right angles to the long one and runs eastward from it, but does not reach to the bluffs of the rock gorge. The kame rises to a height of 25 to 40 feet above the base-level plain, and is from 100 to 300 yards in width. It overlies the clayey deposit of the subjacent plain, as proved by excavations into the gravel which reached the clay below, a thickness of 11 feet of the latter being here noted.

On the base-level plain of the Connoquenessing, which is half a mile wide and typically developed for about four miles up that stream and half a mile back from Rock Point, there is another kame about 200 yards in length and 40 feet in greatest height. On its surface it bears a typical kettle-hole, and also another partly formed. The direction of this kame is approximately north-and-south, or at right angles to the Connoquenessing valley at this point. The Ellwood Short Line railroad cuts through the highest part of the kame, and the exposed section shows stratified sand and gravel with numerous bowlders up to one foot in diameter.

On the western side of the Beaver, just opposite the mouth of the Connoquenessing valley, but more than half a mile back from the rock gorge, there are two smaller kame-like deposits of gravel which abut against the western bounding hill of the base-level plain; also at Clinton, further southward, there is another good-sized kame-like deposit. All these lie on the base-level plane.

Potholes.—About half a mile above Rock Point, on the western bluff of the rock gorge of the Beaver, there are three quarries in the Homewood sandstone, the top member of the Conglomerate series (XII), which stratum here forms the rock floor of the base-level plain. In one (the most northerly) of these quarries the writers discovered a group of phenomena, which, from their position with reference to the glaciated region as generally delineated, are unique in the history of glacial geology. The quarries are worked by stripping off the gravel and clay from the surface of the rock, the gravel being derived from, or belonging to, the large L-shaped kame before mentioned, whose lower end lies about fifty yards west of the quarries.

The Newcastle and Beaver Valley branch of the Pittsburgh, Fort Wayne and Chicago railway runs along the bluff at an elevation here of 860 feet above tide, and about forty feet below the surface of the base-level plain, which is 180 feet above present river level.

With the most southerly of the three quarries we have here nothing to do. In the second, about fifty yards north, on the exposed rock surface, there are, or were, numerous potholes, mostly shattered by blasting, but several nearly perfect. The best example was 3 feet wide, 4 feet long, and 24 inches deep. Its steep side is toward the south, the other side being much eroded—this difference in the two sides being commonly observed in modern potholes. All the other potholes were seen to present their steep sides at their southern portion, not one exception being noted in the whole number examined.

Observations on modern potholes show that they always have their steep side up stream, the lower side being eroded by the water falling upon it from the upper side.

From these facts we conclude that the current that formed the potholes seen in this quarry must have flowed toward the north along the base-level plain. The question of the date of their formation will be referred to in another place.

Base-Level Remnants.—It is not alone on the evidence of the potholes, however, that we conclude the forming stream flowed toward the north. We referred above to the difference in absolute level of the base-level plain between the mouth of the Beaver and Lawrence Junction, the base-level plain sloping slightly to the northward. If, however, any allowance be made for the greater postglacial elevation to the northward, a correction must be made to restore the floor-level of the old valley in preglacial times. To the evidence shown by the base-level plain on the Beaver, we must add the fragments of what appears to be the same plain found both down the Ohio from the mouth of the Beaver, and up that river and its parent streams. The evidence of the Monongahela and Allegheny rivers seems to indicate that the "higher river terraces" of President Chamberlin, or old base-level plains of river erosion, fall with the present streams, but less rapidly.* Between Pittsburgh and the mouth of the Beaver several remnants are also found that indicate a general slope with the present stream. Passing down the Ohio as far as Steubenville, the remnants are frequently seen; few of them have, however, been examined. Opposite Steubenville, Professor Wright gives the elevation of the remnant as 285 feet above low-water mark of the Ohio,† which would be 940 feet above tide. The elevation of the terrace at

* Bulletin U. S. Geological Survey, no. 58, 1890, pp. 24–32.
† Ibid., p. 81.

Middletown, twelve miles below Pittsburgh, is 940 to 970 feet above tide, while the elevation of the same terrace as seen on the lower fifteen miles of the Beaver is from 890 to 920 feet above tide. These facts, meager as they are, tend to confirm the local evidence of the direction of the flow of the old river toward the north, and, if any allowance whatever is to be made for the postglacial elevation to the northward, seem to render any other conclusion impossible. This elevation has been placed beyond doubt by the work of Spencer, Gilbert and McGee, and renders it almost certain that this drainage was toward the north.

Ice Markings.—It is in the most northerly of the three Rock Point quarries that we find the phenomena of special interest. This quarry lies about fifty yards north of the one containing the potholes, and is similarly situated in reference to the rock gorge and railroad. Almost the whole surface of the rock exposed by stripping is more or less glaciated, the glaciation consisting of grooves, striæ, gouges, etc.

The Homewood sandstone, forming the cliffs of the gorge, is here a massive, coarse-grained rock, stained with iron, and has the characteristics which make the stone of that stratum so much desired for heavy foundation work in the upper Ohio valleys. It is hard and difficult to cut, and is not the rock to be easily striated and grooved by an ice-sheet. On the west, the hill bounding the old valley rises with unusual abruptness, and is capped with a stratum of hard, massive sandstone. The quarry has been but little worked, the surface which was stripped was small, and the grooves could be followed but a few feet on account of the overlying gravel of the kame. The face of the quarry is cut by the grooves and striæ at an angle of about 60°, the direction of the grooves being about southeast by south, or practically at right angles to the general direction of the glacial border as heretofore delineated.* The eroding ice must have crossed the old valley at an angle of nearly 45°, descending, from the bounding hill on the west to the point at which the grooves were seen, fully 250 feet in a distance of less than half a mile, and yet retaining sufficient eroding power to cut great grooves, the largest seen being about five feet in width and eighteen inches deep. The entire surface is striated in the direction of the grooves, and, considering the character of the rock, the striæ are well preserved. At the quarry immediately south of the grooves, where the potholes were seen, the surface is also striated in the same direction. The striæ at this point are not so well preserved, and probably were never so regular as they are at the grooves, for the sandstone is here almost a conglomerate, the pebbles being very numerous and reaching about half an inch in diameter. No indication of the ice having affected the edges of the potholes was seen; they are sharp as those now forming in the same and similar sandstones.

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* Lewis and Wright, loc. cit., p. 194.

Summary.

It will be seen that these grooves, with the accompanying striæ, lie two miles or more south of the drift margin,* as located by Lewis and Wright. All grooves of large size heretofore observed lie many miles back from the front of the drift, unless with the single exception (so far as known to the writers) of the groove on Table rock, at the Delaware water-gap, observed by Lewis and Wright,† which lies ten miles behind the moraine.

It may be said that these grooves do not lie south of the drift margin, for Lewis has described "the fringe," consisting of isolated or grouped erratics, as extending some miles in front of the moraine in this neighborhood. The fact remains, however, that the grooves are south of the terminal moraine, as mapped and described by Lewis and Wright. Whether the discovery of these phenomena indicates that the line of the moraine must be drawn further south in this locality, or that these grooves do really lie outside the terminal moraine, cannot at present be positively stated. It has been suggested that "the fringe" is the mark of the first glacial epoch, and that possibly the grooves may belong to that epoch.

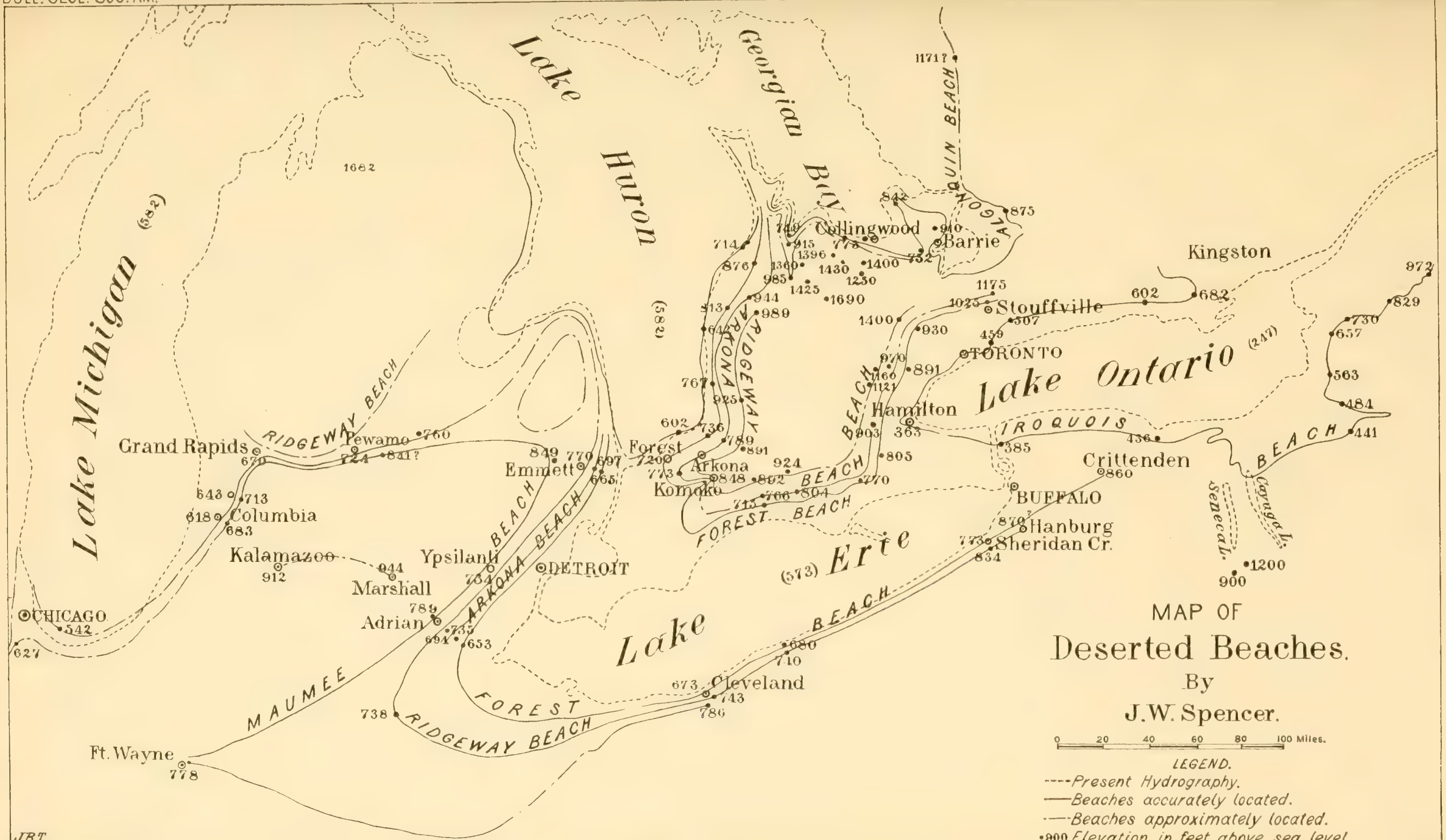
In the states of Ohio, Indiana, Illinois, Iowa and Nebraska, Chamberlin records striæ outside the terminal moraine and inside the drift margin, but, so far as the authors are aware, no large grooves have been reported as occurring in that interval.

Glacialists are pretty well agreed that the eroding power of the ice-sheet decreased toward the margin, where it was thinner and lighter. That grooves of the size of those here seen could be carved in the massive and resisting sandstone at the very margin of the ice-sheet seems well-nigh incredible. They lie at an angle of 45° to the direction of the old valley, of which the base-level plain forms the floor, and (looking in their reversed direction) are directed towards the western-bounding hill of the plain, which is here exceptionally abrupt and 250 feet in height, having cliffs of the harder strata along its front. That any conceivable ice-sheet could have descended such an abrupt slope and, after having advanced one-fourth to one-half a mile from its bottom, could make the observed grooves, is almost beyond belief. But the gouges and striæ within and accompanying the grooves make thus much certain, viz., that if the large channels so well seen on Kelly's island in Lake Erie and elsewhere are glacial grooves, the grooves described in this paper must also be so classed; for their similarity, amounting almost to identity of appearance, precludes any difference in origin.

* The nearest striæ reported are half a mile northwest of Newcastle; Loc. cit., p. 196.
† Loc. cit., pp. 85, 87.

The occurrence of potholes so near at hand complicates the question not a little, unless they be regarded as of different date of origin from the grooves. This seems to be the proper solution of the difficulty, as they indicate a north-flowing stream of no short duration, which could not have existed at the time the grooves were formed if that was done by an ice-sheet. As the potholes are immediately on the bluff of the rock gorge they must antedate the time of the formation of the gorge; for potholes are not formed on the brink of a 300-foot fall.

Beaver Falls, Pa., *November* 27, 1890.


Lake Michigan
(582)
1662
Lake Huron
(582)
Georgian Bay
Lake Erie
(573)
Lake Ontario
(247)
ALGONQUIN BEACH
RIDGEWAY BEACH
ARKONA BEACH
FOREST BEACH
MAUMEE
IROQUOIS BEACH
Kingston
Collingwood
Barrie
Stouffville
TORONTO
Hamilton
Forest
Arkona
Komoko
Crittenden
BUFFALO
Hanburg
Sheridan Cr.
Cleveland
DETROIT
Ypsilanti
Emmett
Marshall
Adrian
Kalamazoo
Columbia
Grand Rapids
Pewamo
CHICAGO
Ft. Wayne
Seneca L.
Cayuga L.
MAP OF
Deserted Beaches.
By
J.W. Spencer.
0 20 40 60 80 100 Miles.
LEGEND.
----Present Hydrography.
—Beaches accurately located.
-·-Beaches approximately located.
•900 Elevation in feet above sea level.
J.B.T.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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POST-PLEISTOCENE SUBSIDENCE VERSUS GLACIAL DAMS.

BY J. W. SPENCER, M. A., PH. D., F. G. S. (L. AND A.).

(*Read before the Society December* 29, 1890.)

CONTENTS.

General Continental Oscillations.

The growing interest in the evolution of the continent now calls for more accurate information than formerly, regarding the changes of level of land and sea in recent geological times. As these oscillations constituted some of the most important factors in the building of the Great Lakes, the study of their history has contributed to our knowledge of the changing relations of the continent and the sea.

From investigation of the submerged channels along the American coast, it has been shown that the continent was greatly elevated during some epoch or epochs intervening between the middle Miocene and the early Pleistocene periods. The elevation of the land was over 3,000 feet higher than now, and probably reached for a short time to over 5,000 feet.*

This elevated condition of the continent was followed by a depression of the land to far below the present altitude before the upward movement produced the now existing condition. There may have been more than one episode of elevation and depression; but the problem that we seek to solve is, *What was the maximum depression of the later Pleistocene times*, after the great beds of bowlder clay were formed; for the great elevation was shortly before that period?

Most geologists are ready to accept the high continental elevation, but there are differences of opinion respecting the amount of the subsidence.

* "The High Continental Elevation preceding the Pleistocene Period," by J. W. Spencer: Bull. Geol. Soc. Am., vol. I, 1889, pp. 65–70.

Although many have their own views upon this subject, few serious attempts have heen made to solve the problem uncolored by theory.

Evidence of recent regional Emergence.

We must seek for the evidence of the recent regional submergence in the remains of old shore-lines, such as beaches, terraces and sea-cliffs, now elevated and more or less disturbed and obliterated. Isolated remnants of beaches are not accepted by all as proof of a recent elevation, although found at high altitudes; but the beaches often contain the direct proof of their own elevation.

No better example is found than the Iroquois beach of the Ontario basin (shown in the map forming plate 19). This elevated shore-line is one of the youngest and best preserved in the Great Lake region. It rests upon the youngest till deposits. Since its formation it has been warped toward the northeast, and thus at Fine, north of the Adirondack mountains, it has been lifted over 600 feet above its own elevation at the head of Lake Ontario.* By another series of deformed shore-lines † it has been found that the Iroquois beach, at the head of the lake, has been lifted its own height above the sea. Hence, there is measured proof that the northern side of the Adirondacks has been lately elevated 1,000 feet, or that it was recently 1,000 feet lower than now. The initial point of this movement was near the head of Lake Michigan. Its maximum deformation occurs in the Adirondacks, and amounts to six feet per mile. Whether this rise continues to the Atlantic, or is transformed into a depression, or is faulted east of the mountains, remains to be determined. Only fragments need be looked for east of the region already explored, for the deserted shore has been traced into a region of broken mountains and wilderness.

Three hundred feet above the Iroquois plain, the Algonquin beach of the Huron basin is located.‡ In, it there is a similar deformation to that recorded in the Iroquois shore, but the initial point of the warping is beyond the head of Lake Michigan. With the deformation continuing toward the northeast, it would appear that the Laurentian mountains, north of the Great Lakes, were very much depressed during the Algonquin episode. The evidence of the formation of the Algonquin beach at sea-level has already been set forth.§

While there is great deformation recorded in the higher beaches, the surveys of these more broken geological records do not enable us to trace the

*"The Deformation of Iroquois Beach and Birth of Lake Ontario," by J. W. Spencer: Am. Journ. Sci., vol. XL, 1890, pp. 443–451.

† Ibid., p. 447.

‡ "Deformation of the Algonquin Beach and Birth of Lake Huron," by J. W. Spencer: Am. Journ. Sci., vol. XLI, 1891, pp. 12–21.

§ Ibid., p. 21.

shore-lines down to sea-level, as in the case of the Iroquois, and to nearly as perfect an extent in the Algonquin beach. Consequently, it is necessary to rely more fully upon the perfection of the structure of the deserted shores, and upon their positions, which would preclude their formation in confined lakes. Such conditions exist in Ontario, Michigan and Ohio, where extensive surveys have been made.

The lower of these shores, as the Ridgeway beach,* like those before named, were formed about bodies of water which opened only toward the north or east. But, ascending a little higher, the Maumee beach † occurs at altitudes which permitted its formation in water having free communication to the Ohio and Mississippi valleys by two depressions. Above this plain, there are higher gravel terraces and plains in Michigan and elsewhere, notably those between Kalamazoo and Marshall, with an elevation of a little more than 900 feet above the sea. From them the country falls away by steps toward the lakes; but the sheet of water which they once bounded had at least five connections with the drainage of the Mississippi system. Other higher terraces about more insular points are found in the same region, and farther north, in Michigan, they are said to occur on the summit of the highest land east of Grand Traverse bay, at 1,682 feet above tide.

In Ontario there are well-marked sea-cliffs carved out of the Niagara escarpment, as westward of Collingwood, especially at elevations of from 1,200 to 1,425 feet above tide. At various intervals between the plain of the Algonquin beach and the highest land of the peninsula (1,709 feet) there are also terrace and beach deposits moulded out of the drift. These remnants of shores are seen to within 20 feet of the highest point of land. The shore markings of these elevated lands are rendered more certain by the perfectly water-worn stones, and the extent of the beach and terrace structure. The sea-cliffs are too deeply graven to represent evanescent coast lines. But all of these records are interrupted, owing to the topography of the country, erosion by atmospheric agencies, and the recent Pleistocene deformation of the region.

Some of the positions of the surveyed coast lines are shown on the accompanying map; but for the detailed list of localities reference should be made to a paper on "High level shores in the region of the Great Lakes and their deformation." ‡

Again, at Dog lake, north of Lake Superior, Professor H. Y. Hind observed terraces at 1,425 feet above the sea.§

After allowing for all the measurable Pleistocene and recent deformation of the region, these elevated shores stand so high above every natural bar-

* "High Level Shores in the Region of the Great Lakes and their Deformation," by J. W. Spencer: Am. Journ. Sci., vol. XLI, 1891, p. 207.
† Ibid., p. 208.
‡ Loc. cit.
§ Assiniboine and Saskatchewan Expedition, 1859, p. 120.

rier, even far away toward the south as well as toward the north, that their occurrence demands explanation by other than local causes.

The highlands of the Ontario peninsula do not form nilometers reaching more than 1,700 feet above the sea; but in Potter county, in western Pennsylvania, 100 miles south of Lake Ontario, they develop a water-shed, rising to 2,680 feet above tide, with the Genesee river flowing northward to Lake Ontario; the Alleghany to the Ohio river; and Pine creek to the Susquehanna. About the highest flattened knob, of only a few acres in extent, and rising to within 20 feet of its summit, there is a low ridge of small, well water-worn gravel, nearly free from sand. Mr. Carvill Lewis speaks of it as kame-like, but its structure and form are not different from that which may be a true beach. This is emphasized by the occurrence of a zone of bowlders, forming a pavement a few feet below the gravel ridge—a feature so commonly developed in front of the deserted beaches of the lake region. This gravel ridge rests upon the highest point of, and at the very front of, the "terminal moraine" of Mr. Lewis, with the land declining to the north, as well as falling away to the south. These gravels form a superior deposit, resting upon till charged with angular shingle of local Carboniferous sandstone, and it is out of this material that the pebbles were formed.

There are similar superficial gravels on other, but of course inferior, knobs along the very foremost portions of the "terminal moraine;" but the drainage from these ridges is toward the north, and Mr. Lewis emphasized the fact that there is no drift in the small streams flowing toward the south.* The theoretical importance of this observation will be noted later.

Besides these highest of all the superficial gravels south of the Great Lakes, which I have examined, I have also visited the high terraces of the Genesee river, flowing northward from the deposits just described. Here several pauses in the receding waters are recorded. These are notable from an elevation of 1,900 feet downward. At this high altitude, the valley is nearly a mile wide and now 250 feet below the terrace. Our knowledge of these elevated and disconnected water deposits is yet very scanty, but certainly very suggestive when supplementing the surveys of the lower coast markings in the lake region.

A very interesting terrace remains in a valley three or four miles east of Horseheads, New York. The altitude of the terrace is 1,200 feet above tide, while the gravel-covered floor of the valley, at Horseheads, is only 900 feet. This last valley is over a mile wide, and it is that connecting the trough of Seneca lake with the Susquehanna valley.

Similar elevated terraces have been noted by Professor I. C. White along the upper Potomac valley facing the Atlantic, and along the adjacent tributaries of the Monongahela, which drain to the westward. These deposits

*"Terminal Moraine," by H. C. Lewis: Geol. Surv. of Pa., rept. Z, 1884, p. 143.

he notes up to an elevation of 1,675 feet above the sea, and 175 feet above the valley, along a tributary creek above St. George, West Virginia.*

At Nachvak, in Labrador, Dr. Robert Bell found beaches of great distinctness at 1,500 feet above the sea. Gravel and shingle terraces were also found to an estimated height of 2,000 feet.†

It has already been noted that the differential rise of the Iroquois beach, north of the Adirondack mountains, amounts to six feet per mile, and that it has there been lifted to a thousand feet. If this rise continues to the White mountains, then the equivalent of the Iroquois beach may be found among the terraces of the high valleys in that region. Its records may be preserved still further northeastward on the drift-covered sides of Mount Katahdin in Maine. Mount Desert, on the coast of Maine, rises to 1,500 feet,‡ and shows remnants of coast action to its summit; consequently it is too low to bear records of the Iroquois shore, unless the warping of the earth's crust becomes one of depression east of the Adirondacks.

In Ontario, some of the high shores, referred to above, occur at elevations of 1,000 feet above the Iroquois plain; therefore their equivalents in the northern Adirondacks should be looked for at about 2,000 feet above tide. The beaches reported in Vermont by Professor Hitchcock at or below 2,300 feet, doubtless correspond to some high shore-lines of the Ontario peninsula. Upon the same basis these high beaches should be looked for at 3,000 feet in the White mountains, and at greater elevations on Mount Katahdin in Maine.

If we regard the gravels of the highlands of Pennsylvania as having been formed at sea-level, then it would be reasonable to look for their counterparts in New Hampshire, at elevations of over 4,000 feet on Mount Washington and to the summit of the drift (4,400 feet) on Mount Katahdin. These conjectural estimates, based upon a possible uniformity, may aid in the correlation of the topographic features of the mountain region of the east with the lake region.

Interpretation of the Evidence.

So far as relates to the northeastern portion of the continent, our observations on Neptunian phenomena have now been epitomized. An explanation is necessary. That the pebbles of the beaches and the shore-lines were the results of wave or current action no one questions, but there are differences of opinion as to the conditions under which the waters moulded their coastlines. Were these deserted shores constructed at sea-level, or were they moulded in glacial lakes? These are the theoretical questions before us.

* "Rounded Bowlders at High Altitudes," by I. C. White: Am. Journ. Sci., vol. XXXIV, 1887, pp. 375–381.

† Rept. Geol. Surv. Can., 1885, DD, p. 8; and Bull. Geol. Soc. Am., vol. 1, 1889, p. 308.

‡ "Geology of Mount Desert," by N. S. Shaler: 9th Ann. Rept. U. S. Geol. Surv., 1888, p. 993.

The difficulties which the sea-level theory present to some minds may be stated as: (1) a great regional depression of the continent; (2) the absence of absolute continuity of the beaches; (3) the absence of marine organisms in the beaches; and (4) the personal equation of theoretical views. On the other hand, the theory of glacial dams presents such obstacles that their value will be considered at length.

The idea of the hydrostatic stability of the continents must not be too strongly relied upon, for the evidence adduced, which shows that the continent lately stood 3,000 or temporarily even 6,000 feet higher than now, appears conclusive. Such mobility of the earth's crust being established, there appears no reason why the terrestrial pendulum could not have moved equally in the opposite direction, and carried down the highlands of Pennsylvania to nearly 3,000 feet, or those of New England to twice this depth. The objections to such subsidence could only be based upon its magnitude, which observations must settle.

The absence of the continuity of the shore-markings is an objection only to a limited extent. Part of the reported absence arises from the imperfection in the explorations, owing to their changing character; to the local non-formation of beaches as described in a previous paper;* to the failure of identification of separated points, owing to subsequent terrestrial deformation; and to the interruptions occasioned by topographic features and subsequent obliteration by erosion. All of these difficulties are greatest in the higher regions, for there the beaches must be looked for among islands and detached mountain knobs.

The absence of marine remains seems perhaps the greatest obstacle to the acceptance of a sea-level formation of the beaches, as marine organisms are found only up to 520 feet.† But the Pleistocene gravels occur in Georgia and Alabama, in positions facing the sea, at altitudes of 700 or 800 feet, and higher up the greater valleys at 1,500 feet,‡ without containing any marine remains. Even where marine Pleistocene beaches occur on the coast of Norway there are very few localities where shells are found. How many of the older geological formations are unfossiliferous? How many of those ancient beach deposits, now represented by conglomerates, porous sandstones, and indeed many clays, are entirely barren? Under such conditions have we a right to pronounce judgment on the freshness of waters based on the absence of aqueous organic remains? This question will be referred to again in considering the glacial dam theory.

As to the personal equation, it ought not to pass beyond the limit of conservatism, but it is quite proper that it should be considered; for, as Pro-

*Ancient Shores, Bowlder Pavements and High-Level Gravel Deposits in the Region of the Great Lakes, by J. W. Spencer: Bull. Geol. Soc. Am., vol. 1, 1889, p. 77.

†At Montreal.

‡On the upper Etowah river of Georgia.

fessor Geikie has said, "when controversy ceases the interest in the investigation declines."

Glacial Dams Considered.

Glacial lakes are of two kinds: those whose waters are retained by morainic barriers; and others sustained by ice barriers alone.

The former class is represented in several valleys in the Alps, where lateral glaciers enter and cross greater valleys; sometimes the glacier carries its lateral moraine across the valley and builds a more or less permanent earth dam. Such lakes remain long after the glacier has melted away, and even when drained show evidence of their origin. A consideration of this class of glacial lakes does not enter into the subject of this paper.

In Switzerland, Greenland and Alaska other glacial dams are now well known. These are retained by the ice alone. When glaciers, free from morainic materials, descend lateral valleys and cross other valleys, they do not obstruct the rivers, for they continue to flow beneath the ice. However, there are many places where glacial lakes occur between the ice and the sides of the valleys: especially is this the case where two glaciers meet at the end of a mountain spur, like Lac Tacul in Switzerland. Small glacial lakes, like the Marjelen see, sometimes occur where lateral valleys unite with the glacier-filled channels. All modern glacial lakes are of small size. One of the largest lakes described in Greenland is not over three or four miles long and a mile wide. Such lakes, when they exist above sea-level, are evanescent. Mr. H. Topham described some glacial lakes of Alaska which discharge by a tunnel, eight miles long, under 500 feet of ice. Mr. I. C. Russell makes similar reports. The outflowing waters enlarge the tunnels, thereby draining the lakes; but the ice roofs fall in, and by the accumulation of ice blocks the tunnel becomes temporarily obstructed, causing the water of the lakes to rise. In the very nature of the case, large lakes could not be expected, for the conditions which would permit their formation would cause the glaciers to recede. Especially would this be the case if the glaciers were hundreds of feet above the sea, with rivers draining beneath or through them. It would be difficult to conceive how any water-level could be maintained long enough to permit the waves to carve out terraces and sea-cliffs. With glaciers coming down into the sea, it is easy to understand how bays and inlets could be obstructed by the ice so as to allow the water to be freshened. In such lakes the water-level could be maintained long enough to leave inscriptions in the form of terraces and beaches.

Such is a brief account of the natural history of glacial dams. It has been said that the easiest explanation of the theory of our Great Lakes is by regarding them as formerly great glacial dams: so it was thought ten years ago that the least troublesome hypothesis of the origin of the Great Lake basins was by their excavation by glaciers; but the writer, going into a field of investigation almost sealed by prejudgment, has shown that glaciers did not scoop out the basins, and has otherwise found satisfactory explanation of their origin * without invoking the necessity of ice being converted into rock-diggers. So, also, the evidence of glacial dams has not been found, so far as my investigations have extended.

Let us examine how the glacial-dam theory applies to the shore-lines already described.

The physical features of the Ontario basin are the most favorable for the constructions of a great lake retained by glacial dams. As proved by its deformation, the Iroquois beach was formed at sea-level. If this proof of the altitude of its birth-place did not exist, the evidence of its elevation would be obtained from a consideration of the ability of glaciers to close the St. Lawrence valley to the northeast. Such a barrier would have been from 60 to 100 miles wide and from 800 to 1,300 feet deep (below surface of water), according to location. Yet the drainage of the then expanded lake, over 300 miles long (so far as surveyed) and 100 miles or more in width, was against, into, or under the supposed glaciers, except to a limited extent in its earliest stages, when a partial overflow was by the Mohawk valley. Had the lake been above sea-level, a river as large as the St. Lawrence would soon have eaten its way through the ice and lowered the lake, for in that direction alone it had to flow; consequently, it appears that the great cut terraces and beaches, requiring centuries or millenniums of time, could not have been formed except at sea-level.

If the Algonquin beach of the upper lakes were formed in a glacial lake, then the ice barrier in the region of Lake Nipissing would have reached 600 or 700 feet beneath the surface of the water. The drainage must have been under the ice, and have amounted to a discharge equal to that of the modern Detroit river, as the discharge of Lake Superior, Lake Michigan and Lake Huron basins would have been thus borne seaward, descending 300 feet to the level of the Iroquois water. Under such conditions, the question may be asked, How could the lake surface be retained long enough at any level to carve out the deeply graven water lines and terrace plains of the Algonquin beach, in place of the discharging waters melting away the icy barriers, which were supposed to have been the means of retaining the lake 300 feet above the level of the Iroquois waters?

We now rise to the shores which bounded the Warren water. These I have explored from Lake Michigan to New York, and to northeast of Toronto, upon the Ontario peninsula. Upon the glacial-dam theory, this sheet

* "Origin of the Basins of the Great Lakes of America," by J. W. Spencer: Quart. Journ. Geol. Soc., vol. XLVI, 1890, p. 523.

of water would need a barrier to the north as well as to the east. The drainage of the lake, at all stages from the Ridgeway beach downward, was to the northeast, and beneath a greater mass of ice than in the case of the Algonquin or the Iroquois water; but above the Ridgeway beach,* at the Maumee level,† there were outlets across Ohio and Illinois, if a lake it were. The difficulties are increasing.

The shore markings occurring at Kalamazoo, at about 900 feet above tide, represent a sheet of water having at least five outlets across Ohio and Illinois. Again, the sea-cliffs of the Ontario peninsula, at from 1,200 to 1,425 feet and more, and the beaches now found up to 1,689 feet, would demand great dams toward the south and west as well as toward the north. But such dams could scarcely have existed with open waters carving out sea-cliffs and terraces on the high peninsula of Ontario, and also leaving records 200 miles southward. It should be noted that gravel deposits of the so-called kame and osar structures occur at all high levels; but of these I do not take cognizance.

The drainage of the high country, such as the Genesee valley, with terraces up to 1,900 feet or more, and of the "terminal moraine," up to 2,680 feet, was toward the north without obstruction.

Ascending now to Potter county, we find the gravel ridge at 2,660 feet, on the very edge of the highest knob of the "terminal moraine." This high point could not have stood out of the ice as a Greenland "nunatak," with a lake around it, for it is at the margin of the drift, and glaciers do not deposit their terminal detritus within the ice, but at their very margins. It seems impossible to conceive a glacial mass retaining a lake about this flattened knob, even if the country were submerged to almost sea-level. There are other similar deposits on adjacent summits. Again, had a glacier existed on the top or on the southern side of this "morainic" ridge, which is a water-shed, its melting ice must have carried great quantities of drift into the valleys toward the south, which neither Mr. Lewis nor I have seen. But the drainage was toward the north, into the hypothetical glacier, which, if it permitted sub-glacial drainage, could scarcely have formed lakes.

Conclusions.

Under these conditions, fairly stated I think, whether is it easier to accept a great subsidence of the continent, to nearly 2,700 feet in western Pennsylvania, or account for the phenomena by glacial dams formed on land vastly lower toward the north? Indeed, the great deformation of the lake regions

* "High Level Shores in the Region of the Great Lakes and their Deformation," by J.W. Spencer: Am. Journ. Sci., vol. XLI, 1891, p. 207.

† Ibid., p. 208.

had scarcely begun, and, consequently, even the modern highlands north of the Great Lakes were then very much lower than now, when compared with the region to the south. I cannot hesitate forming a conclusion that the evidence is in favor of a late continental subsidence rather than in favor of glacial lakes hundreds of miles long and broad, like nothing ever seen, and which could not answer the requirements.

The difficulty in accepting the subsidence without the occurrence of marine shells has in part been pointed out. But their absence in the lower beaches may be accounted for, in part, by the sheets of water being more or less cut off from the sea and receiving great quantities of fresh water. This, however, will not explain their absence on the higher beaches. The varying climatic conditions of the water and the changes of level destroying the life, too rapid to allow of remigration, may in part account for the absence of organisms in the seashore lines.

The record of subsidence deciphered in the high shore-lines of the lake region is supported by the observations of Dr. G. M. Dawson, Mr. R. G. McConnell and others, on the monuments rising above the great plains of northwestern Canada, and on the mountains between there and the Pacific coast. Dr. Dawson* finds gravel terraces upon the high sides of the Rocky Mountains, facing the east, in position showing their origin not to have been river terraces.

From extensive observations Dr. Dawson concludes that the Pleistocene submergences amounted to 4,000 or 5,000 feet in the region of the international boundary (the 49th parallel), while in Alaska it did not exceed 2,500 or 3,000 feet. He also postulates two episodes of submergence, the latter being less extensive than the former. Further, he regards the elevation and subsidence of the great plains and western mountains as alternating, and that the drift material of the plains was deposited at sea-level.

Mr. R. G. McConnell informs us that on Cypress hills, with an altitude of 4,800 feet, the drift does not rise above 4,400 feet. One hundred and fifty miles northwestward, the drift is not found above 3,400 feet on Hand hills (Tyrrell); but south of Cypress hills, near the 49th parallel, the drift occurs up to 4,660 feet on Three Buttes (Dawson). From these observations Mr. McConnell shows a differential level of 7.2 feet per mile, the elevation being greater nearer the 49th parallel.

In the east, the history of the changes has not been fully deciphered. Erratics occur on top of Mount Washington to 6,300 feet, while on Mount Katahdin, in Maine, they occur only to 4,400 feet (Upham). Conforming with Dr. Dawson's views, as applied to the west, we have a greater rise in the White mountains than eastward. The altitude of beach formation on

*"Later Physiographical Geology of the Rocky Mountain Region in Canada, with Special Reference to Changes in Elevation, and the History of the Glacial Period:" Trans. Roy. Soc. Can., vol. VIII, sec. IV, 1890, pp. 3-74, pls. I-III.

the highlands of Labrador (1,500 to 2,000 feet), shows the recent northern uplift to have been less than in New England.

Combining the movement of the east and the west, it would appear that the great Pleistocene uplift reached its maximum along a line between the Gulf of St. Lawrence and Vancouver island, rather than in higher latitudes. The youthfulness of the northern topographical features shows that the elevation of the lands in the higher latitudes, above the base-level of river erosion, has taken place in recent geological times, for there is a lack of such great cañons in the country north of the great lake zone as occur in the region to the south of it.

If the subsidence of the northern portion of the continent appears to have been great, that of Barbadoes, toward the southeast, appears to have been greater; for Messrs. J. B. Harrington and A. J. Jukes-Browne* have pointed out that there are on the island oceanic deposits resting upon beds of sandstone and shales of probably Miocene age, and beneath coral formations of age not greater than the Pleistocene. These deposits indicate an origin of not less than a thousand fathoms, and, as Mr. Jukes-Browne points out, probably of vastly greater depth. This geologically recent subsidence was not likely synchronous with that to the north, but may have been one of those alternating conditions suggested by Dr. Dawson.

The fjords of the coast of Norway show that the Scandinavian peninsula lately stood 4,000 feet higher than now. The silt and terrace deposits at 3,000 feet† point to a subsidence of that region the same as similar deposits in the mountains of America.

The deep submerged channels south of Asia, like that of the Ganges, which is 3,570 feet deep, proves a recent submergence of that amount. But such deep channels are not known north of Asia; consequently the higher latitudes do not show a great amount of late depression. The Pliocene deposits in Sicily, at 3,000 feet, demonstrate a recent elevation.

Pliocene deposits in the southeast of England are now found at 600 feet above tide. Their counterparts at Utrecht have been shown by Mr. Clement Reid to be now submerged more than 1,143 feet.‡

The oft-quoted Moel Tryfean deposits, in northwestern Wales, show marine shells at 1,400 feet, with similar but unfossiliferous beds rising to nearly 2,000 feet. These deposits, which I have visited, I consider to have been formed where found; but they do not represent so late a subsidence as our deposits in the lake region, for they are not the superficial gravel, but are covered by a few feet of more recent till.

These few foreign examples just cited show that the continental movements, as set forth in this paper, are not peculiar to America; but they were

*Geology of Barbadoes, 1890.
†"High Level Terraces of Norway," J. R. Dakyns: Geol. Mag., sec. II, vol. IV, 1877, p. 72.
‡Brit. Admir. Chart, no. 70.

not probably synchronous, although they have taken place in the most recent geological times.

This paper must of necessity be imperfect, as it is the first attempt to work out the detailed evidence of the recent terrestrial subsidence from records in ancient shore-lines of the Great Lake region, many of which have only recently been reported by the writer. All of the phenomena cited show that in recent geological times there have been gigantic movements causing the earth's crust to heave to and fro, producing conditions which have greatly modified the physical features, climatic conditions, and distribution of life.

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ON THE GEOLOGY OF QUEBEC AND ENVIRONS.

BY HENRY M. AMI, OF THE GEOLOGICAL SURVEY OF CANADA.

(*Read before the Society December* 31, 1890.)

CONTENTS.

Introduction.

The purpose of this paper is to give a brief résumé of the conclusions arrived at by the writer respecting the different faunas included in the different terranes in and about Quebec city. These conclusions are based upon an examination of several recent collections of fossils (made by Mr. Weston in 1877, 1887 and 1890; by Dr. Ells, l'Abbé Laflamme and Mr. Giroux in 1888; by Mr. St. Cyr in 1888, 1889 and 1890; and by the writer in 1886, 1887, 1888 and 1890) and upon an examination of the extensive collections and material which Sir William Logan and Mr. Billings made use of in describing the geology and paleontology of this interesting though complicated region.

The localities from which the collections above mentioned were made are all included within a radius of about fifteen miles from Quebec city as a center. The following localities are included:

I. *Quebec City (northern side of the St. Lawrence).*

a. Between the drill shed and Grande alleé.
b. 100 yards south of Montcalm market.
c. St. John street, numbers 71 and 73.
d. Côte d'Abraham.
e. Côte de la Negresse.
f. Côte Sauvageau.
g. The coal fields.

II. *Lévis (southern side of the St. Lawrence).*

a. I. C. R. cutting.
b. Road from Lévis to St. Joseph.
c. 150 yards west of *b*.
d. Cliff south of Carrière and Lainy's foundry.
e. City hall, Lévis.
f. Near toll-gate, South Quebec.
g. Between toll-gate and Victoria hotel, South Quebec.

III. *Montmorency Falls (northern shore).*

a. Above the falls; Trenton limestone, etc.; left bank.
b. Above and close to the falls; right bank.
c. Ravine below the falls; left bank (limestones).
d. Ravine below the falls; left bank (shales).
e. Gorge between the steps and mouth of river.
f. Mouth of the river; East point.

IV. *Beauport (northern shore); Parent's quarries.*

a. In shales.
b. In limestones.

V. *Charlesbourg (north of Quebec City).*

a. Templeman's quarry.
b. 50 yards south of Charlesbourg church.
c. 1 mile west of village.

VI. *Lorette (falls of St. Charles river).*

a. In the upper thinly bedded limestones.
b. In the lower heavier bedded limestones.

VII. *Island of Orleans (east of Quebec city).*

a. False point (limestones and shales).
b. Near Bel-Air hotel (shales).

VIII. *St. Nicholas (southern shore).*

Two miles above the village.

IX. *Pointe-aux-Trembles, Quebec.*

a. In bituminous shales.
b. In limestone beds.

The fossil remains obtained from these localities have been identified in so far as the mode of preservation and condition of the specimens permit. The collections made by Mr. Weston in 1890 have not yet been examined as critically as might be desired, but they only serve to intensify the results obtained in the examination of previously obtained material.

The researches of Sir William Logan, Mr. Billings, Dr. Sterry Hunt, Dr. Selwyn, Sir William Dawson, Professor James Hall, Professor Emmons, Professor Walcott, Professor Marcou, Dr. Ells, Professor Lapworth, and many others, on the geology of Quebec and its environs, have made that region classic ground to the student of North American geology. The famous Quebec group controversy, as well as its closely related friends, the Taconic question in geology and the Lorraine-Hudson River problem, are all involved in the geologic history of Quebec. Much diversity of opinion has existed as to the exact geological position of some of the terranes at and about Quebec city, as also along the whole line of the great Appalachian or St. Lawrence-Champlain fault; and this is not at all astonishing, seeing that profound dislocations exist, intricate foldings of strata occur, and several terranes are met along a comparatively short section, faulted and folded together in anything but a simple manner, which require exceedingly detailed and careful examination before satisfactory conclusions are arrived at.

The rocks forming the Citadel hill or promontory of Quebec (Cape Diamond) have been assigned to different positions in the geological scale by different writers at different times. An interesting review of their views is given in Dr. Ells' last report to Dr. Selwyn (1888), and published by the Geological Survey of Canada, which extends from Dr. Bigsby's paper (1827), down to Professor Lapworth's report, etc., published in the "Transactions of the Royal Society of Canada" (1887). These Quebec rocks have been referred by Logan to the age of the Quebec group (Lévis division), by others to "Utica-Trenton," "Trenton-Utica," "Utica-Hudson" and "Lorraine" age, while still others, and the majority at present, regard them as newer than the Trenton limestone, *i. e.*, as of "Hudson River" age, or newer than the Utica terrane, and forming part and parcel of an extensive series of sedimentary strata classed under the term "Hudson terrane."

I shall not attempt to enter into a discussion of the views held by geologists, both in Canada and in the United States, in this matter. Such a task I had to undertake and accomplish for myself previous to this, and I will not burden the Society with it on this occasion. I wish merely to call attention to a number of plain facts obtained in the field and from an examination of extensive collections of fossils. When series of strata are found lying between dislocations and faults, presenting no clear stratigraphical relations to the adjoining strata, the lithological character of the beds along with paleontological evidence must necessarily come in to assist us in ascertaining the definite horizon to which they belong. With the aid of these criteria some interesting notes have been obtained.

The Terranes exposed about Quebec.

The rocks about Quebec city and within the scope of this paper (leaving out of consideration the "glacial" and "marine" clays of post-Tertiary times) include the following series of well-marked natural divisions :

	I.		II.		III.
Archean.	Laurentian or Archean.	*Quebec.*	Quebec massif.	*Trenton.*	Lorraine.
			Lévis.		Utica.
			Sillery.		Trenton.

These seven terranes are clearly seen in a section from Lorette or Charlesbourg southward through the city of Quebec and across the St. Lawrence at Point Lévis. They occur in the following geographical succession, beginning toward the north:

1. Laurentian or Archean.
2. Trenton.
3. Utica.
4. Lorraine.
5. Quebec (massif).
6. Lévis.
7. Sillery.

Between the Laurentian and Trenton terranes, numbers 1 and 2, there occur an unconformity and an overlap, as seen at Lorette and Charlesbourg. There we find the Trenton directly overlain by the Utica terrane, which is in turn overlain by the Lorraine shales—in the district lying between Lorette and Côte Sauvageau, Quebec city,—these three affording a regular ascending series of sedimentary strata, whose characters are readily seen and recognized throughout the region in question. Then follow toward the south the calcareo-bituminous rocks, indurated shales, compact limestones, and conglomerate bands which form the Quebec city massif, bounded on the north by a thrust fault which brings them against the disturbed and twisted edges of the Lorraine shales, and bounded on the south by the St. Lawrence river and another fault which brings them in contact with the Sillery rocks toward the southwest and with the Lévis toward the southeast. On the southern side of the St. Lawrence we find next the Lévis shales, limestones and conglomerate bands coming in over the Sillery shales (red, green and gray) and sandstones, with which they are folded and faulted many times. Taking these terranes in their natural and present geographical order as above, they may be described in detail.

Description of the Terranes.

The Laurentian or Archean.—Granites and gneisses, hornblendic and micaceous rocks of usual occurrence in the lowest divisions of this system of rocks, are met with at Montmorency falls underlying the Trenton limestone; at Lorette falls, below the lowest beds of Trenton limestone there exposed; and also north of Charlesbourg village and quarries, presenting a series of more or less elevated rounded bosses which, toward the west, north and east, develop into hills and mountains of greater magnitude, whose southern limit in the Quebec city region and vicinity seems to mark the line of an ancient escarpment, which predicates the existence of an extensive dislocation in the Archean crust and accounts for the peculiar absence of that series south of this line. Mr. A. P. Low, of the Canadian Geological Survey, is now engaged in mapping the geological features of the Archean area north of

Quebec, and Dr. Selwyn has placed an interesting collection of these rocks, made by Mr. Weston at Montmorency falls, in the hands of Mr. Ferrier, who will discuss their lithological and petrographical characters in the near future.

The Trenton: Lorette.—At Lorette falls, on St. Charles river, the Trenton limestones are seen to rest unconformably over the Laurentian. They consist at the top of thinly bedded, impure limestones, holding a number of characteristic fosssls, including—

Strophomena alternata;
Leptæna sericea;
Orthis testudinaria;
Bellerophon bilobatus;
Trinucleus concentricus;
Illænus, sp. und.

There are some fifty feet of strata exposed in the whole escarpment (which faces the north) here along the line of contact at the falls, the lowest of which are rather heavily bedded and consist of light gray semi-crystalline limestones, abounding in fossil remains characteristic of the Trenton, the presence of *Lituites undatus*, Emmons, at the base indicating proximity to the Black River formation. The following species were obtained in the lower beds of the exposure :

Pachydictya acuta;
Batostoma ottawaënse;
Prasopora lycoperdon;
Discina pelopea;
Lingula philomela;
Strophomena alternata;
Leptæna sericea;
Orthis testudinaria;
" sp. und.;
" sp. nov. (?);
Anastrophia hemiplicata;
" var. (?);
Conularia trentonensis;
Theca, sp. nov.;
Bellerophon bilobatus;
Bucania punctiferous;
Ctenodonta dubia;
Ambonychia bellistriata (?);
Pterinea trentonensis;
Lituites undatus;
Endoceras proteiforme;
Aparchites mundulus;
Primitia whiteavesii;
Isochilina amii;
Primitia mundula;
Beyrichia, sp. und.;
Ceraurus pleurexanthemus;
Calymene senaria;
Encrinurus vigilans;
Dalmanites callicephalus;
Trinucleus concentricus;
Asaphus platycephalus;
Lichas, sp. und.;
Illænus milleri.

Charlesbourg.—At Charlesbourg the Trenton terrane may be seen to advantage some four hundred yards north of the village, and also at Templeman's quarry, a few paces east of the road. Here the strata are horizontal, while at Lorette they are considerably inclined, the dip there increasing from four or five degrees to nearly thirty in the vicinity. The rock at Templeman's quarry is rather pure and crystalline, takes a good dressing, and the beds vary in thickness from four or five inches up to a foot, and contain several characteristic species as follows:

Pachydictya acuta;
Ptilodictya falciformis;
Prasopora lycoperdon;
Crania, sp. und.;
Schizocrania, or *Discina;*
Lingula riciniformis;
Strophomena alternata;
Leptæna sericea;
Orthis testudinaria;
Murchisonia gracilis;
Endoceras proteiforme;
Illænus, sp. und.;
Calymene senaria;
Dalmanites callicephalus.

Beauport.—Proceeding farther eastward along the line of outcrop, the Trenton occurs at Beauport and at Parent's quarries, where the limestones are overlain by the black bituminous shales of the Utica. The following species of fossils were obtained by Mr. St. Cyr, curator of the museum of the Department of Public Instruction, Quebec:

Amplexopora discoidea;
Prasopora lycoperdon;
Lingula obtusa;
Strophomena deltoidea;
Anastrophia hemiplicata;
Conularia trentonensis;
Orthoceras, sp. nov.;
Asaphus platycephalus;
Calymene senaria;
Ceraurus pleurexanthemus.

Montmorency.—The Montmorency river at and above the falls, before plunging its waters headlong down the steep height of 251 feet, flows over Laurentian or Archean rocks. It has cut its way through the thinly bedded impure limestones, which are often interstratified with very thin beds of fissile shale, such as is also said to occur in the lowest beds of the quarry at Charlesbourg. Along each bank on this river the Trenton is well developed and carries with it a large assemblage of fossils, among which *Trinucleus concentricus*, *Bellerophon bilobatus* and *Solenopora compacta* may be said to occur in great abundance. Along the left bank of the river and above the bridge the following species were obtained by Dr. Ells and the writer:

Pachydictya acuta;
Prasopora lycoperdon;
Solenopora compacta;
Lingula curta (?);
Strophomena alternata;
Leptæna sericea;
Orthis testudinaria;
" *pectinella;*
Anazyga recurvirostra;
Zygospira (?) *modesta;*
Conularia trentonensis;
Bellerophon bilobatus;
Bucania punctifrons;
Murchisonia gracilis;
" *perangulata;*
Orthoceras, sp. nov.;
" *laqueatum* (?);
Vanuxemia, sp. und.;
Harpes, sp. und.;
Encrinurus vigilans (?);
Asaphus platycephalus;
Ceraurus pleurexanthemus;
Illænus milleri.

In this district the Trenton is again seen to occur at the foot of the falls up the brook and ravine at the north end of the gorge, where the limestones are made to abut at a high angle against the Archean escarpment by a downthrow fault. The limestones are light-gray colored, impure and bituminous. There are only a few feet of apparently upper Trenton beds seen at this point between the cliff and the disturbed Utica beds alongside of and overlying them.* The following is a list of the species of fossils obtained from the limestones up the ravine and along the brook:

Hyalostelia, sp. und.;
Glyptocrinus, or *Glyptocystites*, sp. und.;
Leptœna sericea;
Strophomena, sp. und.;
Orthis testudinaria;
Primitia, sp. und.;
Illœnus, sp. und.;
Calymene senaria.

On the right bank of the river and close to the falls on Mr. Hall's property (near his residence) the following Trenton species were obtained:

Crinoidal fragments;
Dictyophyton (?), sp. und.;
Lingula, sp. und.;
Orthis probably *testudinaria;*
Zygospira modesta;
Strophomena alternata;
Conularia, sp. nov.;
Trinucleus concentricus.

Pointe-aux-Trembles.—Among the remaining localities where the Trenton terrane has been met we have Pointe-aux-Trembles, near the mouth of the Jacques Cartier river, where the Utica shales also occur, overlying the limestones. From these the following species of characteristic Trenton fossils were obtained:

Heterocrinus canadensis;
Monticulipora, sp. und.;
Strophomena alternata;
" *deltoidea;*
Orthis testudinaria;
Anastrophia hemiplicata;
Leptœna sericea;
Dalmanites callicephalus;
Calymene senaria;
Asaphus platycephalus;
Ceraurus pleurexanthemus.

The above lists of species from Lorette, Charlesbourg, Beauport, Montmorency and Pointe-aux-Trembles are sufficiently characteristic to leave no question whatever as to the age of the rocks from which they were obtained.

The Utica: Distribution.—The Utica shales are observed at several places about Quebec city, and are readily recognized by the fauna which they contain. For the most part the shales consist of brown or buff weathering and black bituminous calcareo-argillaceous materials in a finely divided state and very brittle or friable. At Montmorency falls, Beauport and Charlesbourg

*The quartzose limestone or calcareous sandstones of Trenton age, underlying the Trenton and overlying the gneiss at Montmorency, are also of Trenton age, no Potsdam, Calciferous, or Chazy being present.

a number of interesting collections were made by Dr. Ells, l'Abbé Laflamme, Mr. St. Cyr, Mr. Weston and the writer, and the following lists of species have been prepared therefrom.

Montmorency.—In the soft, brittle calcareo-argillaceous and bituminous shales which are much disturbed and faulted in a position overlying the Trenton limestones of the brook in the ravine at the northern end of the gorge of Montmorency falls were found the following species:

Diplograptus, sp. und.;
Climacograptus, sp. und.;
Orthograptus quadrimucronatus;
Leptobolus insignis;
Endoceras proteiforme;
Serpulites dissolutus;
Triarthrus becki.

Between the steps leading from the top of the gorge on the eastern side to the foot of the falls and the lower point, the following species were collected by the writer:

Orthograptus quadrimucronatus (?);
Reteograptus eucharis;
Climacograptus, sp. und.;
Triarthrus becki.

Beauport.—Leaving the Utica at the foot of the falls (much disturbed and faulted between the steps and the cliff at the northern end of the gorge) and the more evenly bedded and inclined strata south of the steps to the lower point, and proceeding westward to Beauport, the Utica is again seen at this point. Near the shore, l'Abbé Laflamme obtained a large slab of shale on which were seen a *Climacograptus*, sp. und., several examples of the typical *Leptobolus insignis*, Hall, and *Triarthrus becki*, Green.

At Parent's quarries, a little further northward, the Utica shales were examined by Mr. St. Cyr, and the following species obtained:

Schizocrania filosa;
Leptœna sericea;
Lyrodesma pulchellum;
Endocerus proteiforme;
Asaphus canadensis (=*Asaphus latimarginatus*).

The above species are now in the museum of the Department of Public Instruction, Quebec.

Charlesbourg.—About fifty paces south of the Charlesbourg church the Utica is exposed along the main road. It dips at a considerable angle toward the south, varying in intensity from north to south from a few degrees to nearly fifty degrees. The rock here is a brownish-gray calcareous shale, from which the following species were obtained:

Climacograptus or *Diplograptus;*
Leptograptus (?) *flaccidus;*
Leptobolus insignis;
Strophomena, sp. und.;
Bellerophon bilobatus;
Primitia ulrichi (?);
Triarthrus becki.

A larger collection of specimens from this locality would be interesting. With the exception of *Leptobolus insignis*, Hall, *Bellerophon bilobatus*, Sowerby, and *Triarthrus becki*, Green, all very characteristic Utica species, the forms are not well preserved.

About a mile west of Charlesbourg church, on the road to Lorette, the black bituminous shales of the Utica again crop out in a small brook, and the following forms occur:

Climacograptus, sp. und.;
Orthograptus quadrimucronatus;
Leptobolus insignis.

L'Abbé Laflamme, of Laval university, who has devoted considerable attention to the geographical distribution of the different terranes in this district for the Canadian geological survey, collected a large slab of somewhat indurated black calcareous and bituminous shale on which were the following species:

Orthograptus quadrimucronatus;
Leptobolus insignis;
Triarthrus becki.

Pointe-aux-Trembles.—In 1888, Dr. Ells obtained the following species of Utica fossils, overlying the Trenton limestones of Pointe-aux-Trembles:

Orthograptus quadrimucronatus;
Leptobolus insignis;
Triarthrus becki.

These three forms are, as can be readily seen, typical and characteristic and generally abound in every collection of Utica specimens.

The Lorraine: General Character and Distribution.—The Lorraine shales form the fourth of the series of geological terranes occurring along the line of section from north to south, and consist for the most part of very thin, fissile and evenly bedded calcareo-argillaceous and arenaceous shales, weathering yellowish brown, measuring a thickness of 800 or 900 feet, and overlying the black bituminous shales of the Utica terrane conformably. They are extensively developed north of the city of Quebec, at Montmorency falls, at St. Nicholas, along the southern shore, and also farther eastward along the northern end of the Island of Orleans. These shales are not very fossiliferous in most of the exposures, but sufficient fossil evidence has been obtained to fix the position of the shales in the region where the thrust fault which occurs has disturbed the strata considerably. They are separated from the Quebec city massif by the thrust fault already indicated (which is evidently the St. Lawrence and Champlain fault itself), and are also made to abut against the Sillery formation on the same ground.

St. Nicholas.—About two miles above the village of St. Nicholas, Dr. Ells and the writer obtained the following species from the upturned and broken beds of this terrane:

Orthograptus quadrimucronatus;	*Ambonychia radiata;*
Diplograptus, sp. nov.;	*Orthodesma parallelum;*
Leptæna sericea;	*Modiolopsis*, sp. und.;
Orthis testudinaria;	*Trinucleus*, sp. und.
Zygospira headi;	

Côte Sauvageau.—At Côte Sauvageau these shales are also well exposed, and may be seen to advantage along the road leading to the tanneries. Occasionally there is met here, as at St. Nicholas and Montmorency, in the gorge, a band or two of hard, compact quartzite, with thin films of shale separating it from the softer and more fissile strata. These hard bands are well seen in the gorge at Montmorency. One of these bands at Côte Sauvageau showed the presence of *Anazyga recurvirostra*, Hall, and *Orthis testudinaria* in the thin film of shale overlying it, but no other forms were obtained here except very obscure and ill preserved fragments of graptolites, apparently diprionidian.

Montmorency Falls.—On both sides of the gorge below the falls of Montmorency river the Lorraine shales are well developed and form a part of Sir William Logan's original section.* Here the strata are inclined at a high angle, averaging 45°, and are extremely soft, fissile and earthy; the harder bands, which are also lighter colored, standing out in relief. These shales are often stained purple and show evidence of disintegration from a once harder and more compact rock. None of the characteristic fossils of the Lorraine shales which abound at St. Nicholas were found here. *Orthograptus quadrimucronatus*, however, was found, and a careful examination of the strata would no doubt reveal other forms entombed in these strata.

The Quebec: The Quebec Massif.—Next in order comes the series of rocks forming Cape Diamond, the Citadel front and base, and the upper town proper in Quebec city. The rocks which constitute this series are varied and numerous.

At Côte d'Abraham they consist of hard, compact, black, bituminous, calcareous bands, which break with a conchoidal fracture and hold fragments of graptolites, associated with a band of what appears to be a hard and cherty conglomerate, carrying clear grains of quartz and holding a number of fossils, chiefly monticuliporidæ. At this locality the following

* Geology of Canada, 1863, pp. 198, 199.

forms have been obtained (descriptions of which will, it is hoped, soon be published):

Girvanella, sp. und.;
Solenopora compacta, var. *minuta* (var. nov.);
Diplotrypa quebecensis (sp. nov.);
Monotrypa incerta (sp. nov.);
Prasopora lycoperdon, Vanuxem, var. *selwyni* (var. nov.);
Orthis, allied to *O. testudinaria*, Dalman;
Leptœna, like *L. sericea;*
Asaphus, sp. und.; an obscure form.

This peculiar association of forms occurring in such a series of strata will be noted later on.

Côte de la Nègresse.—Farther westward, at Côte de la Nègresse, the hard, compact and fine-grained calcareo-argillaceous and bituminous bands were seen, associated with bands of semi-crystalline and somewhat bituminous limestones, quite different in facies from the strata at Côte Sauvageau; and at the turn of the road up the hill along Richmond street two obscure fossils were obtained, one of which appears to be a *Camerella* or *Anastrophia*, the other a *Platystrophia* or other coarsely ribbed brachiopod. The strata here dip at an angle of 45° southward.

Montcalm Market.—Immediately south and again about one hundred yards southwest of Montcalm market, in the city of Quebec, we have a series of black bituminous and calcareous shales holding abundance of graptolites, brachiopods, ortracods and trilobites, with bands of thinly bedded limestones and an occasional hard, cherty, compact, quartz-bearing band, which resembles a conglomerate. The strike of the strata here is N. 45° E. (magnetic), and the dip about 70°, increasing to 78° in some instances. From the exposures north of St. Patrick street and between the roads leading from that street to the market the following fossils have been obtained:

Diplograptus foliaceus;	Crinoidal fragments;
" *angustifolius;*	*Lingula*, sp. nov. (no. 1);
" sp. und.;	" " (no. 2);
" *rugosus;*	" " (no. 3);
" *mucronatus;*	*Paterula* (?), sp. nov.
" *whitfieldi;*	*Discina*, sp. nov. (no. 1);
Climacograptus scalaris;	" " (no. 2);
" var.;	Gen. nov. et sp. nov.;
" sp. und.;	*Leptœna*, sp. nov.;
" *perexcavatus;*	" allied to *L. sericea;*
" sp. und.;	" allied to *L. quinquecostata;*
" *bicornis;*	*Strophomena* (?), or gen. nov. et sp. nov.;

Dicellograptus sextans;
" *anceps;*
" *forchammeri;*
" *divaricatus*, var. *moffatensis*, Carr.;
" sp. und.;
" sp. und.;
Glossograptus, sp. und.;
Dendrograptus, sp. und.;
Leptograptus, sp. und. (cf. *L. pertenuis*);
Dicranograptus ramosus;
" *nicholsoni* (?), Hopk.;
" sp. nov.;
Corynoides calycularis;
Dawsonia, sp. und.;
Orthis, sp. und.;
Stricklandinia (?), sp. und.;
Obolella, or closely related genus;
Euomphalus, sp. nov., or *Ophileta*, sp. nov.;
Primitia logani;
Aparchites mundulus;
" sp. nov., or *Polycope*, sp. und.;
Agnostus, sp. und.;
Aeglina rediviva, Barr. (?);
Bathyurus, sp. und.;
Ampyx, sp. und.;
Asaphus, sp. und.;
Illænus, sp. und.;
Trinucleus (?), sp. und.;
Dionide (?), cf. *D. lapworthi.*

Between St. Patrick street and the Grande allée, and also along the north-western extremity of Parliament square, similar strata occur; dark brown or black compact bitumino-calcareous splintery shales weathering grayish-white, holding cavities in which Mr. Ferrier has recognized crystals of strontianite arranged in stellate groups and associated with terminated crystels of quartz ("diamonds") and an inspissated substance resembling petroleum. These strata dip at an angle of S. 65° E. (average magnetic), and hold fragments of graptolites, *Corynoides calycularis*, and also a *Discina* (undetermined). Measured sections of these exposures have been taken for reference, and serve to connect these beds with those occurring between the drill shed and the Grande allée.

Between Drill Shed and Grande Allée.—Here, as nearly everywhere in Quebec city, may be seen the upturned and denuded edges of the shaly and calcareo-argillaceous strata for a considerable distance. An artificial section at this point gives an average dip of 55°, S. 20° E. (magnetic), varying from 50° at the southern extremity to 58° or 60° as we proceed northward. The strata are somewhat disturbed at the southern end, but are very evenly bedded and contain quite an interesting series of fossils, chiefly graptolites throughout. The presence of iron pyrites in these rocks has stained many of the layers, which present a very rusty appearance. The following is a list of forms (provisionally identified) recognized from this section 45 paces in length:

Diplograptus angustifolius;
" *foliaceus* (?);
" sp. und.;
Dicellograptus sextans (?);
Climacograptus perexcavatus;
" *confertus* (?);
Dawsonia, sp. und.;
Primitia mundula, Jones.

Similar strata were observed farther along the Citadel front, where the landslide took place in September, 1889, and along Champlain street by Saut-au-Matelot street, Sous-le-Cap street, Côte d'Ambourgés, and St. Charles street, where the dips observed showed clearly that round Cape Diamond the strata, as Sir William Logan noted,* form a synclinal basin at Quebec. Alongside and up Mountain street a bold cliff of conglomerate occurs, containing large bowlders imbedded in a shaly and calcareo-argillaceous paste, with the admixture of quartz grains. This deposit, as well as most of the exposures in Quebec city, deserves very special attention and will no doubt afford interesting notes and material. The *Corynoides* band which occurs at the Cove field and near Montcalm market was again noticed along St. John street in excavations on the lot where numbers 71 and 73 of that street occur. *Dicellograptus sextans* was collected here. The strata dip at an angle of from 40° to 70° southward, increasing in intensity toward the northern end of the lot, close to St. John street.

Review.—So far the fossil remains, while numerous and many of them well-known "Hudson River" forms, are but little known and require detailed study.

Before assigning a definite position to the rocks of Quebec city in the scale of terranes in America, it is necessary for the writer to state that so far he has been unable to find any evidence in the field, either stratigraphical or paleontological, whereby the Hudson River rocks and Lorraine shales, as originally understood by Emmons, could be correlated and referred to the same or an immediately following geologic terrane.

The fossils collected at Côte d'Abraham have a decided lower Trenton facies, as the presence of *Solenopora compacta*, or a variety of this species, seems clearly to indicate. From the long list of species obtained in the Montcalm market rocks it can readily be seen that we have there represented a fauna which has never yet been found either in the Lorraine, Utica, or Trenton terranes—a fauna distinct from the faunas included in these three terranes, whose characters are so well known throughout the continent in their undisturbed and complete development. It is the same fauna which has received in numerous places the name "Hudson River," *e. g.*, at Normanskill and many other localities in New York and Vermont, and in Canada, at False point, Island of Orleans, on the Etchemin river between St. Henry and St. Anselme, at Drummondville, on Crane island, Gagnon's beach, the Marsouin and Gros Mâle, a mile and a half below the Tartigo river, at Griffon cove, and in many other localities. Similar strata have also been observed in northern Maine, in Newfoundland and New Brunswick.

Now, the question presents itself: What is the age of these rocks and what the horizon to which the internal fossil evidence points at those localities where this fauna is found? A number of vexed questions arise. But, tak-

* Geology of Canada, 1863, p. 230.

ing into consideration the stratigraphical, lithological and paleontological relations and dicta of the rocks of this clearly distinct and well-marked terrane in the scale of geologic terranes in America, we can readily separate them from others, such as the Lorraine and Utica terranes, with which they have been for years made synchronous or newer. The fauna enclosed in the typical Lorraine shales, *i. e.*, in those shales which overlie the Utica shale and underlie the Oswego, or, as it is now called, Medina, sandstone, is well known and can be studied to advantage in Canada around the Manitoulin islands, at Collingwood, and at various points from that place to Oakville and southeastward by Weston and Toronto, in New York and in the valley of the Richelieu river, in the Ottawa Paleozoic basin and near St. Nicholas, at Côte Sauvageau, in the St. Charles river valley, at Montmorency below the falls, at Ste. Famille, and on the Island of Orleans at Ste. Anne de Beaupré, at St. Joachim, and also along the northern shore of Anticosti.

There seem to occur then two distinct faunas entombed in distinct series of strata and holding a different position as to age. The apparently lower Trenton aspect of a portion of the Quebec massif as seen at Côte d'Abraham and Côte de la Nègresse gives us an indication of the age of the strata at these points. Cut off on all sides by faults and separated from the Lévis rocks by the St. Lawrence river, the Quebec terrane (which name I beg to propose for this series of strata such as we meet at the Montcalm market, Parliament square, and drill-shed exposures) stands by itself in an anomalous position very similar to rocks of similar age which Professor Lapworth designated as "unplaced in the series." *

There is a marked physical resemblance between the Quebec massif and the Lévis rocks south of the city, but one series is a highly bitumino-calcareous terrane; the other not so. The presence of such forms as *Agnostus*, *Aeglina*, *Ampyx*, *Dionide*, *Bathyurus*, etc., point to a rather lower horizon than the Trenton, while I believe that it is perhaps premature to give the precise geological position of the strata at Quebec, in the present light of our knowledge. Suffice it for this occasion to separate this terrane from that of the Lorraine shales or Lorraine terrane, *i. e.*, overlying the Utica, and recognize it as a distinct one, whose more exact position will form an interesting object of research. But a few days, comparatively speaking, have been spent in examining the strata at Quebec, and the limestone bands and shales interstratified are richly fossiliferous.

The Lévis.—Next in order comes the Lévis terrane, whose characters, both paleontological and stratigraphical, are given in detail in the reports of the Canadian survey and in many other interesting memoirs and publications. Along with Dr. Ells, the writer has made an examination of the fossiliferous

* This same authority had recognized the earlier age of the "Hudson River rocks" in America and their identity with the Glenkiln shales of south Scotland as their European equivalents.

strata occurring there. The lists of species and descriptions of the beds are given in the "Second report on the geology of a portion of the province of Quebec," which Mr. Walcott has recently reviewed in the American Journal of Science.

The probably Calciferous age of these strata, termed Lévis, has been proven by Mr. Billings on paleontological evidence. The abundance of graptolites and of certain well-marked zones of these in different portions of the series of Lévis strata, along with the recurrence of the conglomerate bands carefully mapped by Sir William Logan, enable the geologist to trace out the foldings and recurrence of strata at different points. The occurrence of large cephalopods in pebbles of the conglomerate, besides the Cambrian forms which many of these hold, is a point worthy of closer scrutiny.

The following is a list of species collected by Dr. Ells, Mr. Giroux and the writer at Lévis, all obtained from definitely located places:

GRAPTOLITIDÆ.

Nemagraptus capillaris (?);
" sp. und.;
Didymograptus bifidus;
" *constrictus;*
" *extensus;*
" *furcillatus;*
" *pennatulus;*
" sp. und.;
Tetragraptus approximatus;
" *caduceus*, Salter
(= *T. bigsbyi*, Hall);
" *denticulatus;*
" *fruticosus;*
" *headi;*
" *hicksi;*
" *quadribrachiatus;*
" *serra*
(= *T. bryonoides*);
Dichograptus octobrachiatus;
" *richardsoni;*
" *ramulus;*
Loganograptus logani;
Clonograptus rigidus;
" *flexilis;*
" sp. und.;
Goniograptus thureaui
var. *selwyni;*
Diplograptus dentatus, Bgt.
(= *D. pristiniformis*, H.);
Diplograptus (?) *tricornis;*
Phyllograptus anna;
" *angustifolius;*
" *typus;*
Trigonograptus ensiformis;
Ptilograptus plumosus;
Dictyograptus irregularis;
" sp. nov.
(= *D. delicutula*, Dawson);
" sp. (cf. *D. homfrayi*);
" sp. und.;

BRACHIOPODA.

Lingula quebecensis;
" *irene;*
" sp. nov.;
" sp. und.;
Elkania desiderata;
Leptobolus (?), sp. und.;
Linnarssonia, sp. und.;
Siphonotreta (?) *micula;*
Orthis, sp. und.;
Shumardia granulosa.

These fossils were all derived from the shales and evenly bedded limestones of Lévis age. This number and list can no doubt be swelled considerably after careful collecting and determination. There are many species both of Cambrian and Cambro-Silurian (Ordovician) age included in the pebbles of the conglomerates of the Lévis terrane. These should be carefully collected and noted. Fossils from the paste of the conglomerate, if any, should be carefully kept separate, and interesting results will no doubt be forthcoming.

The Sillery.—Underlying the Lévis and faulted together at many points we find the Sillery, red, green and black shales associated with sandstones and conglomerates. The leading paleontological characters of this series so far is the presence of *Obolella* (*Linnarssonia*) *pretiosa*, Billings, in great abundance wherever that terrane is met with. At the Chaudière River railway bridge this shell occurs in great abundance, associated with other forms of *Obolella* and two species of *Lingula;* also with a *Protospongia*, akin to *P. tetranema*, Dawson. The presence of these spicules of sponges, referred to the genus *Protospongia* by the writer in 1883 along with *Obolella*, point clearly to the antiquity and earlier age of the Sillery than that to which it was for a long time assigned. A number of obscure compound graptolites and a species of *Phyllograptus* also occur at the Chaudière river exposures, indicating the probably transitional character of these passage beds between the Cambrian and Cambro-Silurian (Ordovician) epochs.

Conclusion.

Having thus briefly described the various terranes as they are seen along the line of section north and south, it will be observed on resuming the question of the probable age of the Quebec city massif that, when these are compared with the Lévis terrane, their physical character, the presence of the conglomerate bands, the similarity of strata in sedimentation and in their lithological characters, together with the general field aspects give them, owing to their intimate relations as having been subjected to similar pressures and foldings, the appearance of being a part and parcel of that greater series of sedimentary strata to which Sir William Logan advisedly gave the name "Quebec group." It would also appear that the Quebec terrane, while distinct from the Lévis terrane paleontologically, still exhibits numerous points in contact and would form an upward extension of that series at the base of which we find the Sillery. This would, I hold, materially assist in demonstrating the proper interpretation of the term "Quebec group" as Sir William Logan and Mr. Billings knew it, as regards the fossiliferous portion of that interesting series of sedimentary strata.

We should thus have the Quebec group divisible into three natural and well-marked parts:

3. The Quebec or upper division;
2. The Lévis or middle division;
1. The Sillery or lower division,

just as we find the Trenton group divisible also into series of terranes; and these divisions are all marked by peculiar and distinct faunas, each of which is characterized by fossils to be given in the table hereto appended.

The Trenton group characterizes the upper portion of the Cambro-Silurian or Ordovician system; the Quebec group characterizes a portion and peculiar development of the Cambro-Silurian or Ordovician.

Distribution of Genera and Species.

Genera and Species.	Terranes.				
	Lorraine.	Utica.	Trenton.	Quebec.	Lévis.
SPONGIÆ.					
Hyalostelia, sp.			x		
HYDROIDA.					
Leptograptus flaccidus, Hall		x			
" sp.				x	
Nemagraptus capillaris, Emmons					x
" sp.					x
Didymograptus bifidus, Hall					x
" *constrictus*, Hall					x
" *extensus*, Hall					x
" *furcillatus*, Lapworth					x
" *pennatulus*, Hall					x
" sp.					x
Tetragraptus approximatus, Nicholson					x
" *caduceus*, Salter (= *T. bigsbyi*, Hall)					x
" *denticulatus*, Hall					x
" *fruticosus*, Hall					x
" *headi*, Hall					x
" *hicksi*, Lapworth					x
" *quadribrachiatus*, Hall					x
" *serra*, Brongniart (=*T. bryonoides*, Hall)					x
Dichograptus octobrachiatus, Hall					x
" *richardsoni*, Hall					x
" *ramulus*, Hall					x
" sp.					x
Loganograptus logani, Hall					x
Clonograptus flexilis, Hall					x
" *rigidus*, Hall					x
" sp.					x
Goniograptus thureaui, McCoy, var. *selwyni*, Ami					x
Diplograptus dentatus, Brongniart (= *D. pristiniformis*, Hall)					x
" sp. und.		x			
" *foliaceus*, Murchison				x	
" *angustifolius*				x	
" *rugosus*, Emmons				x	
" *mucronatus*, Hall				x	
" *whitfieldi*, Hall				x	
" *tricornis*, Carruthers					?
" sp. nov.	x				
Dicellograptus anceps, Hall				x	
" *moffatensis*, Carr., var. *divaricatus*, Hall				x	
" *forchammeri*, L.				x	

Distribution of Genera and Species—Continued.

Genera and Species.	Terranes. Lorraine.	Utica.	Trenton.	Quebec.	Lévis.
HYDROIDA—Continued.					
Dicellograptus sextans, Hall				x	
" sp.				x	
" sp.				x	
Dicranograptus ramosus, Hall				x	
" cf. *D. nicholsoni*, Hopkinson				x	
" sp. nov.				x	
Climacograptus bicornis, Hall				x	
" *scalaris*, Hisinger, var. *normalis*, Lapworth				x	
" *scalaris*, His., var.				x	
" *scharenbergi*, Lapworth				x	
" *perexcavatus*, Lapworth				x	
" sp.				x	
" sp.				x	
" sp.		x			
Orthograptus quadrimucronatus	x	x			
Phyllograptus augustifolius, Hall					x
" *anna*, Hall					x
" *typus*, Hall					x
Glossograptus ciliatus, Emmons					?
" sp.				x	
Reteograptus eucharis, Hall	?				
Cœnograptus gracilis, Hall				x	
Trigonograptus ensiformis, Hall					x
Ptilograptus plumosus, Hall					x
Dictyograptus irregularis, Hall					x
" sp. nov. (= *D. delicatula*, Dawson)					x
" cf. *D. homfrayi*, Lapworth					x
" n. sp.					x
Dendrograptus, sp.					x
" sp.				x	
Corynoides calycularis, Nicholson				x	
Dawsonia, sp.				x	
" sp.					x
CRINOIDEÆ.					
Glyptocrinus decadactylus, Hall	?				
" sp.			x ?		
Heterocrinus canadensis, Bill.			x		
Crinoidal fragments				x	
VERMES.					
Serpulites dissolutus, Billings		x			
BRYOZOA.					
Amplexopora discoidea, James			x		
Batostoma ottawäense, Foord			x		

Distribution of Genera and Species—Continued.

Genera and Species.	Terranes.				
	Lorraine.	Utica.	Trenton.	Quebec.	Lévis.
BRYOZOA—Continued.					
Prasopora lycoperdon, Vanuxem	?				
“ *lycoperdon*, Van., var. *selwyni*, var. nov.			x		
Monotrypa incerta, sp. nov.		?			
Diplotrypa quebecensis, sp. nov.				?	
Pachydictya acuta, Hall			x		
Ptilodictya falciformis, Nich.			x		
Girvanella, sp.			?		
Solenopora compacta, Billings			x		
“ *compacta*, B., var. *minuta*, var. nov.					
BRACHIOPODA.					
Lingula curta, Hall		x			
“ *obtusa*, Hall		x	x		
“ *philomela*, Billings			x		
“ *riciniformis*, Hall			x		
“ *quebecensis*, Billings					x
“ *irene*, Billings					x
“ sp. und.					x
“ sp. nov.					x
“ sp. nov. no. 1				x	
“ “ no. 2				x	
“ “ no. 3				x	
Obolella, sp.					x
“ sp. nov.				x	
Elkania desiderata, Billings					x
Linnarssonia, sp.					x
Leptobolus insignis, Hall		x			
“ sp.	x				
“ sp. und.					x
Paterula (?), sp. nov.				x	
Schizocrania filosa, Hall		x			
Siphonotreta micula, McCoy					?
Crania, sp.			x		
Discina, sp.	x				
“ *pelopea*, Billings			x		
“ sp. nov. no. 1				x	
“ sp. nov. no. 2				x	
Skenidium, sp.			?		
Strophomena alternata, Conrad			x		
“ *deltoidea*, Conrad	?				
“ sp. nov.		x		x	
“ sp			x		
Leptœna sericea, Sowerby	x			?	
“ sp. nov.				x	
“ sp. allied to *L. quinquecostata*				x	
Orthis emacerata, Hall	x				
“ *testudinaria*, Dalman	x		x		
“ sp.	x				

Distribution of Genera and Species—Continued.

Genera and Species.	Terranes.				
	Lorraine.	Utica.	Trenton.	Quebec.	Lévis.
***BRACHIOPODA*—Continued.**					
Orthis pectinella			x		
" sp.		x			
" sp. nov.			x		
" sp. nov.				?	
" sp.					x
Zygospira headi, Billings	x				
Anazyga recurvirostra, Hall	x ?		x		
Stricklandinia (?), sp.				x	
Anastrophia hemiplicata, Hall			x		
" sp.		?			
LAMELLIBRANCHIATA.					
Pterinea trentonensis, Hall			x		
Ambonychia radiata, Hall	x				
" *bellistriata*, Hall			x		
Modiolopsis, sp.	x				
" sp.	x				
Vanuxemia, sp.			x		
Ctenodonta dubia, Billings			x		
Lyrodesma pulchellum, Emmons		x			
" sp.	x				
Orthodesma parallelum, Hall	x				
GLOSSAPHORA.					
Murchisonia gracilis, Hall			x		
" *perangulata*, Hall			x		
Euomphalus, or *Ophileta*, sp. nov.				x	
Bellerophon bilobatus, Sowerby	x	x	x		
Bucania punctifrons, Emmons			x		
Conularia trentonensis, Hall			x		
Theca, sp. nov.			x		
CEPHALOPODA.					
Orthoceras laqueatum (?), Hall			x		
" sp. nov.			x		
Endoceras proteifrome, Hall		x	x		
Lituites undatus, Emmons			x		
OSTRACODA.					
Primitia mundula, Jones				x	
" "			x		
" *logani*				x	
" " var.	?				
" *whiteavesii*, Jones			x		
Aparchites mundulus, Jones			x		
Polycope, sp.				x	
Isochilina amii, Jones			x		

Distribution of Genera and Species—Continued.

Genera and Species.	Terranes.				
	Lorraine.	Utica.	Trenton.	Quebec.	Lévis.
TRILOBITA.					
Shumardia granulosa, Billings					x
Aeglina rediviva (?), Barr.				x	
Ampyx, sp.				x	
Agnostus, sp.				x	
Harpes, sp.			x		
Trinucleus concentricus, Eaton			x		
" sp. nov.	x				
" sp.				?	
Bathyurus, sp.				x	
Calymene senaria, Conrad			x		
Asaphus platycephalus, Stokes			x		
" *canadensis*, Chapin		x			
" sp.				?	
Illænus milleri, Billings			x		
" cf. *T. bouchardi*, Barr.				x	
Dionide, cf. *D. lapworthi*, R. Etheridge, Jr.				x	
Dalmanites callicephalus, Green			x		
Ceraurus pleurexanthemus, Green			x		
Encrinurus vigilans, Hall			x		

Explanation of Plate 20.

Section 1—A sketch section across the strike from Lorette to Lévis in a southeasterly direction (see also Bull. Geol. Soc. Am., vol. 1, p. 464, map accompanying Dr. Ells' paper). It includes the following terranes in their geographical sequence, beginning toward the northwest: *a.* Laurentian or Archean; *b.* Trenton; *c.* Utica; *d.* Lorraine (Hudson River of most geologists); *e.* Quebec (new terrane, separate from others); *f.* Lévis; and *g.* Sillery. The last three, *e, f,* and *g*, form part and parcel of the fossiliferous Quebec group, while *b*, *c*, and *d* form the Trenton group, which are separated by a fault—the great Appalachian fault (the "Quebec fault" of Ells, or the St. Lawrence and Champlain fault, or a branch of it, of other geologists).

Section 2—Sketch section at Montmorency falls, across the measures east of the gorge and across the Island of Orleans. The notation is the same as in section 1. The Utica shales are much disturbed here, both in their contact with the Trenton below and with the Lorraine shales above. Below the horizontal Trenton, capping the Laurentian gneiss, there are found calcareous sandstones of Trenton age, which have been called Potsdam "quartzites." A downthrow fault passes in front of the bluff over which the waters fall.

Section 3—Sketch section across the measures near Montcalm market, Quebec city, showing the high angle of dip and the shales with limestones interstratified.

Section 4—A general view of the strata flanking the Citadel hill at the landslide of 1889. The structure there exhibited is that of an inclined denuded anticline.

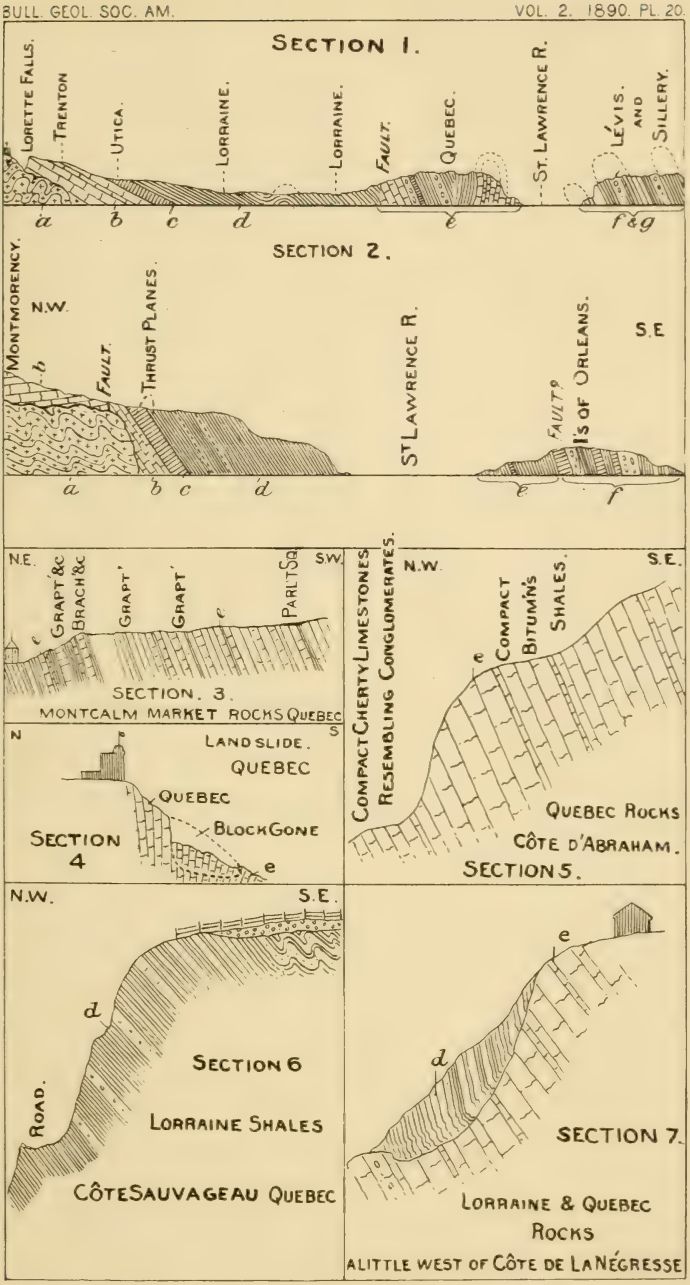
Section 5—Sketch section through the calcareo-bituminous rocks and compact shales, with conglomeratic cherty bands associated, at Côte d'Abraham, where the monticuliporidæ have been obtained.

Section 6—Sketch section showing the thin, fissile and soft earthy shales of the Lorraine terrane—newer than the Utica—inclined at a considerable angle along the road at Côte Sauvageau, west of Martelle tower no. 4.

Section 7—Sketch section exhibiting the dying out of the outcrop of Lorraine or newer shales on the edge or brow of the hill near Martelle tower no. 4, between Côte Sauvageau (section 6) and Côte de la Négresse, where a series of impure semi-crystalline, bituminous and fossilifuous limestone occurs. Côte de la Négresse is west of Côte d'Abraham. The contact between the two series is very much broken up, *i. e.*, between *d* and *e*.

Legend.

a = Laurentian or Archean;	
b = Trenton terrane *c* = Utica terrane *d* = Lorraine terrane	Trenton group.
e = Quebec terrane *f* = Lévis terrane *g* = Sillery terrane	Quebec group.



SKETCH SECTIONS IN THE VICINITY OF QUEBEC CITY, CANADA.

DISCUSSION.

Dr. Alfred R. C. Selwyn:* Sir William Logan alone assigned the rocks of the city of Quebec to the Lévis division of his Quebec group; † Selwyn alone assigned the rocks of the city of Quebec to the Hudson-Utica horizon, or above the Trenton, and pronounced them, before any fossils had been found in them, to be the same as those on the northern shore of the Island of Orleans, which had been assigned by Logan to Hudson-Utica. Fossils since found in the city of Quebec have proved the correctness, so far, of Selwyn's view. Whether Logan and Selwyn are right in placing these rocks above the Trenton is thus the only question now at issue.

Do the fossils determined by Mr. Ami conclusively prove his contention, that they are not above but below? In this connection, see "Geology of Canada," 1863, pages 199 to 204, for list of fossils and description.

Mr. C. D. Walcott: Sir William Logan, in his original definition of the Quebec group, divided it into two parts in the vicinity of Quebec. The Point Lévis series consists of the graptolite-bearing shales of Point Lévis, with their enclosed conglomerates, in which upper Cambrian or Potsdam fossils were found, as he supposed, in association with fossils of the age of the Calciferous formation of New York. Although no fossils were found in the rocks of Quebec city proper they were correlated with the Lévis series. Mr. Ami has now found a fauna in the Quebec city rocks which is distinct from that of Point Lévis, and I think that there should be two names, one for the rocks of Calciferous age at Point Lévis, and another for the Quebec rocks. I think the name Quebec should be restricted to the Quebec city rocks, which carry a distinct fauna from the strata at Point Lévis, and that the name Lévis should be applied to the graptolitic shales and the limestones in which the Calciferous fauna occurs. If Mr. Ami's determination of the fauna is correct, the horizon of the Quebec city rocks is that of the Trenton, probably the lower Trenton, and perhaps the upper portion of the Chazy of the New York section. As the rocks at Quebec are of a peculiar physical development and contain a peculiar fauna, I would suggest, if acceptable to the Canadian geologists, that the name Quebec be restricted to that series of rocks, and that the Point Lévis rocks be arranged under the name Lévis.

For the series of strata that have been formerly included under Quebec as about the Calciferous-Chazy horizon, as originally defined by Logan, which includes the Point Lévis series, the Quebec city series, the Phillipsburg

* In a note communicated to the Society.
† "Geology of Canada," 1863, p. 201.

limestone series, it might be possible, in the absence of any other name, to call it the Eolian, from an historical point of view. There are strong objections, however, to this name, and I do not wish this to be considered as a proposal for its use. Collectively the Quebec, Lévis, Phillipsburgh, Calciferous, Chazy and other formations, occurring between strata of the Potsdam and Trenton terranes, can well be assembled under the term "Canadian" as proposed by Professor J. D. Dana.

Dr. Ezra Brainerd: I should object to the term Eolian, since it is not a geographic term, but simply a fanciful name; and I do not consider it applicable to the series of rocks mentioned by Mr. Walcott.

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THE COMANCHE SERIES OF THE TEXAS-ARKANSAS REGION.

BY ROBERT T. HILL.

(*Read before the Society December* 30, 1890.)

CONTENTS.

INTRODUCTORY STATEMENT.

The Comanche series of rocks has been partially described by the writer and others in several previous papers. They represent in time the marine sedimentation between the lacustral land epoch of Permo-Triassic red beds and the upper Cretaceous subsidence begun in the Dakota epoch. Without attempting a minute correlation of its numerous horizons with any beds of the eastern hemisphere, it has been conceded generally that at least the upper portions of this series are of lower Cretaceous age because of their clearly defined stratigraphic position unconformably beneath the Dakota sands, which all authorities have conceded to be of Cenomanian affinities; a conclusion strengthened by the striking paleontologic resemblance of the whole upper Cretaceous (or Meek and Hayden Cretaceous) series to that of Europe. The lower beds of the Comanche series have affinities which entitle them to comparison with the upper Jurassic, while the upper beds have Neocomian and Cenomanian resemblances. The Comanche series as a whole, however, presents great paleontologic evidence at variance with every European standard, and it is premature to make paleontologic correlations with it. In this paper I shall endeavor to clearly define this series stratigraphically, and leave for others the discussion of the faunal resemblances and differences.

The main area of the Comanche series extends from western Arkansas through southern Indian territory to the meridian of 97° 30′, thence southward and southwestward across Texas to New Mexico, a distance of more than 1,000 miles, and then southward indefinitely into Mexico. Areas also exist in the California-Utah province and in eastern New Mexico, although they are as yet unstudied. The main typical area, however, is in central Texas, and is so extensive that deductions as to its subdivisions have required much time; and although I have been constantly studying it for many years, not until now have I felt justified in dividing it into well-defined terranes. I now propose to show by stratigraphic and paleontologic proof that the Comanche series is divisible into several separate and distinct terranes, the lower two of which may possibly be of pre-Cretaceous age.

Definition of the Terranes.

CONSTITUTION OF THE COMANCHE SERIES.

C. The Washita, or Indian Territory Division.
- 11. The Denison Beds.
- 10. The Fort Worth Limestone.
- 9. The Duck Creek Chalk.
- 8. The Kiamitia Clays or *Schloenbachia* Beds.

B. The Fredericksburg or Comanche Peak Division.
- 7. The Goodland Limestone.
- 6. The *Caprina* Limestone.
- 5. The Comanche Peak Chalk.
- 4. The *Gryphœa* Rock and Walnut Clays.
- 3. The Paluxy Sands.

A. The Trinity Division.
- 2. The Glen Rose or alternating beds.
- 1. The Trinity or Basal Sands.

THE TRINITY OR BASAL DIVISION.

Separation.—In previous papers I have defined this as an arenaceous littoral deposit at the base of the Comanche series in Arkansas and Texas. During the past year, however, I have discovered that the beds described under this general term really include two stratigraphic subdivisions separated by distinct lithologic and paleontologic characteristics, the Trinity or basal sands, and the Glen Rose or alternating beds, respectively.

The Trinity Sands.—While in many places these vary in composition with that of the underlying floor, they are usually composed of fine, white, cross-bedded sand, mostly unconsolidated, very porous, calcareous, sometimes free from lime. In places there are deposits of small jasper and quartz pebbles, seldom exceeding a pigeon's egg in size, exceedingly rounded and worn, and often cemented by a matrix of iron and lime, sometimes harder than the pebbles. This pebble deposit is of various hues—white, black, and jaspery red—and often remains as a residuum, over large areas of the red beds and Carboniferous strata, from which the post-Trinity beds have been denuded, as seen in Taylor, Tom Green, Nolan, Montague and many other counties of the Abilene and gypsum country.* Silicified wood and occasional fragments of hard lignite occur, the latter seldom, if ever, in continuous beds or strata, but as if the remnant of some solitary log or tree floated out from shore.

These sands can be seen in contact with the underlying Carboniferous and the overlying Glen Rose beds all along the western margin of the Comanche area except around the immediate perimeter of the Burnet-Llano region, where in places the Paleozoic continent persisted above the Trinity shore-line until the Comanche Peak epoch. Fifteen miles south of Burnet, however, in another pre-Trinity topographic valley, now followed by Colorado river below Smithwick Mills, where the lithologic nature of the beds is entirely different, consisting of coarser rounded pebbles of Silurian and and Carboniferous limestone and Llano schists, as well as quartz from the Burnet granite, and fine cross-bedded sands and shell débris (resembling, as seen at Travis Peak post-office, in the bed of Cow creek, the Florida coquina). Here also there is an unstudied molluscan fauna including ammonitidæ, ostræidæ, trigoniadæ and other forms, not one of which occurs in the hitherto supposed Cretaceous and overlying beds. Here the Trinity beds are in contact unconformably with hard Carboniferous and Silurian limestones, and contain much débris of the Burnet granite. They also vary in composition and thickness with the irregularities of the floor.

West of the 98th meridian the Trinity sands are deposited unconformably upon the various beds of the "Triassic," or gypsiferous red beds, as seen

* In places these pebbles are cemented into large masses of conglomerate, as at San Angelo, in Tom Green county, where it attains a great thickness and areal development.

along the base of the remnantal Cretaceous mesas of the Colorado-Brazos divide, in Nolan, Taylor and Mitchell counties. Owing to the unconsolidated, pulverent nature of these sands, they are denuded more rapidly than the overlying or underlying strata. As a result of this rapid denudation, the main area of Trinity exposures north of the Brazos is in a narrow valley, seldom exceeding ten miles in width, which extends nearly five hundred miles irregularly northward from the Brazos to the mountains of Indian territory, and from thence eastward to Murfreesboro, Arkansas. This valley is bounded coastward by the escarpment of the more indurated material of the Glen Rose beds.

The Trinity valley is one of the most marked topographic features of the Arkansas-Texas region. Where the underlying beds are of unconsolidated material, however, as in the red bed region of northwestern Texas, the remnantal sands often occur as a thin sheet of loose sand over extensive upland areas, as seen east of Abilene in Taylor county, and in other places. Some of the sand hills along the western escarpment of the plains are also of this nature. This formation, although of limited areal exposure, has a wide range of occurrence along the interior border of the more calcareous beds of the Comanche series from southwestern Arkansas to New Mexico. It is usually absent along the eastern front of the Rocky Mountains from Las Vegas (New Mexico) northward, unless the *Atlantosaurus* beds at Cañon City (Colorado) are synchronous in age, which is not proven. The pink grits at Gallisteo (New Mexico), described by Marcou and Stevenson, and which occur northeast of Santa Fé at Rowe, and at other points near the intersection of the Pecos river, are probably of this formation, and may mark its western border. Upon careful comparison I am also inclined to think the upper half of *Tucumcari* mesa, New Mexico, which I have visited, is composed, below the cap rock, of the Trinity sands. Traces of this terrane are also seen between the Pecos and the escarpment of the Llano Estacado, in southeastern New Mexico, east of Eddy, indicating its extent beneath the Tertiary plains.

In southern Kansas the Cheyenne sandstones have been properly ascribed to this age by Cragin, but I am inclined to think from the anomalies of occurrence there that they are not of continuous sedimentation with that of the main Trinity sea, but were deposited in an embayment or inlet around the western end of a buried mountain system, of which the Wichitas are now the visible remnant.

South of the Colorado and east of the Pecos the occurrence and extent of the sands have not been determined; and, after many journeys in northern Mexico and southern Texas, I have been unable to find the base of the Comanche limestones exposed in this region.

The origin of the Trinity sediments is apparent. They are always derived from the materials of the underlying contact beds, mostly the sandstones of the Carboniferous series, except in the valley of the Colorado east of the Burnet granite area, as previously noted. The origin of the fine, rounded quartzite and jasper pebbles, however, is still problematical; although I have some evidence that it is the redeposit of a conglomerate that belongs to the earlier beds, which was degraded and redistributed over and far west of the present Carboniferous area, as now revealed by the removal of the overlying Comanche series. When one considers the immense degradation of the sandstones of the Carboniferous system in Texas and Indian Territory, the source of the Trinity materials is obvious.

These sands record the beginning of one of the most important events of Mesozoic time, to wit: The invasion of the area of the interior lake region of the red bed epoch (Triassic) by the marine waters of the Atlantic, and the degradation or base-leveling of the narrow continental divide which separated them. The extreme paucity of land débris in the sediments is indicative of the limited area of this divide, for where the Trinity waters bordered the Appalachian continent, as in Arkansas, plant remains are exceedingly abundant.

The Glen Rose Beds.—Immediately overlying the basal sands of the Trinity division just described, and no doubt succeeding them by continuous subsidence, lies a group of strata which are of great importance in our geologic history. These are composed of soft, yellow, magnesian fossiliferous beds, silicious at base, alternating in dimension layers with an exceedingly fine argillaceous sand, with occasional dimension layers of almost pure crystalline limestones, chalk, and magnesian limestones, often oölitic in structure. At Mount Bonnel, west of Austin, there is a distinct oölitic structure in many of the layers of indurated stone and marls, while nodules and geodes of beautiful anhydrite, calcite and strontianite crystals are also quite abundant.

The unequal weathering of the hard and soft layers produces in the eroded topography a beautiful bench-and-terrace effect, so much resembling ancient shore lines along the western escarpment of Grand prairie, where it overlooks the Trinity valley and the lower Paleozoic beds from which it has been eroded, that earlier geologists have often confused these features with shore topography. On fresh fracture these rocks are usually either white or of an intense orange or gamboge color, but weather into a dull gray.

North of the Colorado-Brazos divide the beds contain an abundant and unique molluscan fauna, composed in the lower part of littoral species described by me in a report on the Neozoic geology of southwestern Arkansas, to wit: *Pleurocera strombiformis*, Scloth; *Corbiculidæ*, sp.; *Ostræa franklini*, Coquand; besides numerous undescribed forms, but not one species of the great lower Cretaceous fauna, such as the characteristic *Gryphæa*, of the *pitcheri* type, or ammonitidæ and echinodermata which appear so abundantly two terranes above in the base of the Comanche Peak beds and continue thence, with certain progressive variation, to the top of the Comanche series. The upper beds of this terrane are especially characterized by the immense numbers of abberant molluscs, such as *Monopleura, Diceras, Requienia,* etc., which form great masses of strata.

The upper beds of the terrane contain many deeper water beds, accompanied by a distinct marine fauna, which has never been described. Among the organisms are echinodermata and foraminiferæ (especially the large, strawberry-shaped *Goniolina* or *Parkeria*), together with innumerable casts of pelecypoda and gasteropoda, including species of very large size, such as *Natica* (*Tylostoma pedernalis* (?), Roemer) and related forms, together with occasional fragments of vertebrata. This fauna of the upper beds can be collected all along the western escarpment of stratification, especially in the Paluxy valley at and west of Glen Rose; in the slopes of the Brazos, north and south of Granbury; along the bluffs of the Colorado and Bull creek, west of the mouth of the latter steam; and in numerous other localities south of the Colorado, in Edwards, Sutton, Kerr, Uvalde, Kendall, Kimball, Blanco, Gillespie, and other counties.

The Glen Rose beds north of the Colorado-Brazos divide are exposed along a narrow area occurring as a prairie strip in the heart of the upper Cross-Timbers. Their first appearance northward is in the western part of Wise county, and they increase in area southward, in Parker, Hood, Erath and Comanche counties.

These beds do not occur in Indian territory, owing to the overlap of later deposits, but appear in Arkansas from Ultima Thule eastward to Murfreesboro; the limestones described in my report on Arkansas under the general classification of the Trinity sands belonging to this terrane. In the counties of southwestern Texas between the Pecos and the Colorado and south of the Burnet-Llano Paleozoic region, these rocks attain a thickness of over 2,000 feet, and form the remnant of a great plateau from 2,000 to 3,000 feet above the sea and larger in area than the states of Connecticut and Rhode Island. The Guadalupe, Comal, Nueces, Frio, Medina and Devils rivers have their origin in this sterile, rugged plateau, which is being rapidly base-leveled and cut up into horizontally stratified buttes and mesas by the head-water erosion of these streams.

In the mountains of northern Mexico the beds again appear projecting through the intervening Tertiary plain as a part of the Santa Rosa and Arboles ranges, but here they are metamorphosed into a hard blue limestone which has been mistaken for Silurian by some.* In the southern area these

* Report on San Rafael Mines, Santa Rosa district, Mexico, by Professor Adolphe Rock: Mobile, Ala., 1876.

beds are surmounted by the Walnut clays, or *Exogyra texana* beds, which I assume in this paper to be the base of the true Cretaceous. North of the Lampasas they are overlain by the Paluxy sands, an arenaceous terrane hitherto unrecognized and undifferentiated from the Trinity division.

There are in these beds many layers of dimension stone of almost identical lithologic character with that of the celebrated Caen quarries of France, so largely imported into our northern seaports. This stone is extensively quarried at Weatherford, Granbury, Belton, Oatmanville, Kerrville and other places, and will no doubt some day occupy an important position in the resources of our country.

The Thorp Springs limestone subdivision, found near the base of the alternating beds and overlying the Trinity sands, is *one* of the *Caprotina* limestones of Shumard. It is a massive stratum, composed almost exclusively of shells of the peculiar *Requienia* (*Caprotina*) *texana*, Roemer; a fossil not confined exclusively, however, to this bed. In thickness it is about twenty feet. It outcrops for many miles along the bed of the river at Granbury and Thorp Springs, and also in the bed of the Paluxy at Glen Rose. Near Travis Peak post-office, on the Colorado, this horizon is again seen, and is apparently persistent. Owing to the excessive faulting in the vicinity of Austin, it is impossible to say what relation this stone bears to the *Caprotina* limestone west of that city.

The different lithologic and stratigraphic features of the Glen Rose alternating beds, their position beneath the Fredericksburg division (separated in the north by a sandy, littoral terrane), and the entire absence of the great characteristic fauna of the hitherto recognized Fredericksburg division, entitle these beds to a distinct position, although they are separated by no structural unconformity. I cannot here enter into a discussion of paleontologic details, but I consider the deposits of Jurassic rather than of Cretaceous affinities. The question of age is secondary to definition, however, and I shall leave this to a future time. The fossils have not yet been studied critically; but I have in my possession a representative series of these fossils, which I propose to make the subject of a separate paper at an early day.

THE FREDERICKSBURG OR COMANCHE PEAK DIVISION.

General Composition.—This is the second of the great divisions of the Comanche series, and is distinguished from the others by its more chalky character and its unique molluscan fauna. The Paluxy sands are placed with this series only tentatively, for there are some few reasons which might be sufficient to class them with the Trinity division. The rocks of this division, although of wide extent, have their characteristic exposure and development in the region of Texas west of the meridian 97° 30′, and between the Trinity and Lampasas rivers.

The Paluxy Sands.—North of the Colorado-Brazos divide the alternating beds of the Trinity division are succeeded by a terrane of fine, white pack-sand, oxidizing red at the surface, about 100 feet in thickness, resembling very much the Trinity sands and hitherto confused with them. They outcrop along the eastern edge of the Brazos valley, in Parker and Hood, and also in Erath, Comanche, Coryell and Bosque counties. South of the Colorado-Brazos divide they disappear, the Comanche Peak beds resting directly upon the Glen Rose beds. These beds are especially conspicuous southwest of Granbury, forming the timbered upland of that region.

The Paluxy sands, which are so called from the town and creek of that name in Somerville county, can first be separated from the Trinity sands in Wise county at a point between Decatur and Alvord. At Decatur the beds are well developed. In general character they are somewhat similar to the Trinity sands. There are differences, however: the Paluxy sands have none of the fine pebbles which characterize the base of the Trinity; and the Paluxy beds are rather calcareous and argillaceous in places, while those of the Trinity are more ferruginous.

At Decatur the Paluxy sands contain some layers of honey-combed and very argillaceous limestone. The gradation from the Paluxy to the overlying and underlying beds at Decatur is also rather gradual. At Comanche peak the sands form the plain upon which the butte stands, making a belt of forest region surrounding its base. Here the beds have a thickness of about a hundred feet, and are of character similar to that at Decatur. West and south of Comanche peak they occupy a considerable area, while they extend many miles down the Brazos, finally disappearing at the Bluff mills, near Kimball, where they make the shoals over which the river runs. Jonesborough, Coryell county, is situated directly on the outcrop of these sands, and the Lanham road northward from the town crosses it several times. A few miles north of Jonesborough the sands have a thickness of only about fifteen feet, showing their decreasing thickness southward. The transition from the sands to the underlying Glen Rose alternating beds is rather sharp, but that of the overlying beds is a little more gradual, for which reason these sands are placed in the Comanche division.

The sand is stratified, and occasionally cross-bedded, and there are local hardenings. The color varies from gray to yellowish, and the amount of ferrugination which is here found is variable. The sand is also marked by the growth of forest timber, largely post-oak, though smaller growths, such as sumac, also occur. The sands probably extend for a considerable distance down the Leon valley, although it is difficult to determine their exact extent on account of confusion with the drift of the Leon river, composed of this débris. The sands appear only in scattered spots further toward the south. Thus, east of Burnet, on the Mahomet road, they appear as occasional areas of reddish sandy lands, bearing a growth of post-oak. Sometimes these localities are very small, and may be seen on one side of a slight valley of erosion but not on the other at the same level. Elsewhere, however, they have a very considerable and unmistakable outcrop, as for instance, near the junction of the northern and Russell forks of San Gabriel river.

To the northward, the Paluxy sands increase in development, overlapping interiorward on the Glen Rose and Trinity beds, and abutting against the Paleozoic area in Indian territory from a point west of Ardmore eastward to the Arkansas line, where they occupy the escarpment valley of the basal Comanche Peak beds or Preston limestone. They also appear at Preston bluff, near Denison. These sands, which the writer has hitherto classed as Trinity, and which may yet prove to be inseparable from them, have been traced out by him during the past year from the Arkansas line westward. At no place in Indian territory east of the 97th meridian do the Glen Rose beds outcrop, and it is my opinion that they still remain concealed there by this uneroded overlap of the Paluxy sands; for the alternating beds are again exposed beneath them in Arkansas.

The absence of these sands south of the Colorado-Brazos divide is an interesting feature, which can best be explained on the hypothesis that the littoral sedimentation diminished away from the main land area to the southward, and by the existence of a buried pre-Trinity and pre-Paluxy topographic protuberance of Carboniferous limestones, which persisted above the Trinity waters in the Burnet area until the basal Comanche Peak epoch, and which extends from northern Burnet and Llano counties eastward into Lampasas county, and which then divided the country into a northern embayment and a southern open sea. The presence of this ridge is shown by the difference of level in the pre-Comanche floor, as exposed by the erosion of the Comanche sediments at Lampasas and Burnet, and also by the horizontal deposition of the latter upon its unequal altitudes. This is especially well shown in the profile from Burnet to Smithwick Mills post-office, the Carboniferous floor being revealed in unconformable contact with the Trinity at all altitudes from 650 to 1,200 feet. This Paleozoic barrier of central Texas has little or no arenaceous strata upon its southern side, and hence the absence of the Paluxy sands in that direction, the existence of which would imply the occurrence of a pre-existing arenaceous terrane. These sands mark a return to land conditions in northern Texas at the close of the Trinity epoch, and the beginning of the main great subsidence as recorded in the Comanche Peak, Washita and Denison beds of the overlying division. No fossils have been found in the Paluxy sands, save silicified wood, which occurs in great abundance, and has been mistakenly considered Quaternary in age.

The Gryphæa Rock and Walnut Clays.—The Paluxy sands are everywhere succeeded throughout their extent by a stratum of grypheate oysters, occurring sometimes in solid masses from ten to fifty feet thick, in some places imbedded in a calcareous matrix. This terrane is sometimes underlain and overlain by yellow laminated clay marls containing *Exogyra texana*, Roemer. Hence the *Gryphæa* rock and *Exogyra* clays must be discussed as one terrane. The yellow clays also contain occasional flags of hard, crystalline limestone, composed largely of shells of *Exogyra texana*. For these the name of *Walnut clays* is proposed, after their characteristic occurrence at Walnut, Bosque county.

At Comanche peak the beds encircle the base of the butte, forming a well-marked bench around the mountain. Below them are the timbered Paluxy sands. The stratum is here fifty feet thick, and composed entirely of the shells of a small *Gryphæa* resembling *G. incurva* of Europe, but as yet not differentiated from the various species called *G. pitcheri* in our nomenclature. The shells are more or less loosely cemented, and form one of the most unique rock-sheets in the region. This stratum extends from the Trinity to the Lampasas, and is beautifully exposed in the counties of Parker, Wise, Hood, Erath, Comanche, Hamilton, Coryell, Bell and Lampasas, forming a foundation for the Walnut clays, whose exposure is coincident with it.

The Walnut clays, or *Exogyra texana* beds, overlying and underlying the *Gryphæa* beds, are alternating strata of thin limestone flags and yellow clay marls, accompanied by inconceivable numbers of *Exogyra texana*, Roemer (= *Ostræa virgula*, Goldfuss, and *Exogyra matheroniana*, D'Orb.), the lowest and first unmistakably Cretaceous form in the Comanche series. These clays weather into an exceedingly fertile, chocolate-colored soil, forming the chief agricultural lands of the Fredericksburg division. In extent these beds coincide with the *Gryphæa* breccia. North of the Lampasas they are separated from the Glen Rose beds by the Paluxy sands. South of that river they rest directly upon these sands, and constitute a prominent topographic bench or plain near the summit of the buttes, as seen west of Austin, in Travis county.

The Comanche Peak Chalk.—Overlying the Walnut clays and succeeding them rather abruptly there is a more chalky terrane, for which Dr. Shumard proposed the name of the Comanche Peak beds. This chalk is hard, but readily disintegrates, and usually occurs as the slope or escarpment of the buttes and mesas. It is exceedingly fossiliferous, and its numerous and characteristic species are given in my check-list. The thickness of this bed averages about 100 feet in central Texas, but it thins rapidly to the northward and thickens to the southward. The beds grade upward into the *Caprina* limestone, from which it is differentiated, however, by displaying more regular and frequent lines of stratification, by crumbling nature, and by a unique fauna. The typical occurrence of the Comanche Peak horizon is along the sides of the buttes and mesas of central Texas which are capped by the *Caprina* limestone, such as Comanche peak and others. The bed is usually covered with a growth of rather thin, scrubby oaks; the soil is thin or absent, and the angular fragments of the weathering rocks make up the surface. Frequently, however, there are large areas over which the Comanche Peak horizon extends as the surface formation.

The Caprina Limestone.—The next member of the Comanche Peak group is the *Caprina* limestone of Shumard. This is the direct continuation of the Comanche Peak chalk, only the limestone is harder and more persistent, and the fossils less numerous and characterized by the occurrence of a few peculiar forms, especially *Rudistes*, which have already been referred to by me in other writings. Genetically it is inseparable from the underlying and overlying beds, since there is no sharp demarkation between them. It is a deposit of deeper waters than the underlying Comanche Peak chalk, however, as shown by its lack of lamination and stratification planes.

At Comanche peak the limestone is between thirty and forty feet thick, and though it increases to the southward it does not change greatly. It can correctly be called an indurated chalk. It is more or less stratified, although usually a great massive bed from top to bottom. Some parts are harder than others, and so make up a curved outline to the bluffs; others are materially softer, and frequently are eroded away, leaving either honey-combed cavities or shelves under the overhanging harder layers.

Topographically, the *Caprina* limestone is one of the most important factors in Texas, since its superior hardness and resistance have preserved it as the capstone of the innumerable buttes, mesas and plateaus of the central portion of the state, where it forms a great plane of resistance to denudation. So perfectly does this limestone find expression in the topography that its extent can readily be traced by the highest contours of the United States Geological Survey topographic sheets of Coryell, Bell and other counties. It may be said to be the determining factor in the topography of the region. All of the buttes or so-called mountains north of the Colorado are capped by it; the great scarps which often run for miles overlooking the prairies to the west represent the same stratum; the walls of the cañons which many of the streams have cut are almost invariably composed of the *Caprina* limestone.

But little need be said in regard to the distribution of the *Caprina* limestone. In northwestern Texas the Double mountains of Stonewall county are capped by the *Caprina;* so are also Comanche peak, the mesa and almost all the buttes east of the Brazos opposite Glen Rose, the high bluffs marking the cañon of the Brazos from the Bluff mills near Kimball far down the river, the buttes and mesas about Walnut and Iredell and toward the south, those about Meridian, Jonesborough and Valley mills, and the Jehosaphat plateau of Travis county and western Williamson county. It is seen in grand bluffs along the Nolan river at Blum, and in some of the smaller streams near Fort Graham; it outcrops in the creek at Belton, and makes up the whole surface of the broad mesa, extending thence westward for several miles to the point where it makes the cap of the great bluff facing westward—a magnificent illustration of the relations of uniform and gentle dip, together with comparative hardness, to the processes of erosion. It caps the buttes as far west as Kempner and southward toward Florence, where it makes again the level surface of the mesa. Pilot knob, north of Liberty hill, Williamson county, and many of the buttes high up the Colorado about Anderson mills, are capped by it. The *Caprina* terrane is usually covered with a thick growth of scrubby oaks and similar trees, especially where the outcrop is not of large area and the rock comes near the surface. In places there are broad fertile prairies upon its outcrop, as about Pancake and Turnersville.

It has been stated that the *Caprina* is uniform throughout. In the southern portion of its area there is an exception to this rule, and it might be divided into an upper or flinty member, and a lower or chalky subdivision. The flints first appear in the vicinity of Meridian, but only as a few fragments; and they increase very rapidly southward, being seen in grand development about Belton. In the northern part of the region they are comparatively large, oval, flattened nodules, usually of black flint. These occur throughout the larger part of the region studied, extending southward at least as far as Pilot knob, a few miles north of Liberty hill, and thence on to the Rio Grande.

The Goodland Limestone.—Like all the other deeper deposits of Texas, the Comanche Peak group thickens southward and thins northward. In no place does its thickness as a whole exceed or even attain 500 feet; and from the Colorado northward it decreases in thickness until, one subdivision gradually disappearing at a time, it is represented in southern Indian territory by a single persistent layer, which in my Paris-Kiamitia section I have given the name *Goodland limestone*.* This formation resembles the *Caprina* limestone in hardness, but has the Comanche Peak fauna; the *Exogyra texana* layers do not appear until 200 miles west of the Arkansas line. Proceeding westward along the ancient Ouachita shore-line from Arkansas into Texas, the *Exogyra texana* beds (the Walnut clays and *Gryphæa* breccia) are missing until the escarpment is reached north of Marietta, in the Chickasaw nation, where they first appear, thinly represented, beneath the Goodland limestone and above the sands which, as before stated, are supposed to be the homologue of the Paluxy sands.

*After the town of Goodland in Indian territory.

That this gradual deepening of the Comanche Peak waters continued southwestward into Mexico and perhaps South America, there is every evidence, although in northern Mexico and the trans-Pecos region there has been such extensive disturbance and extreme metamorphism that the identity of the paleontologic and stratigraphic subdivisions is lost.

THE WASHITA OR INDIAN TERRITORY DIVISION.

General Aspect.—This division has its prevalent and characteristic development in southern Choctaw and Chickasaw nations of Indian territory, and in northern Texas, in Grayson, Cook and Tarrant counties, where it is the predominant formation. It extends southward to the Rio Grande at Del Rio, but becomes greatly changed in lithologic character, assuming a more calcareous aspect and decreasing in thickness.

The *Caprina* limestone is apparently the culmination of the great subsidence of the Comanche series, for above that terrane the strata begin to display more and more a littoral aspect, and new faunas appear. To this division I give the name of *Washita*, after old Fort Washita, in the Chickasaw nation, where the beds were first noted and described as Neocomian by Marcou. In order to appreciate this division in the region of its greatest development, we must transfer our attention from central Texas to southern Indian territory and the Red river basin.

The Kiamitia Clays or Schloenbachia Beds.—In southern Indian territory and northern Texas the chalky Goodland (Comanche Peak) limestones, which I consider the northern attenuation of the Comanche Peak beds, are succeeded by another large development of marly clays, often stiff and black before oxidation, and accompanied by thousands of individuals of the variety of *Gryphæa pitcheri* so accurately figured by Marcou and White (*G. forniculata* of White), as I have determined by visiting the original localities of Morton, the plains of the Kiamitia. Another conspicuous and characteristic fossil of these beds is the *Schloenbachia acutecarinatus*, Shumard (= *Ammonites pedernalis*, von Buch). Alternating with the clays there are firm, hard, thin dimension layers, composed almost entirely of these shells imbedded in a matrix of yellow lime. The buildings at old Fort Washita are constructed of this stone. These clays were first seen by me at Cerro Gordo, Arkansas, where at first I confused them with the *Arietina* clays; and they are developed westward through Indian territory continually to the great southward deflection of strike west of Marietta (Chickasaw nation), whence they continue southward into Texas.

Among the typical localities in Indian territory where the Kiamitia clays are unmistakably seen and constitute large areas of land are the following: At and around the town of Goodland, on the St. Louis and San Francisco railway north of Paris; thence westward to Fort Washita; at the Folsom crossing of Blue river; and five miles north of Marietta, in Indian territory. There are intervening areas forming the surmounting plane of the Goodland limestone escarpment, constituting, with the Duck Creek and Fort Worth limestones, the only black prairies of Indian territory, including the historic plains of the Kiamitia, near Fort Towson, from which Dr. G. Pitcher, in 1830, collected and sent to Dr. Morton, of Philadelphia, the first fossils ever procured from the American lower Cretaceous (Comanche series). The same beds occur south of Red river, in northern Grayson county, at Dr. Marshall's house, two miles south of old Preston, and in other places, and also northwest of Gainesville, presenting the same topographic dip planes. West of Gainesville and southward to Fort Worth they also occur, but in less conspicuous areas. They outcrop ten miles west of Forth Worth, near Benbrook station, and also in Williamson county, where, being thicker and more calcareous, they form the black lands around Bagdad. This horizon dips beneath the surface in the beds of Duck creek three miles north of Denison, where, with the characteristic ammonite (*Schloenbachia peruvianus*, von Buch), it is seen in the bluffs of the creek.

These clays are the basal beds of the Washita division, and represent a shallower deposition than the chalky *Caprina* beds.

The Duck Creek Chalk.—The Kiamitia clays are surmounted in Indian territory and in Grayson and Cooke counties, Texas, by another chalky terrane, which, from its occurrence on the southern slope of Duck creek north of Denison, I have named the *Duck Creek beds.* This terrane is about 100 feet in thickness, and is composed of a crumbling, white chalky limestone and alternating chalky marls, accompanied by a unique fauna, especially characterized by the fossils *Hamites fremonti*, Marcou; *Ammonites*, sp. nov.; *Inoceramus* (*Aucella?*), sp. nov.; all of which are found only in these beds.

The Duck Creek beds are principally developed in northwestern Grayson county and northwestern Cooke county, in Texas, and along the southern border of the Kiamitia clays, in Indian territory. They have not been differentiated south of Cooke county, although I have seen them west of Fort Worth, near the cement works. The fauna of this terrane is so entirely different from those above and below that I am sometimes inclined to believe this member should be considered a distinct division.

*The Fort Worth Limestone.**—The Duck Creek chalk beds underlie a series of firmer and less pure yellow limestones and marls in alternating strata of from one to two feet, and of great persistency. These limestones are less chalky and of creamy tints, owing to the slight amount of oxidized pyrites they contain, and they also contain a little arenaceous matter. After a little familiarity with them and their unique fossils, they will always be readily distinguished from the other terranes. They are seen in the Den-

* Washita Limestone, old classification of Hill.

ison section, two miles north of Main street, where they form a slight escarpment with overlying dip plane. They are best shown, however, at Fort Worth, where the characteristic structure of their alternating dimension layers and marly clays is shown in the bluff north of the public square, at the quarries near the Union depot, and in the Texas and Pacific railway cuts, as well as in the Union Pacific cut at Hodge station, three miles north of the city. They are also displayed in Indian territory and in Cooke, Tarrant, Denton, McLennan, Bell, Williamson and Travis counties. Two hundred miles southwestward, at Del Rio, near the mouth of the Pecos, they are very pure chalks. The railroad cut in West Austin is another typical locality. Four miles west of El Paso, at the corners of Texas and New Mexico on the Mexico line, the Washita limestone is seen, greatly broken and disturbed. The formation is distinguished by the occurrence of many unique and characteristic species, like the large *Macraster elegans*, Roemer; *Ammonites leonensis*, Conrad; *Gryphæa washita; G. sinuata; Ostræa carinata;* and other species mentioned in my check-list.

This terrane, together with the Duck Creek limestone and clays, constitute the typical Neocomian of Marcou as described at Fort Washita, a fact of importance, inasmuch as it is near the top of the Comanche series and far above the Comanche Peak and lower divisions, which must be older.

The lithologic and stratigraphic features of these beds show shallower sedimentation than the underlying Duck Creek chalks and deeper deposition than the overlying Denison beds; they are sublittoral in characteristic features, indicative of shallowing which continues into the next terrane. These beds are also an important economic landmark, for they occupy a hypsometric position in which artesian wells can always be obtained.

The Denison Beds.—The Fort Worth semi-chalky beds are overlain in the Red river district by a series of shallower deposits of laminated arenaceous clays (the *Arietina* clays), at the base grading upward into sandy clays and occasional limestones, the chalky element of all the underlying Comanche series having finally disappeared. The detail of these beds, as seen with slight variation in Grayson, Cooke, and Denton counties and in Indian territory, presents a threefold division. At the base they are composed of a blue marly clay weathering brown, with occasional layers of immense, rounded fissile indurations, generally brown in color. Above these the beds are more sandy and ferruginous, oxidizing into ironstone and almost indistinguishable from adjacent Dakota sandstones, but separated from them by the uppermost bed of impure yellow limestone, which underlies Main street in Denison.

At Austin the sediments, almost pure clays and limestones, are void of silica and most of the littoral fossils, and from thence to the Rio Grande at Del Rio are represented by marly clays (the *Exogyra arietina* clays of my previous classification), while still further southward, where the open sea continued during the pre-Dakota land epoch, it is very probable that there is no break between these clays and the marly beds of the basal upper Cretaceous. At El Paso, however, the Denison beds are again represented by arenaceous littoral beds, which suggests that there was a shore-line in the vicinity.

At Denison and throughout northern Texas these beds are unconformably overlain by a magnificent development of the Dakota sands. I have failed as yet in Texas to find a single species extending from one formation into the other. In Kansas, however, there are some apparent exceptions to this rule, as has been shown by Cragin.

Variation in Character of the Deposits.

From a study of four parallel sections based upon actual measurements at intervals of from 100 to 200 miles, extending from Indian territory southward to the Rio Grande, the following deductions may be made:

1. That these beds were laid down against the Ouachita mountain system of Indian territory and over the whole preëxisting area of Texas, except the insular mountain areas of the Organ and Guadalupe mountains;

2. That the more littoral terranes of the Trinity and Paluxy beds and the Washita division increase in thickness and littoral character to the northward and diminish to the southward;

3. That the deeper water or chalky terranes, such as the Comanche Peak, the *Caprina* limestone and the Glen Rose beds, thin out northward and enormously increase in thickness southward, thus demonstrating that the profound subsidence was to the southward, in which direction the open sea prevailed, while oscillations of level are recorded only in the northern littoral areas.

Subsidence recorded in the Comanche Series.

Reviewing the sections mentioned, the series resolves itself into stratigraphic groups representing stages of subsidence, but of varying degree and period. The topography of the pre-Trinity continent is not difficult to interpret, a slight land barrier of Carboniferous and Silurian rocks in Texas projecting southward, peninsula-like, from the Ouachita mountains and separating lake from ocean. But little base-leveling was required to transform this peninsula into an island or islands, smaller and smaller, until completely covered by the Comanche Peak sediments. Beyond this barrier the ancient lake bottom, whose inequalities had long since been overcome by the sedimentation, stretched a comparatively unbroken plain to California, with a few mountainous exceptions, like the old post-Silurian islands in the Organ and Franklin ranges.

The Trinity division records in its basal grits the beginning of the great Comanche subsidence, and the disappearance of the wonderful Permo-Jurassic seas of the red bed epoch. The Trinity sands were soon followed by a brackish fauna of the *Pleurocera* beds, which gradually, as the ocean bottom deepened, became sublittoral and marine in character, as shown in the chalkier alternating beds, which indicate a long period of moderate depth. What happened at the close of the Trinity is somewhat more problematic. The Paluxy sands indicate the recurrence of shallower conditions. Toward the south these beds become less and less arenaceous and more argillaceous, foraminiferæ (*Nodosara*) and plant remains (*Equisetum*) having been found associated in them at Del Rio on the Rio Grande. To this southern argillaceous continuation I have previously applied the name *Exogyra arietina* beds.

The Comanche Peak division is, *par excellence*, the deep-water deposit of the series, as attested both by its sediments and by its fossils. The Paluxy sands no doubt represent the beginning of its subsidence, which is further recorded by the succession of the marine *Exogyra texana* clays and the Comanche Peak chalks, which covered all of the Texan and Mexican and no doubt a large part of the South American area, during an epoch perhaps longer than that in which thousands of feet of littoral sediments would have been deposited.

The Washita division, composed principally of laminated calcareous clays (marls), often alternating with impure chalky limestones, with its comparatively deep-water fauna, indicates a shallower condition than the Comanche Peak epoch. This shallowing was the forerunner of the sublittoral conditions that followed the Denison beds. As in the Comanche Peak division, the limestone and chalky characters of the Fort Worth beds increase southward until (as at Del Rio) they become pure chalks.

The Denison beds are preëminently, in their northern portion, a near-shore and shallow-water marine deposit, as illustrated in the character of sediments, in their assortment, and in their gradual lithologic change from argillaceous to a ferruginated arenaceous character, and in the presence of a fauna of littoral species mixed with lignite and other land débris.

Stratigraphic Value of the Terranes.

Having defined the units of the Comanche series so that they may be intelligently discussed, I now propose to present a few general deductions therefrom:

1. Each of these divisions presents a complete and distinct stratigraphic and paleontologic aspect, and they should no longer be discussed as a single geologic unit. In addition to the broad lithologic differences I have enume-

rated, not one species of the Trinity division passes upward into the Fredericksburg division ; only one or two unmistakable species of the Fredericksburg passes upward into the Washita ; while in the Washita division each of the terranes has a unique fauna. The paleontology of the whole series has been sadly confused by the fact that specific descriptions have been made by investigators who have not seen the stratigraphic and faunal association.

2. The foregoing facts being true, each of these terranes, especially those of the Washita division, should be considered a stratigraphic unit; for there is a far greater difference between each of them than there is between the Hamilton and the Chemung (or Ithaca), or between the Carboniferous and the sub-Carboniferous, or between any of the Paleozoic groups of the New York-Pennsylvania region.

Topographic Expression of the Comanche Terranes.

Having described the stratigraphic units which compose the Comanche terranes, attention is invited to the unique topographic forms which are characteristic of them, and to the extensive erosion which they record. Primarily the system, as a whole, may be conceived as a great sheet of strata dipping coastward from the interior at an average rate of twenty feet per mile, and coinciding in strike with the shore-line against which they were deposited. This strike is, first, due east-and-west from Murfreesboro, Arkansas, to Marietta, Indian territory, a distance of 300 miles. From the latter point it is a little west of southward to San Antonio, Texas, whence it deflects westward to the trans-Pecos mountains. The area of this sheet is marked by three long, simple fault lines, which produce the only topographic inequalities due to disturbance. The first of these begins at the angle of the intercepting strike in Indian territory and Texas, and extends northwestward and southeastward through a point north of Denison, Texas, for over fifty miles. The downthrow is 600 feet to the northward, and Red river flows along the line of this fault for twenty miles or more. The second great fault extends from near Dallas to Del Rio, Texas, passing by Austin, New Braunfels and Uvalde, with increasing downthrow as we proceed westward. The third is along the eastern border of the trans-Pecos mountains, and is frequently disconnected, but has a regular northwestward and southeastward trend. The whole series, in common with the post-Cretaceous coastal strata, has been elevated along the interior edges by the post-Cretaceous continental uplifts and trans-Pecos mountain disturbances.

There have been at least three great epochs in the destruction and denudation of this ancient Comanche rock sheet. The western border was faulted and much elevated during the northern Mexican, trans-Pecos and southern New Mexican mountain-making epoch, for its rocks enter into their disturbed structure in increasing quantity southward. The sediments of the great Neocene lake epoch, which constitute the Llano Estacado formation, and which were laid down horizontally between the mountain blocks of the above area, are largely composed of Comanche débris. So extensive was the denudation and erosion of this little appreciated Neocene lake epoch that the western two-thirds of the Comanche series was degraded, and entered into the composition of these lake deposits. It has been my pleasure during the past year to find several remnants of the Comanche series west of the Llano Estacado outcropping beneath its escarpment of Tertiary beds.

That this first great denudation of the Comanche series took place since the Eocene is further demonstrated, first, by the utter absence of Eocene débris in the sandy littoral beds of the latter formation: the base-leveling of Eocene time did not cut down to the Comanche series. Secondly, by the fact that the Comanche débris again enters into the composition of the post-Eocene formations of the coastal region, of probable synchronous age with the Llano Estacado epoch.

The second epoch of destruction of the Comanche series by denudation thus far recognized was in late Quaternary time, when the Gulf coast coincided with the present eastern border of the Cretaceous. By this process the older strata are exposed, and the escarpments of all the terranes are slowly receding eastward.

It is impossible at present to enter into a discussion of the evolution of the present drainage, across the strike and with the dip, which has produced the unique and characteristic topography, further than to say that there are two important stages in its history independent of the above-mentioned Neocene Llano Estacado epoch, when the extension of the Comanche terranes westward from the 100th meridian were almost entirely degraded, and their débris entered into the composition of the Llano Estacado sediment: The older is the system of rivers embracing the Red, Colorado, and Brazos, all of which have, by headwater erosion, cut their way completely across the Comanche area and deep down into the Paleozoic floor. The second and later epoch of erosion belongs to a superimposed drainage system composed of such streams as the Trinity, Paluxy, Lampasas, Guadalupe, Nueces, Frio and Devils rivers, which are now carving the great plateaus once separating the streams of the older system into remnantal buttes and mesas and reducing them to base-level.

By this double erosion and degradation by far the greater part of even the post-Llano Estacado remnant of this magnificent series has been eliminated and what is now exposed, although covering an immense area of country, is only a remnant of the previous extent.

The present topographic forms of this erosion can be readily understood.

The firm persistent limestones and harder chalks outcrop as escarpments of stratification, producing landmarks which can be traced for immense distances. Thus, the outcrop of the Goodland limestone in Indian territory forms an escarpment some 200 miles long, overlooking the valley of the Trinity and Paluxy sands. The Duck Creek, Denison, Fort Worth and *Caprina* limestones produce similar landmarks. The softer disintegrated chalks nearly always occur on the slopes or faces of these escarpments; while the clays and sandy terranes, such as the Walnut clays and Trinity and Paluxy sands, weather into extensive plains or semi-valleys extending interiorward from the escarpments. Where the headwater erosion of the superimposed drainage above mentioned encroaches upon the shorter and more precipitous drainage slopes of the older and deeper incised drainage, buttes and mesas are evolved. When the Comanche Peak beds, surmounted by the *Caprina* limestone, constitute the divide, these buttes are invariably of the following types: (1) Flat-topped mesas surrounded by precipitous escarpments; (2) Slopes of 45° composed of the Comanche Peak chalk; (3) Basal plains or pediments composed of the *Exogyra texana* clays and the *Gryphæa* beds. If the divide is composed of the Glen Rose beds the resulting buttes are usually conical, encircled by benches resulting from the alternating soft and hard layers. The great difference of induration in the respective terranes is also productive, especially in the eastern half of the area, of extensive plains coincident in slope with the dip, and terminating eastward against an escarpment of the overlying beds, which invariably deflects the drainage parallel to the strike, and on the west by a jump-off or escarpment of its own foundation strata. These dip planes are beautifully shown in northern Texas and southern Indian territory, where they constitute the prevalent topography and extend over vast areas. So extensive have been this planing-off in central Texas from higher to lower dip planes and the successive pauses at harder strata in the process of base-leveling that in the Burnet-Llano district the old plains can be traced where the drainage valleys have widened or narrowed and cut through from the *Caprina* limestone to the Glen Rose beds, the Glen Rose beds to the Carboniferous limestones, the Carboniferous limestones to the upper Cambrian, until finally the Archean and granite rocks are reached in which the Colorado is now cutting some 700 feet below the base of the Trinity and 4,000 feet below the former level of the upper Cretaceous.

It has been denied* by those who have not studied the Mesozoic and Cenozoic history of the Texas region that this erosion has taken place, and that this central Paleozoic district was ever covered; but he who restores the denuded strata or studies the topography so beautifully recorded in the

*Preliminary Report on the Geology of the Central Mineral Region of Texas, by Theo. B. Comstock: First (Second) Annual Report of the Geological Survey of Texas, Austin, 1889, pp. 314–316.

topographic sheets of the United States Geological Survey, or has seen the remnantal buttes of the Cretaceous, red bed, Carboniferous and Cambrian formations standing as mute witnesses above the older rocks will see most undisputably recorded their deep burial beneath the Cretaceous seas.

The Age of the Comanche Series.

To me, the age of the Comanche series has and ever will be a question of secondary consideration to its stratigraphic and faunal definition. I cannot refrain, however, from calling attention to a few data which must be of interest to those who insist upon trans-oceanic correlation.

It being admitted by all students that the Dakota sands, which rest unconformably upon the Denison beds in Texas, are the base of the upper Cretaceous and show remarkable specific identity with the upper Cretaceous beds of Europe, the stratigraphic position of the Comanche series as a lower formation cannot be doubted. In my check-list of the invertebrate fossils of the Texas Cretaceous, I have endeavored to give the history and stratigraphic range of each known species. Since that work was prepared I have made many additions and a few corrections. If the paleontologist will compare the species and faunas enumerated in that list with those of Europe, he will soon come to the conclusion that there is no specific similarity in the beds below the *Exogyra texana* clays, and that there are the most radical differences in stratigraphic occurrence. He will find that in the lower half of the Comanche series (the Glen Rose and Trinity beds) there is not a single species of characteristic Cretaceous age, and that while there are no criterional forms, such as ammonitidæ, echinodermata, etc., any of the genera can be as well referred to the Jurassic as to the Cretaceous.

In the Fredericksburg or Comanche Peak division, the lowest occurring and most abundant species, the *Exogyra texana* (*E. matheroniana*), which occurs here only in the very lowest beds of the undoubted lower Cretaceous, are characteristic of the very uppermost member of the European Cretaceous, the Senonian. This is the only species of the Comanche Peak division, however, which is known positively to occur in Europe. The two Ammonites (*Ammonites pedernalis*, Roemer, and *Schloenbachia peruvianus*, von Buch) are unknown in Europe, and the first is of a Triassic ceratitic type, while the other is found only in South America and Benguela land, Africa, in beds of undetermined age. The echinodermata have been pronounced by Professor Louis Agassiz to be of Neocomian type, while the variety of *Gryphæa* is a Jurassic type in Europe. Again, in the *Caprina* limestone occurs the only *Hippurite* in all the north American Cretaceous, while in Europe the genus ranges through the middle and upper divisions. In the Washita division, however, there are many species of undoubted European similarity if not identity, and Mr. Jules Marcou, in his geology of North America, has shown many of these to be of Neocomian occurrence. There are other species, however, which are characteristic of the Gault. The upper, or Meek and Hayden, section of the North American Cretaceous shows, in its dicotyledonous plants, its ammonitidæ, its echinodermata, its ostræidæ, its inocerami, and in its other fossils, a remarkable resemblance to the European upper Cretaceous faunas, *i. e.*, the Cenomanian and Senonian. But in the American upper Cretaceous strata there is an utter absence of *Hippurites* and *Nerinæa*, genera which so abundantly occur in Europe.

This discordance of paleontologic occurrence of species, however contrary to the tenets of ancient descriptive paleontology, is in thorough harmony with modern biologic and stratigraphic doctrines; for the species would require great intervals of time to migrate the long distance between Texas and Europe, during which intervals wide differences in sedimentation and stratigraphy would occur.

The writer fully realizes that, notwithstanding the years of labor of his able predecessors and himself, we have as yet only begun the study of this great series, and that there still remains in them an extensive field for patient investigation.

DISCUSSION.

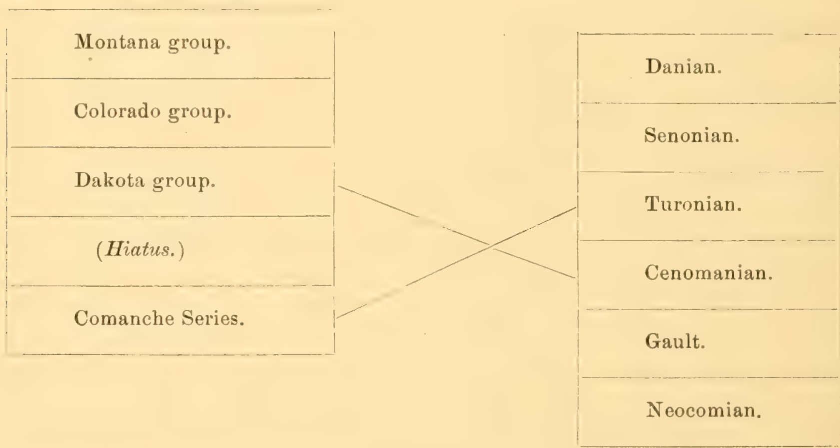
Dr. C. A. White: The Trinity beds, to which Mr. Hill refers as lying at the base of the Comanche series, I have, in a work now in press, provisionally referred to the base of the North American lower Cretaceous. They contain, besides some undetermined dinosaurian remains, a few species of non-marine mollusca; but I am at present unable to say whether these forms are more suggestive of Cretaceous than of Jurassic age.

The fossils which Mr. Hill has exhibited as coming from strata beneath the Comanche, I am at present unable to specifically identify. If they really came from the horizon indicated, I think they represent a hitherto unknown molluscan fauna, and that they are of very great interest.

I quite agree with Mr. Hill in the opinion that the different subdivisions of the Texan Cretaceous cannot be definitely correlated with subdivisions of the European Cretaceous. I also think that the assumption of such correlations as have been published, by various authors both in Europe and America, is much to be deplored, because it retards rather than advances true scientific knowledge. For example, the venerable and distinguished Professor Roemer, of Breslau, who has published so much upon the fossils of the Texan Cretaceous, and who knows the paleontology of the European Cretaceous as well as any person living, has referred a collection of Comanche species to the upper Turonian. He does not merely say that the forms which he published are analogous to those of that subdivision of the European Cretaceous, but he refers them definitely to the same, as if it were as clearly recognizable here as in Europe. On the other hand, the Dakota group, after the early claims that its flora indicate Tertiary age subsided, has by common consent among a large number of geologists been regarded as of Cenomanian age.

Comparatively late investigations have shown that strata equivalent to the Dakota group in Texas not only overlie the Comanche series, but that there is a wide time-hiatus and unconformity between them; that is, the assumed correlations, referred to above, place one assemblage of strata far beneath another when in reality its true place is far above. The accompanying diagramatic table will illustrate the case in hand.

The right-hand column represents in their order the subdivisions of the European Cretaceous, and the left-hand column those of the general Cretaceous section of the southern interior portions of North America. The positions of these two portions of the table with relation to each other is not intended to show the taxonomic relation to one another of their respective subdivisions, because I am not yet in possession of any very clear ideas upon that subject. It is only intended to show graphically the effect of the assumed correlation to which I have referred; that is, if we draw a line from the space representing the Dakota to that representing the Cenomanian, and another line from the space representing the Comanche to the upper part of the one representing the Turonian, they will cross each other. The shifting of the relative position upward or downward of the right-hand and left-hand portions of this table to meet the views of different persons as to the general correlation of the American and European Cretaceous will not affect the fact intended to be expressed by the crossing of the lines between them.



Many similar cases of theoretical paleontology at fault might be cited, to some of which I have already called attention in my writings, but which I have not now time to consider. I think I am justified in saying that theoretical attempts like these at special correlation of subdivisions of any geological system for different continents are unscientific, and, with due respect to those who hold different views, that it is time we were done with them.

Professor Hill: All analogies between the American and European formations seem to cease when we reach the Comanche group; yet there are many species of the Comanche which are almost indistinguishable from European forms, and afford the paleontologists of the old world a foundation for their attempted correlations.

Mr. C. D. Walcott: Professor Hill has brought up the question debated by many geologists—whether the Cretaceous and later formations ever extended over the central Paleozoic area of Texas. A few years since I examined the latter rocks of this area and saw the escarpments of the Cretaceous strata facing the central Paleozoic area. As the last report of the

Texas state survey takes the ground that this Paleozoic area was an island in the Cretaceous sea, it is interesting to see how far the facts accord with this theory. From the statements communicated by Professor Hill and from analogy it seems that he must be correct, and that the Cretaceous overlapped this central area; otherwise it would now be reduced to base-level by erosion. I should like to hear what the geologists of the Texas state survey who are present have to say about this theory.

Mr. E. T. Dumble: I am not personally acquainted with the geology of the central area save in a general way. Dr. Comstock, who is in charge of the district, has given in his report some of the reasons why he considers this area to never have been covered with the Cretaceous rocks; among other reasons, urging that many points of this area are higher than any points of the surrounding Cretaceous area.

Professor Hill: Generally one can look over the Paleozoic area from the Cretaceous escarpment. It may be true that the Paleozoic does, in some places, rise to the level of the Cretaceous escarpment; but it is necessary to have at least 4,000 feet of Cretaceous strata removed to bring the two horizons on a level, and consequently the Paleozoic would require to be at least that much higher than the present escarpment to have been uncovered by the Cretaceous sea.

Dr. Cooper Curtice: To what has already been said in regard to the erosion of the escarpment surrounding the central basin of Texas, I wish to contribute the following remarks:

In going from Burnet, Texas, situated on the edge of the escarpment, southward to Marble falls, on the Colorado river, one successively crosses the following strata: lower Cretaceous, Burnet marble series (either Carboniferous or Silurian), Potsdam, Capitol granites, and Carboniferous. The Burnet marble appears to abut against the Potsdam sandstone. The sandstones rest horizontally upon the granites, and their lower beds are made of small masses of feldspar and quartz entirely like that of the granite. The summits of the sandstone beds rise over a hundred feet higher than the Carboniferous at Shinbone ridge, which they approach to within a couple of miles.

The semi-crystalline limestones of Shinbone ridge abut against the granites, but dip away from them. Carboniferous fossils were found within a very short distance from the contact, in an abandoned prospect hole. These limestones were on a level with the granites, or about on a level with the base of the Potsdam sandstone.

On the road westward from Burnet to Bluffton the following exposures were observed: Near Spring creek, a contact of the Burnet marble with Potsdam (*Lingula*-bearing) sandstones, with the Potsdam lying on granites; between Spring creek and Clear creek, apparently stratified granites; at

Clear creek, upturned Packsaddle schists, with inclosures of the granites. The granites underlying the Potsdam and intrusive into the Packsaddle schists were apparently of the same mass.

Potato hill lies about a mile north of the Clear creek crossing and two miles west of the escarpment. It is entirely composed of Potsdam sandstone, and its top is on a level with the crest of the adjacent escarpment. Its strata dip gently toward the northwest. *Conocephalites tripunctatus* (or *roemeri*), a fossil peculiar to the middle of the Potsdam series, occurs in its topmost bed. At the foot of the escarpment, a little north of east of Potato hill, Potsdam shales lie in contact with Burnet marbles. Toward the top of the escarpment, fossils said by Professor Hill to be from the horizon of the Trinity sands, the base of the 4,000 feet of Cretaceous strata, are quite plentiful. These are about on the level of the Potsdam fossils not two miles away.

The contact of the Carboniferous with granites, which are overlain by horizontal sandstones, and of the Potsdam sandstones and shales with Burnet marbles at three different localities, suggest the presence of a system of faults—vertical displacements—which must be taken into account while considering the level of the central area when the Cretaceous was deposited.

The injection of granitic material into the Packsaddle schists; the clean, fault-like contact of the "Shinbone" Carboniferous with the granites; and the apparent formation of the lower beds of the nearly horizontal strata of the Potsdam from the decomposed constituents of the underlying granites, all point out the post-Packsaddle and pre-Potsdam age of the latter.

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CARBONIFEROUS FOSSILS FROM NEWFOUNDLAND.

BY SIR J. WILLIAM DAWSON, F. R. S., ETC.

(*Read before the Society December* 31, 1890.)

CONTENTS.

INTRODUCTORY NOTE.

The plants referred to in this paper are in part specimens submitted to me some years ago by the late Alexander Murray, F. G. S., Director of the Geological Survey of Newfoundland; in part specimens presented to me some time subsequently by Mr. P. Paterson, of Quebec; but principally fossils from recent collections by James P. Howley, F. G. S., now Director of the Newfoundland survey. They are mostly of familiar forms, characteristic of the coal formation as it exists in Nova Scotia and Cape Breton, and especially of the lower and middle portions of it. A few are new, and some others raise interesting general questions. None of them seem referable to the lower Carboniferous or Horton series or to the upper Coal formation or Permo-Carboniferous. The strata in which they occur are similar to those of the coal formation of Cape Breton, and according to Mr. Howley contain several productive beds of coal.

The Carboniferous of St. George's bay, in western Newfoundland, may be regarded as the northeastern outcrop of the beds which dip under the waters of the Gulf of St. Lawrence in eastern and northern Cape Breton; and it is likely that large areas of Coal Measures exist under the Gulf of St. Lawrence in the intervening space. As exhibited in St. George's bay, the Carboniferous rocks include conglomerates, sandstones, green and red shales, with bands of limestone and dolomite, and beds or masses of gypsum, above which occur sandstones and shales representing the Millstone grit and coal formation, and holding the workable seams of coal.

In collections from the lower Carboniferous limestone, made by Dr. Robert Bell and Mr. Paterson, I recognized eleven species previously recorded from the lower Carboniferous of Nova Scotia, and two new species, *Serpulites murrayi* and *Macrocheilus terranovicus.* These were described in the report of the Peter Redpath museum for 1883.

The fossil plants are of interest as extending the flora of the Nova Scotia coal fields a little further toward the northeast, and as indicating the vegetation of the parts of the island of Newfoundland then above water, and which constitute the nearest portion of known Carboniferous land in America to the great coal fields of southern Wales and of England.

I shall begin with the description and discussion of certain plants which raise new points, or are new species, and shall then give a list of the better known species with their localities elsewhere.

New or remarkable Fossil Plants.

GYMNOSPERMEÆ.

In the original collection sent by Mr. Murray there was a fragment of calcified wood having its tissues much disintegrated by crystallization, so that in longitudinal sections the woody fibers appeared as irregular tortuous tubes, reminding one of those of the Devonian *Nematoxylon.* On treating fragments with hydrochloric acid, however, it was possible to see that the wood fibers had two to three rows of bordered pores, and that there were simple medullary rays. I therefore considered the wood to be probably that of *Dadoxylon materiarium,* so common in the coal formation of Nova Scotia.

In Mr. Howley's collection there is a large fragment of a trunk in a much better state of preservation, and which is not distinguishable from the species just named. *D. materiarium* is very abundant in Nova Scotia and Cape Breton, and extends from the middle coal formation to the upper coal formation and Permian, where it is associated with leafy branches of *Walchia* in such a manner as to render it probable or certain that it is the wood of that genus.

I may remark here that I prefer the name *Dadoxylon* to the more recent *Araucarioxylon,* as the latter implies a false theory of the affinities of the wood; and that I do not regard the criteria of structures of fossil woods as sufficient to establish good species. They vary much in different states of preservation and in stems of different ages, and the differences of the mere woody structure in fossil woods of different species are too minute to be infallibly ascertained. For this reason it often happens that the same wood in different states receives different names, and that the woods of different species are confounded under one name. As an example of the latter case, while it seems certain that the wood properly called *Dadoxylon* has belonged to *Walchia*, yet there are two or three species of *Walchia* in the upper Carboniferous of Nova Scotia and Prince Edward island, and I have not been able, after examining great numbers of slices, to ascertain a similar specific distinction in the woods showing structure.

Mr. Howley's collection also contains a small stem, about two inches in diameter, showing a very distinct radiating woody structure, with indications of a pith destroyed by decay and compression. The wood of this specimen is more thin-walled than the former, with short and unequal medullary rays and the bordered pores less constant and continuous. These characters ally it with the wood of *Cordaites*, which I believe can always, when well preserved, be distinguished from that of *Dadoxylon*. Leaves of *Cordaites borassifolia* also occur in the collection.

Another remarkable specimen is a quantity of loose and soft fibrous carbonaceous material resembling the mineral charcoal of coal. It contains a small amount of calcareous matter, but not enough to give it coherence, and can be studied only after treatment with nitric acid, when it presents detached carbonaceous fibers. These show two to three rows of bordered pores and traces of the medullary rays, and I imagine it must have been a wood similar to the *Cordaioxylon* mentioned in the last paragraph. Material of this kind, as I have elsewhere shown,* constitutes much of the mineral charcoal of our coals.

Still another specimen, from Codroy river, presented to me some years ago by Dr. Robert Bell, is a black chert, which when sliced proves to be a limpid quartz filled with shreds of vegetable matter. It is, in short, a congeries of fragments of herbaceous plants, appearing as if chopped up finely or disintegrated by maceration, and imbedded in a clear silicious paste. The tissues observed are scalariform vessels, delicate fibers and elongated cells, and parenchymatous cellular tissue, with occasional remains of spore-cases or macrospores. The mass may be characterized as a silicified vegetable mould composed of fragments of the more delicate tissues not usually preserved. In this it resembles some of the specimens found by Mr. Grieve under the trappean beds of Burntisland, in Scotland, which have been described by Professor Williamson. I hope to make further examination of this material, and in the meantime would direct attention to it as possibly affording, in some parts of it, more complete organs of plants than those in the specimens in my possession.

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* Quart. Journ. Geol. Soc., vol. XV, 1859, p. 626.

The gymnospermous remains in the collection are thus of three types only, viz:

1. *Dadoxylon materiarium*, the most common coniferous wood in the coal formation of Nova Scotia;

2. *Cordaioxylon*, sp., the wood probably of the species of *Cordaites* found in the same formation;

3. *Cordaites borassifolia*, leaves of which species occur in the shales, associated with the woods.

LEPIDODENDREÆ.

The genus *Lepidodendron* and its allied genus *Lepidophloios* are at present much involved in that confusion which must necessarily result from the description of mere fragments of large trees. The trunk of a *Lepidodendron* retaining its rotundity, or more or less flattened, showing the outer surface or the inner surface of the epidermal layer, or the surface of the woody zone, or the mere surface of the axis, will under all these different conditions present very different appearances, while leafless or leafy branches or branchlets in like manner are extremely different from one another. Hence the description of fragments of stems without leaves or fruit has encumbered the subject with a load of uncertain synonymy.

My Newfoundland collections contain at least one species which shows the character of the old stem, the branches and the leaves, and which besides belongs to a type of great interest in its relation to other lepidodendra. It may be described as follows:

LEPIDODENDRON MURRAYANUM,* SP. NOV.

(Figures 1, 2 and 3, plate 20.)

The old stem (figures 2 and 3); surface immediately below the thin epidermis has pronounced elongate elliptical leaf-bases, 3 cm. long and 8 mm. broad, running into each other vertically by a narrow isthmus, so as to give from some points of view the appearance of interrupted ribs. The leaf-bases and borders are striate longitudinally, and have on the lower part some transverse wrinkles. The leaf-scar is sub-central but nearer the top of the leaf-base, ovate tending to rhombic, in the natural state inclined strongly inward or prominent at the lower edge. Vascular scars crowded in the center of the leaf-scar; the two outer meet below in a hippocrepian form with the central scar in the middle. This stem has probably been six inches or more in diameter, and has an impression of the axis in the interior. The axis is longitudinally striate and only $\frac{3}{4}$ of an inch in diameter.

* In MS. notes sent to the late Mr. Murray the name *Sigillarioides* was proposed, but this I have found to be preoccupied.

Leafy branches (figures 1* and 3); thickish, with leaf-bases shorter and broader, being about 8 mm. long and 4 mm. broad, but similarly marked. Leaf scars rounded, rhombic, with the vascular scars close together. Leaves about 2 mm. wide and three inches or more in length. Some of these leaves are sufficiently preserved to show under the microscope the scalariform vessels of the midrib in a pyritized state. Loose leaves, probably of the same species, are straight, pointed, and three to four inches in length.

The fruit has not been seen, though there are in the beds certain flattened lepidostrobi which have been long and cylindrical, and also two forms of the genus *Lepidophyllum* of the types of *L. triangulare* and *L. lanceolatum* of authors. Some of these may have belonged to the present species.

In the coal formation of Nova Scotia there is a species which I have described as *L. cliftonense* (figures 4 to 8, plates 21 and 22) from its locality,† and of which I have found very perfect specimens. It is in some respects so near to the above that I have doubted its specific distinctness, though on careful comparison there seem sufficient grounds for a difference of name. I therefore figure this species also, more especially as it has not before been figured and as it shows the fruit and habit of growth.

It will be observed that this species agrees with the last in the forms of the leaf-bases and in the length of the leaves, which are, however, wider and sometimes as much as five inches in length, while the leaf-bases are transversely furrowed above as well as below the scars. The leaf-bases also are somewhat different in shape and more spirally arranged, and the leaves are longer in *L. cliftonense.* Additional specimens might, however, show them to be varieties of one species. The foliage reminds one at first sight of that of *L. longifolium* of Sternberg, but both leaves and scars are altogether different in detail.

I would remark here that the leafy branches in figure 8 (plate 22) are not a "restoration," but taken from a sketch in my note-book of a specimen exposed on a large slab of sandstone. It is the more necessary to remark this as several European paleobotanists have borrowed similar figures from my papers without acknowledgemnt, and have printed them as "restorations." It may also be remarked that though the leaf-bases of *L. cliftonense* are smaller in the older part of the stem than those of *L. murrayanum,* this difference may be more apparent than real, since the specimen of the latter may be from the main trunk, and that of the former from one of the larger branches only.

These plants raise several interesting points in regard to the lepidodendra. As I have elsewhere pointed out,‡ the growth in diameter of stems of lepido-

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* Figure 1 is unfortunately inverted in the plate.
† Geological History of Plants, 1888, p. 164.
‡ Ibid, p. 162; also Acadian Geology, 1878, p. 452.

dendra took place in three different ways: In some, as in *L. Sternbergi*, the bark retains its vitality in such a manner that the leaf-bases increase in size and do not become separated from each other. In others, as in *L. veltheimianum* and *L. pictoense*, the leaf-bases remain small and the intervening bark becomes torn in strips, leaving wide gashes without any scars. An intermediate type is that which we have in *L. rimosum* and *L. corrugatum*, in which the scars increase only slightly in size and then become separated by rims of slightly wrinkled bark. It would appear, from the observations of Williamson and others, that the first condition appertains to those Lepidodendra that possess only a very slight development of the woody axis, while the second occurs in those species in which the woody zone becomes thick and strong.

The two species above referred to evidently belong to the first category; and, as the stems found are not large, still older stems would probably show larger leaf-bases. Such species of lepidodendra approach nearer than others to the genus *Lepidophloios* in the expansion of the old leaf-bases and the small development of the woody axis; and it is interesting to notice that they also resemble them in the great length of the leaves and the thickness of the branches. The lepidodendra whose branches end in slender sprays are usually, if not always, those in which the woody axis is large and the bark of the old stems torn and wrinkled.

I may add that these differences are most important in the discrimination of species of the genus *Lepidodendron* by the markings on the stems, though they have been too often overlooked.

Another noteworthy point is the manner in which the fruit of *L. cliftonense* is borne on slender branchlets with few and short leaves, extending from the thick branches. Such branchlets might, if alone, be readily mistaken for branches of other species. They also help to explain the scars of fructification often found on lepidodendra, as well as on the so-called ulodendra, some of which, however, are not generically distinct from the lepidodendra, and on *Lepidophloios*. In some species, especially of the latter genus, these scars are seen from their form to represent sessile cones, usually of large size; but in other cases they are merely round marks, as if indicating the insertion of branches or buds. The little fertile branchlets of *L. cliftonense*, which would probably die after the maturity of the fruit, would leave such scars, and may probably account for some of the less intelligible of them.

If now we compare our two species above described with others found in America and Europe, and most of which are characterized merely by the forms of the leaf-bases and scars, we may exclude from consideration all those in which the leaf-bases do not expand in growth, and confine ourselves to those having living and expanding leaf-bases. At first sight we might imagine that these would be the oldest, as being simpler than the others in structure ; but though some of the Erian or Devonian species are probably of this type, in the lower Carboniferous, where the lepidodendra first became important, the species with leaf-bases separated by wrinkled bark or by expansion of the cortical tissues between the leaf-bases are apparently predominant, though others also exist, and the type which we are now considering perhaps culminates in the coal formation.

We may first refer to *L. costatum* of Lesquereux, with vertical rows of corrugated leaf-bases, but separated by distinct longitudinal spaces of wrinkled bark. This is a lower Carboniferous species, and is compared by Lesquereux with his *L. brittzi* and with *L. volkmannianum*, Sternberg, of the European Carboniferous, both of which have strong points of resemblance in the characters of the leaf-bases, though differing in the scars and in the leaves, so far as known. The *L. wortheni* of Lesquereux is based on fragments closely allied in general form to our species. So also is *S. diplotegioides*, a species found in the lower coals as far west as Arkansas. None of these species are, I think, sufficiently near to be identified with our Newfoundland and Nova Scotia species, though as most of them are known only by the bark of old stems, this may admit of doubt. In any case, lepidodendra of this general type and aspect were widely distributed, both in Europe and America, in the Carboniferous, and especially in the lower portions of the coal formation, to which in all probability the Newfoundland specimens belong.

I may add here that Zeiller * figures a species as *L. veltheimianum* which can scarcely be that species and may be a branch of *L. murrayanum*, with which it agrees very closely. The same plant is figured by Renault.† The leaf-bases of the Newfoundland species have also some resemblance to those of *L. aculeatum*, Sternberg, but differ in detail.

Another interesting question rises here as to the limits of *Lepidodendron* and *Sigillaria*, as determined by their surface markings. The markings of the latter have usually been considered as characterized by the leaf-scars being placed in vertical rows and often on continuous prominent ribs, and also by the fact that the lateral vascular scars are much larger than the central one; but in such a case as Lesquereux's species, *L. costatum*, the confluent leaf-bases in vertical rows have the effect of ribs, and in a less degree the same remark applies to *L. murrayanum*. I may add that when one happens to find young stems of *Sigillaria* not compressed, the leaf-bases are seen to project in the manner of those of *Lepidodendron*, and that in some non-ribbed Sigillarids, as in *L. elegans*, the very young branches have the scars arranged spirally.‡ In connection with this I may observe that Sauveur§ has described

* Vegetaux fossiles du Terrain Huillier, 1880, pl. XXII.
† Cours de Botanique Fossile, 1881, pl. V, fig. 2.
‡ Acadian Geology, 1878, p. 435.
§ Fossil Flora of Belgium, 1848, pl. LVI and LVIII.

two species of *Sigillaria*, *S. augustata* and *S. undulata*, which are scarcely distinguishable, so far as the old bark is concerned, from *L. murrayanum;* and Goldenberg* has two similar species, *S. aspera* and *S. coarctata*. Goldenberg's two species are by the character of their scars unquestionably *Sigillaria*, but *S. augustata* and *S. undulata* of Sauveur, especially the former, might well have been lepidodendroid trees very near to *L. murrayanum*. This, however, could be certainly ascertained only if more complete specimens could be found. On the whole one might infer that as the spiral and lepidodendroid characters of *Sigillaria* appear most prominently on young branches, the more lepidodendroid and spiral sigillaria are the lowest in type and the ribbed lepidodendra among the highest of that genus. But such a conclusion must be received as liable to many exceptions.

Annotated List of well known Plants.

LEPIDODENDRA.

* *Lepidodendron pictoense*, Dawson†.—Specimens imperfectly preserved, but in general aspect and form of the leaves and cones resembling this species, are not infrequent in the Newfoundland shales. I see that my friend, Mr. Kidston, in the British Museum catalogue of fossil plants, refers this species doubtfully to *Lepidodendron rimosum*. The latter is known to me in Nova Scotia only by the bark of mature stems, but this is entirely distinct from similar portions of *L. pictoense*, in which the leaf-bases remain small but occur in strips closely placed together and separated by deep clefts in the bark. In short it belongs to a type altogether different from that of *L. rimosum*. Its nearest European allies seem to be *L. haidingeri* of Ettingshausen and *L. lycopodioides* of Sternberg; but the latter is now regarded by Kidston ‡ as identical with *L. sternbergi*.

FILICES.

* *Neuropteris rarinervis*, Bunbury.
* *N. auriculata*, Brongt. (or allied species).
* *Altehopteris lonchitica*, Brongt.
* *Pecopteris abbreviata*, Brongt.
* *P. oreopteroides*, Brongt. (or allied species).
* *P. arborescens*, Brongt. This fossil shows rounded impressions of sori on the upper surface of the pinnules.

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* Planzen versteinerungen, 1857, pl. IX.
† Canadian Naturalist, vol. VIII, 1863, p. 431; Acadian Geology, 1878, p. 487, fig. 169.
‡ Brit. Mus. Catalogue, 1886, p. 151.

* *Sphenopteris* (*Cheilanthites*)* *hoeninghausi*, Brongt. This is the most abundant fern in the collection. Several of the specimens show the outer edges of the pinnules strongly reflected in the manner of *Adiantum* when in fructification.

Sphenopteris, sp. A larger broad-leaved species but imperfectly preserved.

* *Dictyopteris*, sp. A single pinnule not well preserved. It may be *D. obliqua*, Bunbury, which is found at Sydney, Cape Breton.

Psaronius, sp. A stem about four inches thick, consisting outwardly of numerous aërial roots, and probably the base of the stem of a small tree-fern.

CALAMITES, ETC.

* *Calamites suckovii*, Brongt.

* *C. cistii*, Brongt. Some of the specimens, from their cylindrical form, would seem to have been erect.

* *C. cannæformis* (?). Decorticated stem.

* *Annularia sphenophylloides*, Zenkel.

* *A. longifolia* (?), Brongt.

Fragment of stem and branches of *Annularia* or *Asterophyllites*.

* *Stigmaria ficoides*. Specimens of large size occur in the collection, and as no specimens of *Sigillaria* are present, these may possibly be roots of *Lepidodendron*. It would seem likely, however, that sigillarids will be found in this coal field as in others in eastern America, and Murray indeed mentions the occurrence of such trees, though he does not seem to have collected specimens. Perhaps, as often occurs, they were too imperfect to deserve preservation.

ANIMAL REMAINS.

The only animal remains seen in the collections are specimens of *Naiadites carbonarius* and *N. elongatus*, *Spirorbis carbonarius*, and a few ostracoid shells. There are also, in a carbonaceus band, some coprolites containing bony scales.

The species in the above notes marked with an asterisk are all found in the coal fields of Nova Scotia and Cape Breton, and especially in the lower beds nearest to the Millstone grit. The collection is small, and some of the more common forms of the coal formation are absent. This is, however, no doubt, accidental, and dependent on the imperfection of the collections, as Mr. Murray in his report of 1873 mentions *Sigillaria* as seen in the beds.

* *Calymmatotheca* of Zeiller.

Mr. Howley informs me that next season he hopes to collect more extensively.

The species present cannot be said to show any special conditions of climate or locality, other than the fact that, as in northeastern America generally, the assemblage of species is more accordant with that of western Europe than with that in the coal regions west of the Alleghanies.

Remarks on the Coal Formation of Newfoundland.

Such details as are known of the structure and distribution of the Carboniferous system in western Newfoundland will be found in the general report on the geology of Newfoundland by Murray and Howley,* and in Mr. Howley's short report of progress for 1889.† Murray estimates the whole thickness of beds seen by him in 1873 at 6,450 feet, composed as follows in ascending order:

a. Coarse conglomerate, with bowlders and pebbles cemented in a greenish sand; also sandstones and sandy shales (this probably corresponds to the lowest Carboniferous or Horton series of Nova Scotia). . . . . . . 1,300 feet.

b. Gypsum, dark-colored limestone and black shale, argillaceous and marly shale (this is probably the lower division of the Windsor or Gypsiferous or Carboniferous limestone series of Nova Scotia) . . . . 150 feet.

c. Gray and black limestones with marine organic remains and veins of galena, included in thick beds of variegated marls and sandstones (this is probably the equivalent of the upper part of the Windsor series in Nova Scotia) . . 2,000 feet.

d. Brown and reddish sandstones and conglomerates, with greenish micaceous and arenaceous shales; carbonized plants (this is the "Millstone grit" series of Nova Scotia) . 2,000 feet.

e. Gray and red sandstones, brown and black shales and clays; abundant remains of plants; beds of coal (this is the lower part of the productive Coal Measures) . . . 1,000 feet.

The sequence corresponds very closely in mineral character with that in some parts of Nova Scotia and Cape Breton, but the development of Coal Measure strata appears comparatively small. Mr. Howley, however, in his later investigations finds that the upper members should be greatly extended, and is now disposed to estimate these upper members at not less than 7,500 feet, which would better accord with the thicker portions of the

* London, 1881, pp. 85 et seq. and 309 et seq.
† St. Johns, Newfoundland.

Nova Scotia coal areas, and would also give a greater probable value to the productive Coal Measures. In so far as these are concerned, the quality and distribution of the coal would seem, as might be expected, to resemble that in the eastern coal fields of Cape Breton. The beds as yet found appear from Mr. Howley's report to be six in number, ranging from 14 inches to 8 feet in thickness, three of them having over four feet of good coal. The coal is apparently a free-burning bituminous variety, resembling that of the Cape Breton mines.

EXPLANATION OF PLATES.*

PLATE 21—FOSSIL PLANTS FROM NEWFOUNDLAND AND NEW BRUNSWICK.

FIGURE 1—*Lepidodendron murrayanum*, Dn.		Leafy branch (inverted).
FIGURE 2—	" "	Old stem.
FIGURE 3—	" "	Leaf scars of stem and branch.
FIGURE 4—*Lepidodendron cliftonense*, Dn.		Leafy branch.

PLATE 22—FOSSIL PLANTS FROM NEW BRUNSWICK.

FIGURE 5—*Lepidodendron cliftonense.*		Old stem.
FIGURE 6—	" "	Leaf scars of stem and branch.
FIGURE 7—	" "	Strobile borne on slender stem.
FIGURE 8—	" "	Branches, as seen on a bed of sandstone; reduced to one-eighteenth natural size.

* The titles printed on plates 21 and 22 are imperfect.

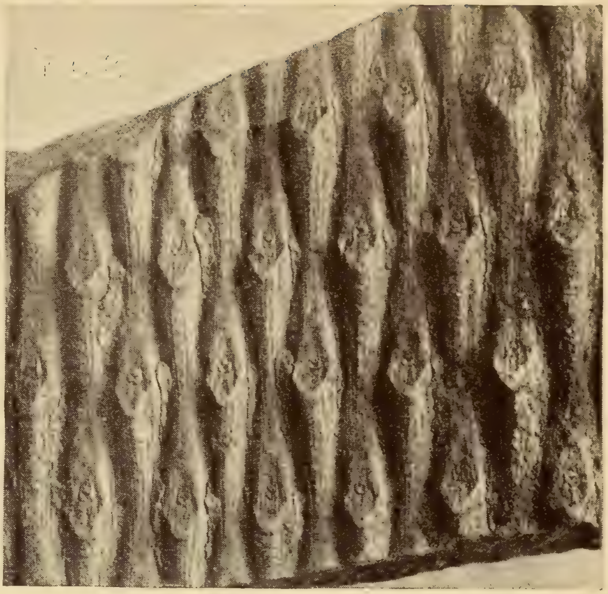
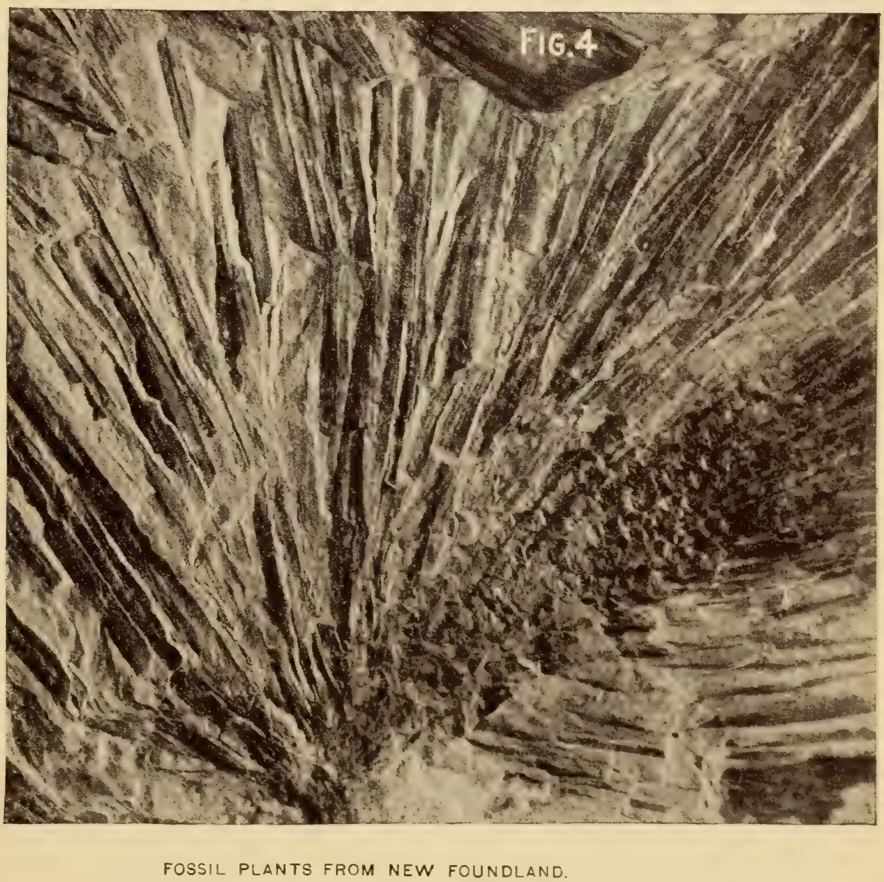


Fig.3.



FOSSIL PLANTS FROM NEW FOUNDLAND.

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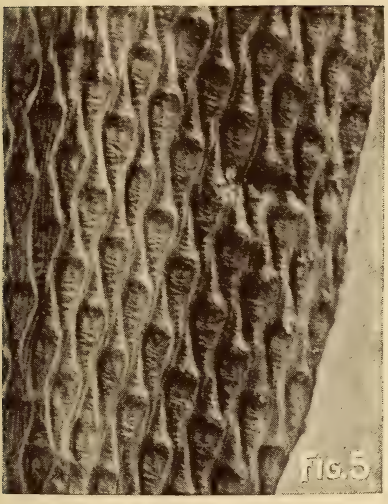

Fig. 5

Fig. 6.

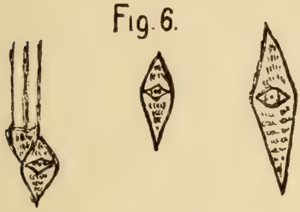

Fig. 8.

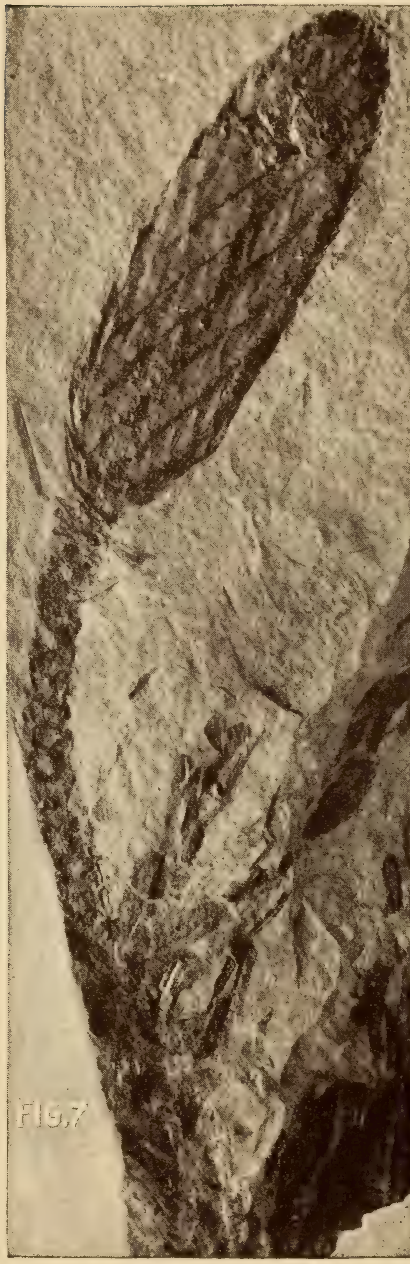

Fig. 7

FOSSIL PLANTS FROM NEW FOUNDLAND.

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VOL. 2, PP. 541-586 JULY 2, 1891

A PROPOSED SYSTEM OF CHRONOLOGIC CARTOGRAPHY ON A PHYSIOGRAPHIC BASIS.

BY PRESIDENT T. C. CHAMBERLIN.

WITH

THE GEOLOGICAL DATES OF ORIGIN OF CERTAIN TOPOGRAPHIC FORMS ON THE ATLANTIC SLOPE OF THE UNITED STATES.

BY WILLIAM MORRIS DAVIS.

CONTENTS.

A PROPOSED SYSTEM OF CHRONOLOGIC CARTOGRAPHY ON A PHYSIOGRAPHIC BASIS.

BY T. C. CHAMBERLIN.

(*Read by title before the Society December* 31, 1890, *in connection with the memoir by Professor William Morris Davis on the Origin of certain Topographic Forms.*)

The determination of time-relations has been based chiefly upon aqueous deposits. Attention is now turning more than heretofore to the study of topographic forms as time indices and as means of correlation. The doctrine of baselevels opened the way to specific studies of land sculpture as a means of determining successfully the varying attitudes of the land and their accompanying time-relations. A considerable body of discriminating geologists have become enthusiastic workers in this new field, and are bringing forth results of great interest and value. It becomes evident, upon consideration, that if it is possible to correlate fragments of topography distributed over the face of the continent, we may connect formations at great distances by a physiographic chain, where sedimentary connection is entirely wanting. Many unsolved problems in correlation will yield to the application of the new method, and many tentative correlations will be overthrown by it.

The method has been applied in certain districts sufficiently widely and successfully to render it desirable to devise some satisfactory method of cartographic representation. To illustrate, Professor W. M. Davis, has determined, as he believes, that the remarkably horizontal crest-lines of the Appalachian ranges in Pennsylvania and New Jersey are remnants of a base plain formed in Cretaceous times. He has also determined that a later plain of much wider extent represents a base plain formed in Tertiary times.

Mr. Gilbert and myself have attempted to show * that certain terrace plains on the Allegheny, Monongahela, upper Ohio, and tributary rivers are synchronous with the earlier glacial epoch, and that certain lower terraces were formed at the time of the later glacial incursion. To say nothing of other determinations, here are four peneplains believed to represent four ages stretching from the Cretaceous to the late Pleistocene. Between these peneplains are slopes contemporaneous with them in formation. It is more than likely that other epochs than these are represented by the topography of that region. Is it not as serviceable to geological history to map these plains and slopes, and thus give tangible and vivid expression to the physiographic history of the region, as it is to map chronologically the contemporaneous sediments of the adjacent coastal region? Such mapping will give sharp expression to the determinations made and to the features that remain undetermined; will direct inquiry into the validity of what has been done; and will promote the developmont of physiographic study.

I therefore propose that a system of physiographic mapping on the chronologic basis be employed, and I submit the following system for discussion and for trial. I am prompted to do this at this time in view of the approach of the international congress of geologists, whose central themes of discussion will be correlations and cartographies, and before whom this subject may come appropriately if it has reached a sufficient state of maturity.

The following genetic classes of plains or peneplains are involved: (1) Plains formed by rivers approaching or at base-level; (2) Plains formed by shore-cutting and sublacustral or submarine deposition; (3) Base plains formed by subaërial degradation; (4) Surfaces formed by glacial reduction and deposition. Some minor classes will occasionally require representation, as lava plains, delta fans, and orogenic forms. There are also slopes contemporaneous with most of these that need appropriate means of representation.

It is proposed that plains be represented by lines, and slopes by dotted surfaces, both to be put on in colors varying according to the age of the formation represented. It is proposed also that the direction of the action of the agency, where practicable, be represented by arrow-heads. Thus, a base-plain formed by a river will be mapped by covering the surface with arrows (without feathers) pointing in the direction of the current, while lacustral plains will be mapped by parallel lines headed with arrow-points on the margin, indicating thereby the shore action, the most characteristic agency in its production. Where there is only a beach-line with a scarcely developed bordering plain to be represented, a row of arrow-heads with their points set against the beach-line on its seaward side may be used. In the case of subaërial plains or peneplains, parallel lines will be used without arrow-heads.

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* Bulletin No. 58, U. S. Geol. Survey, 1890.

To distinguish between a plain and a peneplain which may be quite rolling and yet clearly determinable, continuous lines may be used for the former and broken lines for the latter. The glacial surfaces may be represented by parallel wavy lines where they are approximate plains, and by discontinuous wavy lines where morainic or broken. Where desirable, the character of the wavy lines may be modified so as to imitate in some degree the undulations of the topography. Lava plains may be represented by checks, and delta fans by diverging lines consonant with their formations. Folds may be represented by a succession of arched lines like the old "caterpillar" convention for mountains, but of course in appropriate color, and faulted and tilted plains by a succession of angulated lines imitating the displacement.

These are devices for genetic representation. To introduce the chronologic element, it is proposed that colors be used corresponding to the periods to be indicated, each period to have a single color, in which its subaërial plains shall be represented by parallel lines; its fluvial plains by arrow-headed lines pointing shoreward; its glacial plains by wavy lines; its slopes by dots, etc.

THE GEOLOGICAL DATES OF ORIGIN OF CERTAIN TOPOGRAPHIC FORMS ON THE ATLANTIC SLOPE OF THE UNITED STATES.

BY WILLIAM MORRIS DAVIS.

(*Read by title before the Society December* 31, 1890.)

Introductory Note.

It has lately been suggested to me* that the geological age of topographic forms might be indicated on maps by means of a geological coloring, similar to that employed commonly to denote the age of the rocks themselves. The suggestion is closely pertinent to certain work that I have had on hand for two years past, and in order to experiment upon it, as well as to place it before the geologists and geographers of the country for discussion, I desire to submit the following essay to the consideration of the Society.

The Classification of Topographic Forms according to Age or Degree of Development.

Basis of Classification.—In the attempt to classify geographical forms on a natural basis, I have come to consider them as follows: Every geographic unit, or area of essentially single structure, may be conceived as passing through a complete cycle of topographic forms in its life history, from the time when it is first presented to the destructive forces of the atmosphere, of rivers and of the seashore, to the remote end when it is worn down to a flat surface at baselevel. At the beginning its form is determined by processes of accumulation, elevation and dislocation. Its topography is then constructive, and may be recognized as such by the absence of elaborated drainage forms, and by the unworked outline of its coast. Later on, when the drainage has had time to develop, the surface is of vastly greater variety of form, every part of it having been wrought by the processes of waste under the guidance of the main streams, while its coast is cut and filled into outlines on which the waves of the sea may swing in long, smooth curves. At this time it has the greatest variety and intensity of relief. Finally, when the waste of the valley sides has consumed the hills and reduced the whole to a nearly featureless surface of denudation, a peneplain, the early

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*Cf. this volume, p. 542.

constructive features and the elaboration of middle age are both lost; and if no accident enter to disturb the relation of mass and baselevel, the area will remain indefinitely with insignificant change, maintaining, like the Sibyl, an immortal old age.

The broad constructional forms of youth, the elaboration of maturity, and the featureless simplicity old age, are all recognizable in many parts of the world. The difficulty of the problem is not in finding warrant for this simple ideal life history, but in the proper consideration of the disturbances that interrupt it. At any time in the cycle of life, an area may be depressed and more or less drowned, or elevated and thereby carried into a new cycle; the forms acquired before change of level then taking the place of truly constructional forms as the basis on which further development repeats in many ways the features of youth. The possibility of thus subdividing the history of any district into chapters or partial cycles, each separated by some relatively rapid change of elevation or of attitude, would probably not have been questioned when the prevalent teaching of geology gave belief in hurried and spasmodic movements; but with the introduction of the doctrine of uniformitarianism, and especially with the confirmation of it supposed to be found in the theory of antecedent rivers, doubt would naturally arise as to the possibility of truly dividing the history of any region into long times of quiet and briefer times of relative activity. Yet, so far as I can see, the facts justify exactly such a division. There are several districts whose topography has been carefully examined in relation to their geological history, with the result of practically demonstrating that after a long period of relative rest they have passed through a short period of relatively active movement; and their history may thus be divided into partial cycles of geographic development, more or less complete, the present form of the surface being the product of the combined actions of destructive and constructive forces in all the cycles.

An objection to this conclusion that I have sometimes met is based on an exaggerated estimate of the share taken by rivers in denuding the surface of the land. It is overlooked that most of the land is not occupied by streams, and that the wasting of the interstream areas is very slow. Where large rivers are at work they may truly at times almost keep pace with elevation; but even where this rare relation is found it is characteristic of but a small part of the surface of the land. The interstream surfaces waste with comparative slowness, and the waste slowly washes and creeps to the streams, to be carried down to the ocean after many halts on the way. It is on these interstream surfaces that the records of one cycle are carried over into another.

Factors controlling Topographic Development.—Variations from the order of development of the ideal example are found in several directions. First and most important, as determined by structural peculiarities, in accordance with which it is possible to unite many individuals under a single species or class, as plains and plateaus; mountains, embracing a great variety of sub-species; volcanic structures; and so on with others of less importance, all these species having their own fashion of wasting from youth to old age. Second, individuals differ even in the same species as to rate of development, those of weak rocks in a moist climate being degraded faster than others. Third, there is some variation in the rate of development of certain features in individuals of different resistance; thus, in a hard mass, deep, narrow valleys will be cut down close to baselevel, while the interstream mass is little wasted; in a soft mass, the valleys will be shallow and wide open, and the stream channels will reach baselevel slowly, and not much sooner than the interstream masses, because the rapid wasting of the surface keeps the streams always overloaded and unable to cut channels of faint slope until the load decreases. Fourth, there is a great contrast in the intensity of development according to the altitude of the mass over baselevel: a low country cannot have deep valleys cut into it, however long its rivers work; a high country will in a relatively short time take on forms of strong relief. Fifth, according to the contrast of hard and soft members of the mass, there is a variation in the distinctness of the features of form during development; in a mass of horizontal beds, all of which are soft, there are no significant cliff outcrops contouring around the slopes, such as appear when some of the beds are harder than the others. Sixth, oscillations of level by which new cycles are introduced are much more apparent near the seashore than in the distant interior of a large continent.

It must be understood, also, that a single individual has many features; the valleys of the large rivers being most unlike the main divides between the basins. All these considerations, properly combined, go to explain the topographic form of any geographic individual.

"Age" and "Date" of Topographic Forms.—When topographic forms are thus described, age is not to be taken as a measure of time, but only as indicating the degree of development of the region concerned: a mushroom may grow old while an acorn has not advanced from its infancy; a low weak mass under plentiful rainfall may soon be reduced nearly to baselevel—that is, to a nearly featureless peneplain—while in another part of the world a very hard mass in a dry climate might scarcely lose its constructional form in the same time. One would have become old in the same measure of absolute time as that marking the youth of the other. The two might have the same geological date of beginning, but one would become geographically old while the other was still geographically young. As a corollary of this, it is seen that, in a single individual composed of members of different hardness and surviving several partial cycles of development, the weaker members

will acquire features characteristic of the newer cycle, while the harder members retain features from one or more previous cycles. This corollary is the guiding principle in practical work.

A natural consequence of the continued attack of the destructive forces of geographic development is that the more ancient forms are consumed and obliterated in the production of the new ones. It is therefore characteristic of this kind of work that, as more and more modern time is approached, the recognition of finer and finer subdivisions of time becomes possible. The older cycles that I have identified give us little record now beyond the general statement of a long still-stand. All the presumable minor oscillations during such a period are lost to our belated sight.

All old land forms would be rubbed out were it not for their occasional preservation by burial for a long period, followed by a resurrection, when they may become once more visible. Such surfaces might be referred to two dates: one the date of their first development and burial, the other the date of their rediscovery.

It appears that, when thus regarded, the forms of the land around us have been produced at different times. It is therefore possible to date them in accordance with the geological ages or divisions of time in which they were given their existing forms. In this geological sense, their "age" has an entirely different meaning from the geographic sense in which it has been used above. I shall therefore use the word "date" in speaking of geological time, and reserve "age" for the geographic meaning already indicated.

The Topographic Forms of the Atlantic Slope.

Outline of this Essay.—The thesis maintained in this essay is, in brief, as follows: The Permian and Jurassic constructional topography of the Atlantic slope was practically obliterated over the greater part of the area by the long-continued denudation of Jurassic and Cretaceous times, as a result of which the region was reduced to a lowland of faint relief—a peneplain. The only considerable elevations that remained above this lowland were in the White mountains of New Hampshire and the Black mountains of North Carolina, with their extension in the Blue ridge of Virginia. This Cretaceous lowland was uplifted about the opening of Tertiary time, and constitutes the upland surface of our highlands. The valleys and open lowlands of to-day have been etched during Tertiary time in the uplifted Cretaceous peneplain, their depth depending on the height to which their streams were raised, and their width depending on the weakness of the rocks in which they are sunk. About the close of Tertiary time a moderate elevation occurred, allowing the rivers and streams to trench the lowlands produced in the Tertiary cycle. Near the sea-coast, where changes of level soon have effects of topographic value, minor oscillations must be taken into account; but in the inner country it is possible to classify our present topographic forms in the three categories thus indicated: First, the uplands and the occasional hills that rise above them, these being the product of long-continued and nearly completed Jura-Cretaceous denudation; second, the valleys and valley lowlands of Tertiary date; and, third, the trenches of post-Tertiary date.

*The resurrected pre-Triassic Peneplain in southern New England.**—The most ancient topographic form on the Atlantic slope of which a remnant is known to me as a topographic element of the existing surface is an exception to the general statement just made. It is a small part of the old land surface on which the Triassic monocline of New England was laid down in Massachusetts and Connecticut. The unconformable overlap of the Triassic on the ancient crystalline rocks shows that the latter were deeply eroded from whatever constructional form they may have once possessed before the former were deposited on them. The comparatively even line of the under or western margin of the Triassic beds shows that the eroded surface on which they rest is itself relatively even; hence the pre-Triassic erosion must have endured long enough to reduce the ancient rocks to a surface of moderate relief—that is, to a peneplain. When the post-Triassic disturbance tilted the sandstones into their faulted monocline, the underlying rocks must have shared in the disturbance, and the average surface of the ancient peneplain must have gained the same dip as that given to the monocline. All the part of this old peneplain that was then tilted above the level of the present uplands has been worn away; all that part which still lies beneath the present baselevel is preserved, buried under the remaining Triassic beds; but a belt of the old surface between these two parts has been disclosed to our sight by the removal of the weak Triassic beds from it, and is now visible on the western side of the Triassic belt, in the slope from the crystalline highland plateau into the valley lowland. I do not wish to imply that this resurrected part of the old peneplain has suffered no loss of material whatever, and that its surface is precisely as it was before it was buried; but it does seem probable that the general eastern slope of the western highlands is not simply due to a recent wasting of the crystalline mass, but is essentially an uncovered part of the foundation on which the Triassic beds were laid down. As such, it is a representative of the oldest land surface that I have been able to identify on the Atlantic slope. It is probable that similarly uncovered pre-Triassic surfaces exist in Pennsylvania and Virginia wherever the weak Triassic beds lie on hard crystalline rocks.

The uplifted Cretaceous Peneplain in southern New England.—On ascending the tilted and resurrected part of the pre-Triassic peneplain from the Connecticut valley lowland to its top, we find a plateau-like expanse stretching

* See figure 2, p. 420, of this volume.

away toward the west. Looking from its edge eastward, the trap-ridges of the Connecticut valley are seen rising to about the same height as the plateau, and beyond them portions of the corresponding eastern crystalline plateau may be seen, still closely accordant with the same general scale of elevation. The valleys and lowlands by which the plateau is interrupted may be filled again in imagination to the general level of its surface, and we shall have then restored a part of one of the more important elements, if not the most important element, in the topography of the Atlantic slope. The restored surface is not by any means perfectly even; but its inequalities are moderate, and it may be justly called a peneplain. It is manifestly a surface of denudation, for it is not at all in sympathy with the disordered structure of the crystallines or with the faulted monocline of the Triassic area. It is manifestly a surface of long-enduring denudation at about the same altitude of the land, for otherwise it could not have been reduced to so nearly level a surface as its parts now show its whole to have been before the present valleys were sunk into it. It is manifestly a product of denudation, not at the present altitude of the land, but when the whole region stood at a less altitude, such as would place the surface of the old peneplain close to base-level.* The form, extension, and date of completion of the peneplain, the date of its elevation to its present altitude, the tilting it may have suffered in elevation, and the time during which the valleys that now break it have been excavated, are to be examined.

The form of the peneplain may be seen from any one of the many slightly higher points of its upland surface. For example, taking the Air Line railroad eastward from Middletown, Connecticut † (see figure 1), one soon passes from the open Triassic lowland to the narrower valleys that are cut in the harder crystalline rocks of the eastern plateau; and at the little station of Cobalt, a road toward the north leads to Cobalt hill. The hill consists of a hard quartzitic schist, and affords a fine prospect over the surrounding country toward the east, south, and west. The prevailing feature of the view is the general evenness of the uplands. There are no summits rising like mountain peaks above the general level. The valleys that are cut below it will be referred to in a later paragraph. If an excursion be made eastward from Springfield, Massachusetts, to the hills of the plateau back of Wilbraham, the evenness of the upland is less marked; a number

* See the Topographic Development of the Triassic Formation of the Connecticut Valley, by W. M. Davis: Amer. Journ. Science, 3d ser., vol xxxvii, 1889, pp. 423–434.

† The various towns, rivers, and geographic districts mentioned in this paper are indicated by initial letters on several rough diagrams. The last pages of the essay contain an index of names and abbrevations employed. The diagrams have been prepared in the hope that they might serve a useful purpose to those readers who are not familiar with the details of the region under consideration, for my own experience in reading has shown me that geological arguments of relative simplicity are often obscured by the geographical integument that encloses them. The atlases in common use generally fail to locate small towns and streams; special maps of state surveys are often difficult to examine, as they present much more than is wanted. A good map, especially prepared for this paper, would be too expensive. Diagrams are therefore attempted, somewhat experimentally.

of gently sloping summits here rise above the average height of the country; the old lowland here was less denuded than in Connecticut, and hardly deserves the name of peneplain. Farther northward we find such isolated commanding summits as Monadnock, Sunapee, and Kearsarge, in New Hampshire, conspicuously above the general upland of their district; these might well have been called mountains even when the country about them was a lowland. The same may be said of Greylock, which rises so distinctly above the level of the Hoosac plateau in northwestern Massachusetts, and so with many other examples that might be noted. Still the evenness of the plateau is its first characteristic, as has been pointed out by Emerson. Our mental reconstruction of the lowland of denudation of southern New England must evidently not be too geometrical; it must include gentle hills and occasional low mountains, as well as a nearly featureless intervening low-

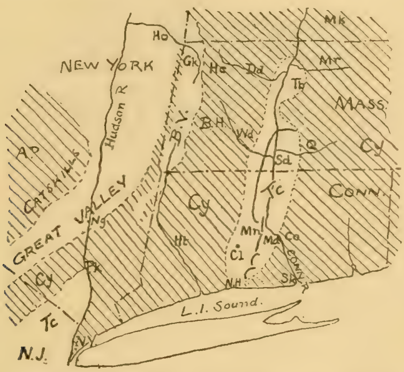

Figure 1—*Cretaceous Peneplain in New England.*

land; but the latter was predominant. The topographic maps of the Massachusetts atlas, lately issued, give very good illustration of the general form of the plateau uplands; the sheets named Hawley, Becket, Sandisfield, Chesterfield, Granville, Belchertown, and Barre may be especially mentioned in this connection.

When one becomes convinced of the verity of the explanation offered for the origin of the plateau—that it was once a lowland of denudation, a baseleveled peneplain—it must be admitted that its entire extent may have greatly exceeded that of southern New England. The process of baseleveling could not have been local, but must have affected broad areas. It is therefore with some confidence that a search for other parts of the old peneplain is undertaken.

New York being unmapped, it is advisable to cross to New Jersey, whose form is so fully represented in the state atlas, and see what may be discovered there.

The uplifted Cretaceous Peneplain in the New Jersey Highlands.—The New Jersey highlands are in many ways homologous with the Berkshire highlands of Massachusetts. They are both composed in greatest part of crystalline rocks; both are greatly disturbed; both lie between belts of Triassic deposits on the east and Cambrian strata on the west. The correspondence may be found in form as well as in structure and associations. The highlands of New Jersey possess in a conspicuous degree the evenness of summit outline that prevails in Massachusetts. Standing on the northern end of Schooley's mountain, near the center of the highlands (see figure 2), the surrounding members of the plateau show a marked tendency to rise to the

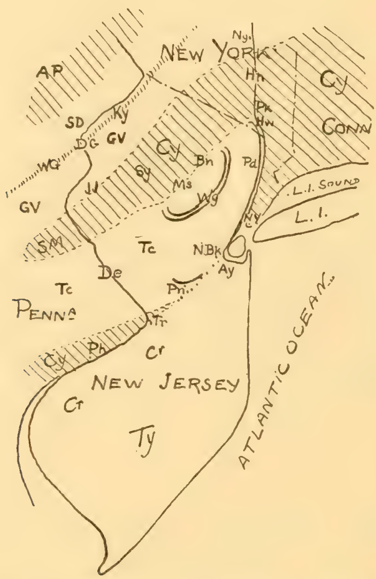

FIGURE 2—*Cretaceous Peneplain in New Jersey.*

general upland level, but not to pass above it. This feature was recognized by Professor Cook some years ago, although it does not clearly appear that he explained it as a result of denudation while the region stood at a less altitude. He wrote:

"The Highland mountain range consists of many ridges, which are in part separated by deep valleys and in part coalesce, forming plateaus or table-lands of small extent. Some of the included valleys are quite as deep as the red sandstone plain on the south and the Kittatinny valley on the north and west. * * * A characteristic feature is the absence of what might be called Alpine structure or scenery. There are no prominent peaks or cones. The ridges are even-topped for long distances and the average elevation is uniform over wide areas. Looking at the crests alone, and imagining the valleys and depressions filled, the surface would approximate to a plane gently inclined toward the southeast and toward the southwest. * * * The new atlas of the state will show how remarkably even-topped these ridges of the highlands are, and enable the reader to construct for himself the plateau indicated here by these crest-lines. * * * They are not to be understood as level, but as diversified by the ridges which rise from 100 to 300 feet above the deepest depressions, the latter being 400 to 600 feet above the adjacent valleys and plain country. Once upon them the so-called mountains disappear and sink into hills, whereas when viewed from the valleys, the plateau or table-land rises up as a mountain." *

Precisely the same arguments that have been used in considering the plateau in New England are applicable here. They lead to the same conclusion in both cases. The whole region must have once stood at a lower level, and long enough to have been denuded to the then baselevel from whatever earlier constructional topography may have once existed. The structure is one of extreme disorder. The topography commonly associated with such structure is that of mountain ranges, and we cannot hesitate in the belief that a fine range of mountains once existed here. If we would study the form that these ancient mountains once had, we should go to regions of more recent mountain growth, like the Alps; while if we would discover the structures that characterize the foundations of the Alps, we should look to the New Jersey highlands and their relatives along the Atlantic slope.

If the observer will ascend the hills on the front of the highland mass, as at Boonton or Morristown, he will see in the east the even crest-line of the Watchung trap ridges in the Triassic formation.† The ridges consist of two lava flows,‡ separated by one or two hundred feet of red shales. The lava sheets dip westward and constructionally ascend toward the east into the air. If the denudation by which they have been truncated from their once greater extent to their present form had taken place in the present position of the mass with respect to baselevel, it would be difficult, if not impossible, to explain their even summit lines. Here, as in the highland plateau, the denudation must have been in greatest part accomplished while the mass stood lower than it does now. Crossing the valley of the upper Passaic from the crystalline plateau to the eastern of the two Watchung ridges, and again looking eastward or northeastward, the outline of the Palisades ridge may be seen in the distance. Like the others, it has an even crest-line, but at a lower level. It is the edge of an intrusive lava sheet, tilted like the others to a moderate westward dip and truncated to its present form. Beyond the Palisades and across the Hudson, we come to the gradually ascending upland of crystallines, which, if continued, would lead us across southern New York and Connecticut, and into Massachusetts once more.

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* Geological Survey of New Jersey, Annual Report, 1883, pp. 27–29; see also pp. 60, 61.

† A view of the front of these ridges, as seen from the lowland on the east, is given in plate 1 of the Annual Report of the Geological Survey of New Jersey for 1882.

‡ N. H. Darton: Bull. 67, U. S. Geol. Survey, 1890.

All these elements of form have been baseleveled—the highlands, the Watchung ridges, the Palisades, and the uplands which lead us back to Massachusetts. Not only so: it is manifest enough from the study of the excellent topographic maps of New Jersey and of the atlas of the Metropolitan district around New York city, published by Bien, that all these baseleveled elements are part of one and the same baseleveled peneplain. The upland surface determined by one element accords with that determined by its neighbors.* The peneplain is truly no longer either a level lowland, as it was when finished, or a level upland, as it might have been if it had been uplifted evenly after its denudation. It is now a warped surface, from which we conclude that its uplift was somewhat uneven. The inequality of elevation was slight; it touches sea-level in Long Island sound and along a line lying a little southeast of New York, Trenton, and Philadelphia. An elevation of 1,000 feet is found in Massachusetts east of the Connecticut valley; of 1,200 to 1,400 or 1,500 in the western or Berkshire plateau; of somewhat more than this where the plateau is cut by the Hudson gorge; of somewhat less in the northern highlands of New Jersey, and thence decreasing southwestward into Pennsylvania. The warping that it has suffered is gentle. It will be further considered in describing the valleys by which the uplifted peneplain is now dissected and whose depth is determined by its uplift.

The geological Date of the Completion of the New Jersey Peneplain.—It is an interesting matter to determine the date of the completion of the peneplain and the processes that may have been chiefly concerned in its production.

The date is well defined in New Jersey. If the gently inclined peneplain is followed from the highlands toward the southeast by means of its remnants now preserved in the crest-lines of the ridges of the hard Triassic lavas, it is found to descend below the oldest of the Cretaceous beds that form the foundation of the deposits in the coastal plain. The contact of the two may be seen in some of the clay pits at Amboy, where the lowest members of the Cretaceous lie unconformably on the denuded Triassic strata. The surface of the latter is of moderate relief; the general line of contact between the two formations is comparatively straight as it crosses the state from Amboy to Trenton. Manifestly, the Triassic beds must have been baseleveled before the submergence that deposited Cretaceous beds upon them. So far as the weak Triassic formation is concerned, it is evident from this relation that it had been baseleveled in Jurassic time, when the Atlantic shore-line stood further east than the present line of contact between the Triassic and Cretaceous formations; and, as a corollary to this, it may be confidently believed

*See the Geographic Development of Northern New Jersey, by W. M. Davis and J. W. Wood, Jr.: Proc. Bost. Soc. Nat. Hist., vol. XXIV, 1889, pp. 365–423.

that the Jurassic strata absent from our Atlantic slope lie concealed under the ocean waters in the deposits of our continental shelf.

The tilted beds of the Triassic formation having been baseleveled, a gentle submergence caused a transgression of the shore toward the crystalline highlands. When these were reached the waters probably halted; for, being harder rocks, they could not have been reduced to baselevel so soon as were the weaker shales and sandstones of the Trias. Playing against the highland shore, with slight oscillations during Cretaceous time, the waste of the crystallines formed the sands and pebble beds, the marls and greensands of the Cretaceous series, the deposits of a shallow sea, not far from shore for the most part. As the sea-floor was spread over with these varied strata, the highlands were worn down to a less and less relief, and when the whole of Cretaceous time had elapsed the highlands must have reached the even surface now so conspicuous in the uniform altitudes of the uplands. Erosion of the surface may have continued into Tertiary time; for we must not imagine that changes of elevation took place at the even hours of our geological clock, as if they were railroad trains starting at even hours of the day. But we shall see reason to regard Tertiary time, as a whole, as one of erosion of the uplifted peneplain; and, therefore, rather as a matter of convenience than with intention of defining geological dates precisely, I shall call the peneplain, of which so much mention has been made, a Cretaceous peneplain—the product of denudation in Jurassic and Cretaceous time, presumably with forms of bold relief in the former period, but of faint relief near the end of the latter. The mass on which the denuding forces acted was the combined crystalline and Triassic area, deformed and uptilted by a post-Triassic—that is, early Jurassic—disturbance. The disturbance was of the peculiar overpushing kind that gave rise to the faulted monocline of the Triassic belts, and that undoubtedly faulted and uplifted the crystallines beneath and for some unknown distance on either side. The constructional forms thus produced may have determined for a time the relief of the region; early Jurassic time may have witnessed a topography of the Sierra Nevada pattern on a small scale. This was followed by erosion forms of greater variety, more accented by peaks and valleys; middle Jurassic time may have been thus characterized. But all the constructional forms and all the subsequent variety of relief were finally obliterated in the lowland of denudation of Cretaceous time. The topographic forms of to-day were nearly all carved in the Cretaceous lowland after its Tertiary elevation. It is for this reason that I regard the Cretaceous peneplain as of so great importance in the study of our topography.

I may here briefly consider a question that has sometimes been put to me in regard to the necessity of supposing that the even crest-lines of the Triassic lava sheets necessarily call for a denudation at a lower stand of the land than that of to-day. It is suggested that the evenness of the crest may be the result of balanced forces of attack and resistance, and that after such a balance has been attained further degradation would not produce irregularity, but would maintain evenness of outline. It appears to me that the general principle here indicated is correct. After a certain amount of degradation of any structure, variety of relief weakens and disappears, leaving simplicity in its place; but I do not think that this stage can be reached in ridges that stand so high above the present baselevel as do those of the Watchung lava sheets. However even their structure, however regular the constructional topography following on their regular uplift, however systematic the attack made upon them by the forces of denudation, their topographic form must increase in variety for a certain share of the time necessary for their complete baseleveling, and thus a maximum variety of relief would be attained. After this, further denudation would reduce the variety of relief until it disappeared in the featureless surface of the baseleveled peneplain. But the most careful analysis that I can make of this process leads me to think that ridges like those of the Triassic lava sheets cannot be produced while their crest-lines are five or six hundred feet above baselevel; they will be lower than they are when they reach the stage of even crest-lines in their present attitude with respect to baselevel.

Evidence from the Palisades of the Hudson.—There is, however, in the Palisades an example that does not leave this conclusion entirely to deductive argument. The Palisades are formed on the edge of an intrusive sheet of lava, which may be traced from Haverstraw, on the Hudson, down the river past Hoboken and Jersey City, opposite New York, and a little further till it descends under the Cretaceous beds in the neighborhood of Amboy. Some twenty miles farther southwestward, and apparently in continuation of the Palisade curve, a perfectly similar intrusive lava sheet rises from below the Cretaceous cover and forms the ridge of Rocky hill, back of Princeton. The variation in the height of the crest-line of this long, partly buried ridge is considerable; near its northern end it rises 700 or 900 feet above tide; near New Brunswick or Amboy, where the Raritan crosses the buried portion of its course, it is probably 100 feet below tide-water; back of Princeton it reaches an elevation of 400 feet. Now, if we are to suppose that the present form of northern New Jersey has been produced by erosion of a formerly greater mass, while it stood at its present attitude with respect to baselevel, how can the variation in the level of the Palisade-Rocky hill ridge be accounted for? So far as its crest is visible, it is relatively even; but at what altitude above baselevel was this evenness attained? No sufficient explanation for its form can be found in denudation without subsequent distortion. In the Amboy district, where the Palisade ridge sinks below sea-level, we find the Cretaceous clays lying on the denuded, baseleveled surface of the soft Triassic shales; that is, in the very district where the supposed Cretaceous baseleveled peneplain, as recorded on weak rocks, is at sea-level, the hard rocks are also at sea-level. This, as it appears to me, gives good reason for believing that the even crest-line of this lava sheet is the product of essential baseleveling, and not of a balance of resistances and attacking forces at some considerable altitude above baselevel, as above suggested.

In addition to this argument, the general accordance of altitudes among the diverse members of the peneplain may be quoted. In Massachusetts the elevation of the upland on the crystalline portion of the old peneplain corresponds in a striking way with the height of the trap-ridges that rise above the Triassic lowland; it can hardly be thought that the altitude of balance between wasting and resistance should be the same in great crystalline masses and in tilted lava sheets. Moreover, the altitude of the peneplain, as indicated either by the crystalline uplands or by the trap-ridges, increases northward from Long Island sound. Such correspondence as this is not to be explained except by supposing that the whole region was once a lowland, and that its present diversity of altitude is due to subsequent unequal elevation, just as its present variety of form is due to still later inequality of erosion on the elevated mass.

Subaërial, not marine, Denudation produced the Peneplain.—The process by which the Jurassic constructional topography was baseleveled may be next considered. A few decades ago the answer to this question would pretty certainly have invoked marine action, and the peneplain would have been called a plain of marine denudation. Our government surveys in the west, more than anything else, have called attention to the greater importance of subaërial erosion, when large areas are concerned, and the pendulum of opinion now swings to that side of the explanation. Something more judicial than the general turn of opinion is needed in deciding such a problem as this. Evidence of a more critical quality may be found in the character of the Cretaceous deposits where they overlie the Triassic shales at Amboy and elsewhere in New Jersey, and in the arrangement of certain river-courses further inland.

The lowest beds of the Cretaceous formation are so nearly free from material ascribable to the underlying red shales of the Triassic formation that Professor Cook was some years ago constrained to refer them to a hypothetical crystalline area now submerged in the Atlantic. This explanation does not accord well with the general origin of the Cretaceous formation elsewhere along the Atlantic border, where it is best referred to the belt of crystalline rocks farther inland. There is no reason to think that New Jersey was an exception to this rule. Hence it must be supposed that the Triassic area of the peneplain was baseleveled by subaërial erosion before that submergence occurred which allowed the sea to reach the crystallines of the highlands; for if the baseleveling had been the product of the shore waves cutting their way inland, then the lowest beds of the overlying Cretaceous series must have been composed chiefly of Triassic waste; and this is emphatically not the case. The peneplain must have been first completed over the area of the weak Triassic formation; then a slight submergence would allow a rapid transgression of the shore-line, halting nowhere until it reached the margin of the crystallines; and in this way the lowest beds of the Cretaceous might reasonably be expected to be almost free from Triassic fragments.

Inland Extension of the Cretaceous Formation.—When the Atlantic reached the edge of the crystalline plateau, it undoubtedly had some effect in cutting its way into the mass, thus aiding the streams that ran out into it in furnishing Cretaceous sediments. But the amount of inward cutting thus performed could not have been great, for the sea was shallow and the rocks were hard. More than this, the arrangement of the streams in the back, or inland, portion of the highlands decides clearly enough that no Cretaceous beds ever reached over their courses; and in all the farther inland extension of the peneplain over Pennsylvania, and perhaps beyond, the sea had no share.

The argument from the arrangement of the streams is as follows: The highlands consist of belts of hard and soft rocks, trending northeast and southwest with the great Appalachian chain. The texture and structure of these rocks leave no room for doubting that they were once deeply buried, and that they are now revealed by long-continued denudation. Whatever the arrangement of the rivers in the beginning of the long denudational work, the smaller of them must have become closely adjusted to the internal structure of the mass before the old age of the region—the peneplain stage in its development—was reached; that is, only those small streams survived that accepted the lead of the weaker rocks. This principle appears to be of general application. Since the peneplain was uplifted, the streams should retain the well adjusted courses that they had gained when it was a lowland; they should still follow the lead of the weaker rocks. But if the production of the peneplain be ascribed to the cutting action of the sea-shore waves, no such correspondence of stream-course and weak rocks need now be looked for. As fast as the plain of marine denudation was produced, it must have been strewn over with the waste from the remaining land farther westward. When elevation came afterwards, the peneplain must have risen with the Cretaceous cover on its back, and the streams then would have taken courses simply consequent on the slope of the cover, just as the streams now flow down the gentle slope of the Tertiary plains of southern New Jersey, indifferent to the crystalline structure that is buried beneath. Streams thus located might later cut through the cover and thus become superimposed upon the unconformable structures discovered below; but in that case they could not exhibit a distinct accordance with the structures. The inland extension of the Cretaceous ocean should therefore be determined by the area over which the streams of to-day exhibit an indifference to the rock structure over which they flow; and further inland than this they should be led by the soft rocks.

McGee* has shown that this is the case in southeastern Pennsylvania, where the Cretaceous sea crept inland a moderate distance over the Philadelphia belt of schists; but it is not necessary to suppose that all of even this slight advance was gained by its own shore-cutting; it may have crept in over a nearly baseleveled and slightly submerged area. I have found the same relation in northern New Jersey,† where streams of both superimposed and adjusted courses may be recognized, the former over so narrow a strip of the crystalline plateau that they may be neglected in speaking of the Cretaceous peneplain as a whole. This great topographic area must therefore be regarded as essentially a product of subaërial denudation, and the date assigned to it in New Jersey may be accepted for the whole area, until evidence to the contrary is presented.

Extension of the Cretaceous Peneplain west and southwest of New Jersey.—Having traced the peneplain from New England into New Jersey, having there determined the date of its completion and the processes concerned in its production, we may again turn to searching for its further extension.

Going now to the northwestern side of the New Jersey highlands, and looking across the Kittatinny or great Appalachian valley from such a commanding point of view as Jenny Jump mountain (see figure 3), the long, even crest-line of Blue or Kittatinny mountain rises in the distance. It looks like a dark blue wall rising to an even height against the light blue of the sky. At the Delaware water gap the wall is cut through to the base; at the wind gap, a little farther westward, it is cut part way down; elsewhere, so far as the sight can follow it, it is surprisingly level. Thus it continues for hundreds of miles. Here and there it is trenched by a river that comes from the back-country lowlands, or is half cut by a wind gap; occasionally it twists or turns where a fold or wrinkle is passed; at the synclinal points of these turns a somewhat greater height is maintained than elsewhere, while where the dip steepens the height falls away by a small amount; yet, as a whole, the crest-line is extraordinarily level. The same may be said of the other ridges of Medina sandstone, of which so many are to be found in the Susquehanna drainage area of central Pennsylvania. Whatever their structure, however high their folds would carry them, they are all truncated in the most obedient manner when they rise to the level of the Cretaceous pene-

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*Three formations of the Atlantic Slope: Amer. Jour. Sci., 3d. ser., vol. XXXV, 1888, pp. 133, 134.
†The Rivers of Northern New Jersey: Nat. Geogr. Mag., vol. II, 1890, p. 81.

plain. Going to the summit of one of the furthest of these ridges, that of Bald Eagle mountain, back of Bellefonte, in the center of the state, the observer may see toward the southeast a series of even-topped ridges, all of Medina sandstone, all in synclinal or anticlinal foldings, and all truncated in the same systematic manner. It must not be inferred that they accord with geometric exactness, but only with geographic exactness, such that if the intervening lowlands were filled up to the crest-lines a very even peneplain would be formed. Looking northwestward from the same ridge, the plateau of western Pennsylvania rises beyond a valley of soft Silurian and Devonian rocks. Still the same general elevation is preserved, but the type of form is altered in accordance with the nearly level position of the strata. The upland of the plateau is a gently hilly country, now deeply dissected by valleys of the post-Cretaceous cycles of development. The upland is not a

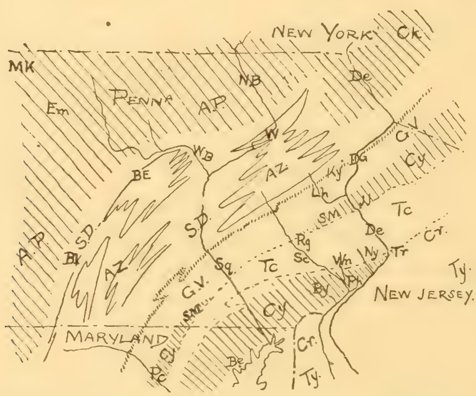

FIGURE 3—*Cretaceous Peneplain in New Jersey and Pennsylvania.*

constructional plateau, that is, its surface does not consist of a single stratum of rock or formation of rock ; it is an eroded surface, a peneplain on which successive formations crop out, one shingled on the next as we cross the country. In this denuded upland, a new set of valleys is now cut in consequence of its elevation above its former lowland attitude. At Emporium, for example, a short walk from the town up to a hill-top near by, a spur of the plateau, gives a fine view of the surrounding gently rolling upland, as well as of the deep valleys that the roads and railroads follow from town to town. When it is recognized that the upland itself has suffered a considerable erosion and yet has a generally even surface, and that deep valleys are sunk beneath it, we are forced to that it once as a whole stood lower than now ; that while lower it was reduced to a rolling peneplain ; that since then it has been raised to its present height, and that during and since this elevation the present deep valleys have been sunk below its old surface. How far the plateau can be traced westward cannot now be stated, for in going westward the rocks become weaker, shales replacing sandstones, and the uplands are less and less continuous. Much more study, aided by good maps, will be needed before the extension of the peneplain into Ohio and beyond can be determined.

South of Pennsylvania the evidence is better than in the Ohio valley. The plateau of West Virginia, Virginia, Tennessee and Alabama is well marked; but, as in Pennsylvania, its upland does not mark a constructional surface: it consists of the obliquely bevelled edges of various beds; and it

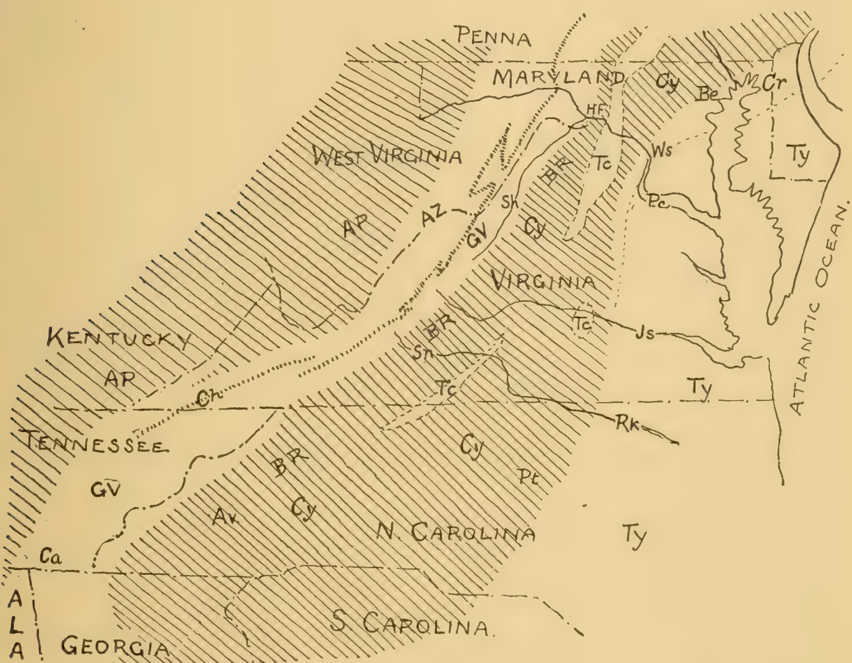

FIGURE 4—*Cretaceous Peneplain in the Middle Appalachian Region.*

is in this eroded surface that the present valleys are excavated. The part of the Appalachians in Tennessee contained between the plateau on the west and the great valley on the east consists of faulted rather than of folded Paleozoic formations. Wherever hard beds appear, they rise to a generally even outline and carry it for many miles. Clinch mountain, in Virginia and Tennessee (see figure 4), is a remarkable example of this kind of form. It is the edge of the Medina sandstone, which there, as in Pennsylvania, is the chief mountain-maker. It is well portrayed on the Morristown, Tennessee, topographic atlas sheet of the United States Geological Survey.

Of the crystalline portions of the southern Appalachians, I can say little from my own observations; but, judging from the topographic maps of the Blue ridge in Virginia, it is likely that observation on the ground would discover the peneplain and the hills rising over it without difficulty. Its presumable occurrence in Virginia may be indicated by returning to New Jersey, where it is so well defined, and tracing it southward along the crystalline belt. Two divisions of this belt are to be recognized, separated more or less continuously by the Triassic formation, which lies in a structural depression between them. It is the northwestern of the two divisions that makes the highlands of the lower Hudson and of New Jersey. Following this into Pennsylvania, it is known as South mountain, by reason of its lying opposite to Kittatinny or North mountain, with the great limestone valley between. South mountain narrows as it is followed southwestward, and at Reading, where the Schuylkill crosses toward the southeast, the plateau ends, because the crystallines here dip under the old Cretaceous baselevel, and indeed below the present base-level as well; and the Triassic belt laps over to the limestones of the great valley. Beyond the Susquehanna the crystallines rise again, just as they sank at Reading, once more bearing the name of South mountain. The evenness of the upland surface is well marked here at several places.* It continues across Maryland, and enters Virginia to form the Blue ridge, already mentioned. The comparative evenness of the upland at Harper's Ferry, where the plateau is crossed by the Potomac, is illustrated in plate V, Bulletin 52, of the United States Geological Survey.

The southeastern division of the crystalline belt begins at Trenton as a narrow wedge between the Triassic and the Cretaceous formations. It corresponds to, and is presumably continuous with, the crystallines of Manhattan island (New York city), which come southward from Connecticut and Massachusetts, the two divisions of the crystalline belt separating on the Hudson where the Triassic belt of New Jersey begins. The interruption of this division between New York city and Trenton is due to the early Cretaceous depression of this part of the peneplain and its consequent burial under the Cretaceous cover, which, though in part worn off again, still remains in sufficient extent to conceal the intermediate part of the crystalline division in question. From Trenton it may be easily traced as it widens to Philadelphia and beyond. At Philadelphia, or rather just northwest of that city, the upland level of the plateau is made all the more distinct by the narrow and deep trenches cut into it by the Schuylkill and the Wissahickon. The gorges of the Neshaminy, Brandywine and other creeks are of like character. The same is true where the Susquehanna cuts this part of the plateau. A view of the lower part of this gorge is given in the Seventh Annual Report of the

* See contoured maps by Second Geol. Surv. Penna., atlases to reports D_3 and D_5.

Director of the United States Geological Survey (1886), plate LVI. A topographic element so distinct as the plateau is thus far, and extending over so large an area, may confidently be expected to continue yet farther; and, with study in the field, or examination of topographic maps, when such are published, it will probably be traced all across Virginia.

In Carolina we fortunately have a very specific account of the upland in question. An article by Willis, entitled "Round about Asheville," published in the National Geographic Magazine,* describes the occurrence of broad uplands among the mountains of North Carolina. The higher summits of the mountains rise indeed several thousand feet above the upland; the deeper valleys are cut five hundred or more feet below it; but when standing at the altitude of the upland surface, its parts all fall in line. A view of this upland is given in Bulletin 52 of the United States Geological Survey (1889), plate II. The considerable remnants of Cretaceous mountains in this district may be ascribed in part to the greater hardness of the rocks, and also to their greater area. Willis suggests that the "balds," as the broad summits of the mountains are called, represent remnants of an even older baseleveled surface; perhaps corresponding to the era of Triassic degradation, here elevated but not greatly tilted or faulted by the post-Triassic disturbance. The comparatively enclosed position of the Asheville upland, with mountains rising above it on nearly all sides, excludes the possibility of its being a plain of marine denudation.

On the eastern side of the same mountain mass, Kerr † has described an even upland in the Piedmont region of North Carolina that presumably belongs with the peneplain under consideration, but demonstration of identity is wanting as yet.

Passing still farther southward the crystalline area sinks below the Cretaceous beds of southern Georgia and Alabama, thus confirming the date of the peneplain as already determined in New Jersey. The same fate overcomes the southwestern extension of the other divisions of the Appalachians—the great valley, the linear ridges, and the plateau. The Cretaceous cover once probably reached further northward over the older formations than now, and here, through the Carolinas and Virginia, as in the north, its extension must be tested by the arrangement of the river courses.

Owing to the small number of maps yet published for the greater part of the large area now reviewed, and also to the small attention that has yet been given to its topographic evolution, it is impossible to describe with any definiteness the various parts of the peneplain beyond Pennsylvania. Its more precise observation offers an excellent field for research.

From this subject we must now turn to the next division of the history of

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* Vol. I, 1889, pp. 291–300.
† Amer. Jour. Sci., 3d ser., vol. XXI, 1881, p. 216.

the Atlantic slope, namely, to the elevation that the peneplain suffered after its production by the forces of subaërial denudation.

The Tertiary Elevation of the Cretaceous Peneplain.—The absence of Jurassic deposits on the Atlantic slope has already been alluded to as evidence that during that period the shore-line stood to the seaward of the present inner margin of the Cretaceous formation. How much further it lay to the seaward cannot be told. It has also been explained that when the Cretaceous submergence occurred, the coastal lands had been reduced to moderate elevation and faint relief by long-continued denudation, and that for this reason a slight submergence caused a broad inland transgression of the sea. The farthest inland reach of the Cretaceous shore has yet to be carefully worked out. In southern New England there are no Cretaceous deposits on the mainland, but on Long island and the other islands farther eastward the edges of this formation are found. Its inland extension for many miles is therefore eminently possible, and must be measured by the degree of discordance with the structure that the streams of the coastal slope exhibit. Connecticut offers a promising field for this study. In New Jersey my own studies have given something of definiteness to this aspect of the problem; the rivers there do not show any trace of discordance with the structure of their basins except east of a narrow marginal belt of the highlands. In southeastern Pennsylvania McGee has shown that the eastern division of the crystalline belt was in good part buried under the Cretaceous formation; the transverse gorges of the Neshaminy, Wissahickon, Brandywine, and other relatively small streams may be taken to indicate superimposition,* but the inland margin of the area of discordant streams is not yet well defined. In the neighborhood of Philadelphia the superimposed quality of the smaller streams is well marked, and with the appearance of good maps typical examples of this interesting relation can be taken from that district. Farther southward no discussion of this question has yet been published.

The changes of level up to the end of the Cretaceous period may be generalized in figure 5. Here we have, in rough diagram form, the land and water profile resulting from the Jurassic deformation of the Atlantic slope (1, 1, 1), the denudation of this form (2, 2) and the advance of the sea in early Cretaceous time, and the late Cretaceous profile of the low peneplain (3), with its overlapping sediments. This brief summary neglects the Potomac oscillation, detected by McGee, as being too early to find expression in existing topographic features.

The subsequent greater changes of level, chiefly in the sense of elevation, are more directly connected with our problem. They are generalized in figure 6, whose uppermost profile corresponds to the lowest profile of figure 5. The results of the elevation of the Cretaceous peneplain are seen, first in the

*See Germantown, Pa., and Burlington, N. J., atlas sheets, United States Geological Survey.

altitude above sea-level attained by its several parts; second, in the valleys and lowlands that have been etched into it, as well as in, third, the stripping off of a good part of the Cretaceous cover.

From this it appears that both in the Cretaceous submergence and in the post-Cretaceous elevation the movement concerned was the same, in so far as it involved a tilting on a fulcrum or axis; but between these two dates the axis was shifted seaward, and thus a different warping resulted in the two cases, particularly at points situated between the two positions of the

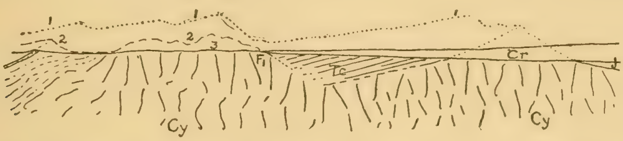

FIGURE 5—*Section illustrating the Development of middle Atlantic Slope Topography.*

fulcrum. In the later movement the fulcrum (F_2, figure 6) lay further to seaward than in the earlier (F_1, figure 5); and hence the previously depressed portion of the Cretaceous peneplain was then elevated: from having been below sea-level, it rose above sea-level.

The general location of the sea-level line on this strip of disputed territory after the Tertiary uplift may be briefly indicated, although the determination of its position is much complicated by late Tertiary and Quaternary oscillations of level of some magnitude and persistence. In New England, since the uplift and the cutting of the valleys, there has been a distinct depression, by which the lower valleys were submerged; the shore-line during

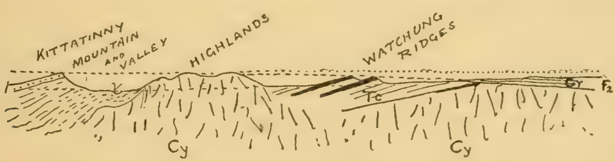

FIGURE 6—*Section illustrating the Development of middle Atlantic Slope Topography.*

the greater lapse of time since the elevation of the old peneplain has therefore presumably stood somewhat to the seaward of the present shore-line. Going southward, signs of considerable Tertiary oscillations, a late Tertiary elevation, and a recent and brief submergence complicate matters; but in a very general way it may be said that the line marking the position of the sea-shore assumed by the old Cretaceous peneplain as it rose with the Cretaceous cover on its back, lay two-thirds or more of the way from the present inner margin of the Cretaceous formation to the present sea-shore.

Altitude of the interior Portion of the Peneplain.—The elevation given to the peneplain as we advance inland can be measured by the altitude of its uplands (minus the altitude of its lowlands consequent on the late Tertiary uplift, which, being of small amount, is not considered here); for while there was certainly some faint slope toward the sea in the final lowland surface of Cretaceous denudation, it must have been insignificant compared to the present slope. The ease with which the rivers trench the plateau is alone sufficient demonstration of this important fact. In northwestern Massachusetts the topographic atlas of the state shows that the uplands reach an altitude of 1,600 feet, and even 2,000 feet in the Taconic range on the western border of the state. The New Jersey atlas shows that the inner or northwestern division of the crystalline belt averages 800 or 1,000 feet along its front, decreasing toward the southwest. Along its northwestern margin, next to the great valley, its height is from 1,200 to 1,300 feet. In Pennsylvania the outer crystalline division at Philadelphia is 200 or 300 feet above tide. The two parts of the inner division, both called South mountain in this state, are elaborately mapped by the Second Geological Survey (see atlases to reports D_3, 1883, and D_5, 1884); the one near the Delaware rises to 800 or 1,000; the one between the Susquehanna and the Potomac reaches 1,800 or 2,000 feet. In Virginia, the Blue ridge, as the crystalline belt is there called, ranges above 2,500, while its upland levels vary between 2,000 and 2,500, as shown on the Luray, Roanoke and Dublin, Virginia, sheets of the United States Geological Survey topographic maps.* In the southern part of Virginia the detection of the peneplain in question is doubtful, but in North Carolina it has been clearly recognized by Willis, who places his "Asheville baselevel" at 2,400 feet elevation, while the piedmont belt on the eastern side of the mountains, as described by Kerr, has an elevation of about 1,000 feet, gradually declining eastward.

It must be remembered that in this part of the Atlantic slope the surface was not by any means reduced to a flat lowland in the Cretaceous cycle; it was a rugged country even at the close of Cretaceous time. In the broad crystalline area of North Carolina, mountainous hills of from 3,000 to 4,000 feet rose above it, these being the mountains of that part of the Appalachians to-day. Further on, in Georgia and Alabama, the ancient surface sinks under the Cretaceous and newer strata.

Returning northward as far as New York, the inner part of the peneplain may be examined. In the Catskills it is probably recognized at the elevation of the general upland surface, above which a series of moderate hills rise to the highest summits and below which a number of narrow valleys are cutting their way down to sea-level. Thus determined, it would stand about 2,500 feet above the sea; the hills rise 500 feet or more higher yet. In Kittatinny mountain, on the northwestern side of New Jersey, the crest-line reaches 1,400 or 1,600 feet, and the plateau farther westward in northeastern

* These maps will hereafter be referred to simply by the name of the sheet and state.

Pennsylvania stands about 2,000 or 2,200 feet. In the geological reports and other accounts of Pennsylvania, crest-line altitudes are seldom recorded; but in a general way an elevation of 1,500 feet may be quoted for North mountain, 2,000 to 2,200 for the inner zigzag ridges, and 2,200 to 2,500 for the plateau.* The crest-lines of the Medina ridges of Blair county are given in the elaborate contour survey of that district as about 2,100 to 2,200 feet.† The sketch topographic map of McKean county ‡ makes the plateau there 2,200 feet above tide. In Virginia and West Virginia, according to the topographic maps of the United States Geological Survey, the dissected plateau possesses an average altitude of 2,500 to 3,000 feet, or even more. In Tennessee, according to the same authority, it averages about 1,800 to 2,000 feet on the Chattanooga sheet; in northern Georgia about 2,000 feet, and in northern Alabama about 1,200 to 1,500 feet, as shown on the Cullmann, Fort Payne, Gadsden, Stevenson and Scotsboro sheets.

It is clear from this rapid survey that the peneplain was distinctly tilted and somewhat warped when it was uplifted; but the tilting weakened and changed to a simple elevation in the plateau belt next west of the folded Appalachians; and still further westward a lower upland surface prevails; but whether this is due to a weaker Tertiary elevation or to a more general degradation of the softer rocks of the Ohio basin, I cannot now determine. In Iowa and Minnesota, however, where remnants of a Cretaceous overflow, advancing from the west, are discovered in thin Cretaceous deposits at an altitude of about 1,000 feet, the elevation was certainly less than along the Appalachian axis.

When the altitude of the Cretaceous peneplain is carefully determined over a large area, contour lines may be drawn upon it to indicate the form that it had before the present valleys were cut out; but it must be remembered that this altitude includes not only the main uplift after the Cretaceous denudation, but all the oscillations of later date. Judging by the valleys, these later oscillations have not been very great, or if great, they have been short lived. The chief one of them, so far as existing topography is concerned, is a late Tertiary or early Quaternary elevation of moderate amount, as a result of which the valley lowlands are trenched by young valleys. This will be briefly considered under a later paragraph.

Tertiary Excavations in the Cretaceous Peneplain.—It will have been noticed that the search for the remnants of the Cretaceous peneplain has been conducted entirely in the belts of hard rocks; in the crystallines, the Medina and Carboniferous ridges, and the sandstone plateaus. In a general way, the reverse is true in the examination of the Tertiary valleys; they are

* These figures for Pennsylvania are in large part taken from a collection of crest-line altitudes made in a thesis by Mr. Collier Cobb, class of 1889, Harvard College.
† See atlas to Report T, 1887, Second Geological Survey of Penna.
‡ Atlas to Report R R, 1885.

excavated for the greatest part in the weaker members of the series, the Triassic belts, the Cambrian limestones of the Great valley, and the Siluro-Devonian members of the folded Appalachians ; but the hard rocks are also trenched by cross-valleys.

Tertiary Work in New England: the Connecticut River.—Beginning in southern New England, the valleys may be classified under three heads, viz: the broad lowland of the Triassic belt; the upland valley of the Berkshire limestones; and the narrow valleys of the crystallines. The Triassic rocks are nearly all so weak that they have been reduced, as a whole, close to the Tertiary baselevel. There are a few exceptions to this rule: First, the lava sheets, of which the thicker ones in a general way retain the altitude of the plateau: these are roughly indicated by curved black lines in the Triassic area of figure 6. Second, Mount Carmel, a group of dikes which probably supplied the lava sheets, and which now rises a little above the plateau, as if representing a low hill of the Cretaceous cycle.* Third, the heavy conglomerates, which in Mount Toby, north of Amherst, Massachusetts, rise as high as the plateau next toward the east.

The upland valley of Berkshire has its floor at an elevation of 800 or 1,000 feet; this is probably to be explained first by the absence of any large master river to drain it; second, by the belts of hard rocks that its streams, the Housatonic and the Hoosick, must cross on their way to the sea ; and possibly, third, by a shift of drainage that I suspect has occurred here. The plateau between the Connecticut and the Berkshire valleys is drained almost entirely by branches of the Connecticut, the divide being close along the western margin of the plateau ; it is quite possible that in the Cretaceous cycle these branch streams drained the Berkshire limestone area as well, and that the present outlets of the valley are the result of headward cutting of formerly external streams ; if this be true, it is quite natural that the valley should not yet be excavated to the same depth as the Connecticut lowland.

The narrow transverse valleys of the crystallines are excellently illustrated by the two pairs of streams that the east-and-west railroads follow; the Quaboag and the Westfield, followed by the Boston and Albany railroad ; and Millers and the Deerfield, followed by the Fitchburg railroad. All of these are deep cut, but still retain steep side-slopes ; their depth manifestly depends as much on the altitude of the uplands in which they are sunk as on the approach that they have thus far made toward baselevel. The Belchertown, Massachusetts, sheet exhibits the narrow and deep longitudinal or structural valley of Swift river. The finest illustration of these features is in the Connecticut river itself. On the northern side of Massachusetts, where the Connecticut is only 200 feet above sea-level, the plateau on either

* See figure 2, p. 420 of this volume.

side rises to 1,200 or 1,300 feet. At Middletown, Connecticut, the river departs from the Triassic trough, and enters the eastern member of the plateau; the reason for this being either an inheritance from the post-Triassic deformation of the region* or a product of superimposition from the Cretaceous cover that may have once stretched thus far north from its present edge in Long Island, as has been suggested to me by Mr. Ralph S. Tarr, who finds evidence of similar superimposition in other streams of southern Connecticut. At Middletown, the plateau has a moderate relief of about 600 or 700 feet; and returning to Cobalt hill, already mentioned as a point of view from which the broad crystalline uplands can be seen to advantage, we may now gain from it a sight of the valleys by which the plateau is dissected as well. The open Triassic lowland is visible through a gap toward the west, and in the distance the lava ridges rise to the sky-line of the western plateau, which is seen at some points in the extreme distance. In the foreground, the noble Connecticut swings boldly into the plateau from the Triassic lowland, turns on a long S-curve, and disappears some ten miles toward the south, past the village of Haddam. The slopes down to its banks are strong, but are hardly to be called steep, unless in contrast with the faint relief of the Crystalline uplands or of the Triassic lowland. The valley bottom is encumbered to a moderate extent with gravels in which terraces have been cut, and from these as well as from the considerable depth of the stream, up which the effects of the tide are preceptible even above this point, we may judge something of the minor oscillations that the region has suffered since its general elevation. Taking the train at a little station a couple of miles below Cobalt hill, the river is closely followed by the Connecticut Valley railroad nearly to Long Island sound; during this run the progressive diminution of height in the uplands that enclose the valley is clearly shown; and finally, where the Shore Line railroad crosses the river at Saybrook, close to the sound, the uplands are hardly a hundred feet above sea-level. In eastern Connecticut the Putnam, Moosup, and Stonington sheets show the same gradual descent of the dissected plateau southward.

This interpretation of the age of the lower Connecticut valley, in terms of the ordinary geological chronology, is a decided gain in the understanding of our physical history. The valley is no longer vaguely referred to the work of erosion on an unknown mass during an unknown time; it is the work of an old stream revived, or locally superimposed, as has been suggested above; the stream has worked on a mass of definite form, a peneplain whose even lowland form was acquired somewhere in late Cretaceous period, and the southern part of which was perhaps veneered over by the thin inner edge of the Cretaceous formation; the work initiated under tolerably well-

* The topographic development of the Triassic formation of the Connecticut valley: Amer. Jour. Sci., 3d ser., vol. XXXVII, 1889, p. 432.

defined conditions has been continued during the greater part of Tertiary time, and thus the open Triassic lowland and the strong-featured valley from Middletown to the sound are to be dated. The lower valley is relatively narrow, as it is cut in hard crystalline rocks; but in the Triassic belt, where the rocks are weak, the valley has widened out to a lowland, although it is no older there than in the crystallines. The wide lowland on the weak rocks and the narrow valley in the hard rocks are both the work of the same cycle of development, and the waste from both has been carried away by the same river. The marked differences of form in the two parts are due to the difference in the resistance of the rocks; not to any difference in the height of the mass; not to any variation in the time of action; not to any inequality in the power of the controlling stream. The same contrast of form, due to contrast of rock-resistance under conditions otherwise similar, is to be found throughout the Atlantic slope.

Tertiary Work in New York: the Hudson River.—Passing now to southeastern New York, we find in the Hudson a close parallel to the Connecticut. In the Highlands the Hudson has cut the finest gorge in the eastern United States; although sometimes spoken of as of great antiquity, it is not so in a geological measure of time, being not more remote than the Tertiary period. Up-stream from the Highlands there is broad lowland stretching toward the Catskills, and including the areas that further to the southwestward are separated by Kittatinny mountain into the great valley and the Alleghany lowlands, but which here are nearly merged, on account of the absence of the Medina sandstone. Throughout all the Hudson valley, from the Highlands to Albany, there is nothing to indicate the height of the mass in which the valley-lowland has been carved, but toward the south and east lies the uplifted peneplain of the New York highlands and of Berkshire, while toward the west rises the hilly upland of the Catskills; and in presence of these witnesses it seems most likely that the surface from which the present Hudson valley has been excavated was truly once a part of the great lowland of Cretaceous times. If one stands on the Catskill mountain front and looks eastward across the valley, this conclusion seems well nigh incredible; the excavation of the lowland from the Catskills to the Berkshire plateau seems too great a work for Tertiary time, but the arguments in favor of it must in the end bring conviction of its truth, in spite of the enormous destructive work that it requires. An indirect argument to the same end is found in the course of the Hudson itself. If the river is followed down from Albany to New York, as it may be in a delightful excursion on one of the "day boats," the Highlands are encountered below Newburgh, where they rise like a great wall across the course of the river, while the lowland bears away to the southwest, continuing in that direction through the Kittatinny valley of New Jersey and Pennsylvania, the Shenandoah valley of

Virginia, and the great valley of eastern Tennessee. The river boldly enters the Highlands and cuts them through from top to bottom, and from side to side. The traditional suggestion of a lake, whose outlet cut down the gorge, or of a cleft in the Highlands by which the lake was drained, is generally offered by more than one of the travellers down the river, if they consider the question at all; but the possibility of the wasting away of the upper valley-lowland contemporaneously with the cutting down of the narrow gorge is hardly mentioned. Of all explanations, this is by far the most consistent with the other conditions of the problem. There are no signs of fracture of modern date, though there may well be here an ancient fracture line on which the gorge would naturally persist in the Tertiary cycle, because all such fractures would have been sought out as valley lines in the Cretaceous and earlier cycles of deep and general denudation. There is no indication of a lake in the upper valley, and, indeed, before any lake could occur there its basin must be provided. The gorge of the Rhine below Bingen is truly the outlet of a lake that once occupied the depressed middle portion of that river's course, and the gorge is cut in an uplifted peneplain of denudation; but this explanation will not apply in the case of the Hudson. The Hudson valley is not of constructional origin; it is not a warped or broken basin; every indication gained from the relation of its structure to its form shows it to be a region of deep denudation; its ancient constructional topography bears no resemblance to its present form. Excepting the natural hesitation in face of so enormous a piece of work, there seems to be no reason for regarding this valley as an exception to the rule of Appalachian valley-making in general. The upper part must have been excavated only as the lower part was deepened, while the widening of either part depended on the resistance of the rocks in which the valley was sunk. The Hudson valley only repeats with greater emphasis the lesson of the Connecticut valley; both are carved out of the uplifted Cretaceous peneplain; both have an upper open lowland portion, excavated in weak rocks; both turn from the lowland and enter a narrow gorge, cut like a trench in a tract of hard crystalline rocks. The respective parts are of greater magnitude in the Hudson than in the Connecticut, but the parts are essentially homologous.

Just as in the case of the Connecticut, the Hudson gorge in the Highlands is of less and less depth from its upper end near Newburgh to its lower end near Peekskill; then, curving a little, so as to follow the outcrop of the bottom members of the Triassic formation, the river leaves the even-crested Palisades on the right and the eastern division of the crystalline uplands on the left, and the valley becomes progressively shallower as these enclosing uplands gradually decrease in height towards the sea, until at New York city they reach sea-level and the valley opens to the ocean.

Tertiary Work in New Jersey and Pennsylvania: the Delaware and Susquehanna Rivers.—In New Jersey and Pennsylvania the same lesson is repeated, but always with the innumerable variations on the main theme that render the study of physical geography so delightful. The main streams are the Delaware and the Susquehanna. They both rise in the plateau belt of the Appalachians, and here their valleys are deep and narrow. The headwaters of the West branch of the Susquehanna particularly are notable in this respect. The North branch of the same river, above Wilkes-Barre, possesses a system of strong meanders, such as rivers often acquire when close to baselevel, but not characteristic of rivers having a relatively rapid descent; it may be that these meanders are inherited from the previous cycle. The case seems analogous to that of the Seine, in whose lower course the meanders are extraordinarily well developed, although the plateau in which they are sunk is but little dissected by the side streams.*

Passing southeast of the plateau, the two Pennsylvanian rivers traverse the Alleghany or folded division of the Appalachians, this being narrow in the Delaware basin but broadly developed about the Susquehanna. The weaker Siluro-Devonian beds are generally reduced to a lowland farming country, except where the Oriskany sandstone or a Chemung conglomerate of more resistance than the adjacent beds rises in ridges of moderate height. The hard Medina and the Carboniferous sandstones hold their crests close to the Cretaceous peneplain. During the passage of the rivers across this division of the country they cross few of the higher ridges, but on emerging from the great valley they perforce must cut their way through the Kittatinny, North or Blue mountain, which runs continuously along its northern side. Here, therefore, the problem of a broad lowland back country drained through a narrow gap in a high ridge again confronts us; and although the supposition of lakes and fractures is often met with, it does not seem to have any support. It is true that at the Delaware water gap there is a fracture in the formation through which the gap is cut, but this fracture is vastly older than the gap, vastly older than the present lowland form of the lowlands; it probably served to locate the river during the Cretaceous or some earlier cycle; but the gap as we see it is practically the work of the stream plus the wasting of the slopes, since the Tertiary cycle was ushered in by the uplift of the Cretaceous lowland. As the stream cut down, the back country was reduced in level; the rock-sill of the gap was the local baselevel of the upper basin.

Although this has been a generally accepted geological principle, since it was so clearly enunciated by Jukes in 1861, it appears necessary to state explicitly the process that it involves in order to counteract the implication that one sometimes meets in the accounts of our river histories; for example, in the Physical Geography of New Jersey, as presented in the first volume

*See the *État major* map of France, 1: 80,000; sheets 19, 20, 30, 31.

(1888) of the final report of the Geological Survey of that State. Here we find attention called to the great work of the forces of denudation in fashioning the present form of the land, and in illustration of this truth the gap cut by the Delaware is mentioned. Now, it is not to be doubted that the opening of this gap was a difficult piece of work, on account of the great resistance of its rocks; nor can it be questioned that the gap is a superb illustration of erosive action; but in instancing it as an example of great volume of erosion, and saying nothing of the vastly greater volume of erosion that has been accomplished in the same period of time over the lowlands on either side of the mountain in which the gap is cut, it is clearly implied that the lowlands were already lowlands when the river began the work of cutting the gap in the mountain. From this the reader must infer that the mountain owes its height over the surrounding country to a local uplift, and this is fundamentally wrong. The relief of the mountain over the surrounding country is due entirely to its superior resistance. The surface of the rocks that now occupy the lowlands was, at the close of the period of Tertiary uplift, raised as high as the surface of the baseleveled mountain. The mountain is still high simply because it has not worn down as the lowlands have. The story is the same whether we consider the Delaware, the Lehigh, the Schuylkill, or the Susquehanna; these being the only large streams that cut their ways across the mountain.

A matter of interest in the development of the Tertiary lowlands is the abstraction of the headwaters of certain small streams that once crossed the mountains, and their diversion into the larger rivers along the strike of some weak stratum up-stream from the gaps, according to principles formulated by Heim, Gilbert and Löwl. The incipient gaps are thus deserted and remain as notches, not traversed by streams, and known as "wind gaps." The most famous of its class is between the Delaware and Lehigh gaps; others occur near the Schuylkill and Susquehanna and further southwestward.

The continuity of the great valley across the line of the rivers is a matter of particular interest. From Newburgh to Alabama there is a continuous belt of lowland, bordered on the northwest by the wall of Medina sandstone and on the southeast generally by the inner division of the crystalline belt. Northeast of the Hudson its features are less regular, apparently because here the thickness of the overlying shales that have been folded with the limestones was so great and their position with respect to the Cretaceous baselevel was so adjusted that they now form considerable hills or even mountains, retaining in the Berkshire valley district even a full measure of the height of the Cretaceous peneplain. But southwest of the Hudson the limestone belt is more continuous, and it is very generally reduced close to the Tertiary baselevel. Slate hills remain somewhat above it, but fail by many hundred feet of retaining the height of the old peneplain. It is clear that the reduction of these Appalachian lowlands so nearly to a baseleveled peneplain in the Tertiary cycle cannot possibly be ascribed to marine action. They are manifestly the product of subaërial action.

The great valley is drained by longitudinal streams that join the few transverse master rivers and then cross the crystalline belt. The degradation of the great valley, as has been already explained in describing the Hudson outlet, has been accomplished only so fast as the trenching of the crystalline belt allowed. The number of rivers that cross the crystallines is small, but they are of large size—the Hudson, Delaware, Schuylkill, Susquehanna, Potomac, James and Staunton. One of the smallest of these, the Schuylkill, is located where the northwestern division of the belt dips below even the present baselevel, thus affording opportunity for a small stream to survive the transverse passage. In contrast with this, it is noticeable that where the crystallines increase in width and height no rivers cross them. New England is not traversed by any cross-rivers, nor are the Carolina mountains. On approaching the latter the great valley is drained toward the northwest, instead of toward the southeast.

The Triassic belts only repeat the lesson of the great valley, being well reduced to the Tertiary baselevel, except where possessing harder beds, as has been stated for New England. The curvature of the trap-ridges, consequent on the faint dishing of the lava-sheets, is a well-marked peculiarity of this belt, appearing in Massachusetts and Connecticut, where the curves are convex toward the west; and in New Jersey and Pennsylvania, with curves convex toward the southeast. It may be noted that the Rogers geological map of Pennsylvania (1856) by no means does justice to the systematic development of this feature, so far as the belt between the Delaware and the Schuylkill is concerned. The large-scale contoured maps of a portion of the Triassic area northward from Philadelphia, surveyed by the water department of that city,* show the curvilinear form of the ridges with great distinctness.

Coming next to the southeastern division of the crystalline belt, it is peculiar in the Philadelphia district in being traversed from the low back country to the coastal plain by streams of relatively small size, as well as by the master rivers of the region. The explanation of this feature by superimposition, as given by McGee and already referred to, appears to be the only one that deserves consideration; and the drainage of the still buried portion of this belt, between Trenton and New York, may be taken as representing now the earlier stage of the transverse drainage that once characterized the remainder. The several streams already named, the Neshaminy, the Wissahickon, the Brandywine and others, all cut picturesque gorges in

* Reprinted by the Second Geological Survey of Pennsylvania (atlas to Report C_7), and in the Quakertown, Pa., topographic sheet of the Geological Survey maps.

this part of the plateau; owing to the gentle uplift here, their depth is, however, moderate compared to the great gorges of the Hudson, the Delaware, the Potomac, the James and the Staunton, which trench the inner and higher division of the crystalline belt. The continuance of this feature to the southward needs further study.

In western Pennsylvania and in the parts of Ohio thereto adjoining, the valleys of the plateau are wider opened than near its eastern border. There appear to be several reasons for this change: In the first place, the rocks of the plateau decrease in hardness in passing from east to west—that is, in receding from the ancient coast-line from which their sediments were derived; in the east they are sandy; in the west, shaly. In the second place, the streams in the west are larger and nearer their mouths, while near the eastern border of the plateau they are as a rule small head-waters, whose beginning of work had in great measure to wait until some considerable advance in valley-making had been accomplished farther down-stream. In the third place, the height of the Tertiary uplift does not seem to have been so great in Ohio as farther eastward; but while this may have had some effect on the speedier development of open valleys, it does not appear to be so important as the other two considerations.

In Kentucky, where there are distinct alternations of hard and soft members of the plateau mass, we find a kind of form that is not present in any significant degree in Pennsylvania or Virginia; namely, structural plains. By this term I would designate an even surface of a hard stratum from which a certain amount of superincumbent material has been denuded, and on which further denudation hesitates by reason of the great hardness of the bed then discovered. Dutton's account * of the successive plateau-like steps surrounding the San Rafael swell in Utah presents the best illustration of structural plains on a large scale that I can quote. Those of Kentucky are tame affairs in comparison, but they characterize the moderate relief of the central part of that State. Structural plains are to be distinguished from constructional plains by the signs of denudation by which they are surrounded. They are to be distinguished from baseleveled plains by their accordance with the structures on which they are developed. In a small way, the sloping backs of the Medina ridges in Pennsylvania are inclined or dipping structural plains; † so are the backs of the lava ridges of New Jersey and Connecticut; but in neither of these cases does the surface of the ground coincide so closely or over so large an area with the surface of the disclosed bed as in horizontal structural plains. Just as the denuded forms of one cycle of development may be taken as the constructional form

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* High Plateaus of Utah, 1880, p. 19.

† R. T. Hill has used the term "dip-plains" for the surfaces here called structural plains (this volume, p. 522); but as dip is not essential and structure is essential to their production, his term does not seem well chosen.

when an uplift introduces a new cycle, so the resurrected pre-Triassic peneplain of New England may be taken as an example of a tilted structural plain, the plain here marking an unconformity, and not simply a change in composition.

Tertiary Work in Virginia and Beyond.—It is not necessary to multiply the examples of narrow valleys and wide lowlands, the work of the Tertiary cycle, in Virginia and further southwest. They all accord closely with the cases already given. The Potomac has its head-waters in portions of the plateau, its middle course across the folded Appalachians, and it then enters its deep gorge in the Blue Ridge at Harper's Ferry. Its chief tributary, the Shenandoah, drains the great valley for many miles. In either the Cretaceous or the Tertiary cycle the Shenandoah seems to have captured the head-waters of smaller transverse streams that then headed in the limestone valley belt and crossed the Blue ridge by independent gaps. The Staunton is the last Atlantic river to cross the Blue ridge from the northwestward; farther southward the crystalline area is too wide and too high to have permitted the development of an Atlantic drainage.

In West Virginia the plateau is so perfectly dissected that it may be taken as the very type of a maturely developed region. Its relief is strong, for its hills are high and its valleys are deep; it has no uplands, for they are all consumed; it has no lowlands, for they are not yet opened; it has so great a number of streams that there is no room for more; its slopes everywhere lead the rainfall by the most rapid routes to the water-courses, allowing the least loss by evaporation, and the area of the slopes must exceed the area of the original peneplain surface by twenty or thirty per cent., so great is the variety of relief. Consequently, with rapid discharge of rainfall and with large area of slopes from which waste is furnished and delivered most effectually, the further development of the mass must be progressing at the highest possible rate. The sheets of the Geological Survey named Hinton, Raleigh, and Tazewell, in Virginia and West Virginia, illustrate all this to a nicety.

The Cumberland plateau of Tennessee and Alabama is less completely dissected; it still preserves considerable areas of uncut uplands; perhaps owing to its rocks being harder. The Stevenson and Scotsboro, Alabama, sheets give a striking representation of this region. Near Chattanooga, Tennessee, the linear plateau of Waldens ridge may be taken as a typical example of a hybrid between plateau and mountain forms; it is enclosed between two structural anticlines, but these are now followed by Tertiary valleys, the result of the disclosure of the weaker beds along their axes after their crests had been baseleveled off in the Cretaceous cycle. The plateau itself is but little consumed by its gnawing valleys.

Occasional peculiar examples of rivers cutting across mountains and neglecting low country by which the mountains could be avoided serve to emphasize the need of explanations for these anomalies based on the location of the rivers during the Cretaceous cycle of denudation, when the hard beds of the mountains had a different relation to baselevel from that which now obtains. This may be seen in the Romney, Virginia, sheet; Mill creek here cuts Mill Creek mountain to join the South branch of the Potomac, although the river could now be joined by running around the end of the mountain on low ground; and again on the Maynardsville, Tennessee, sheet, where Clinch river bisects a short ridge, known as Lone mountain, instead of running around it. As an example of adjustment of smaller streams during the Tertiary cycle, no better illustration can be given than one presented on the Piedmont sheet of West Virginia, where New creek has beheaded a small stream that once rose west of New Creek mountain, leaving a "wind gap" in place of its water gap; two other small streams still maintain water gaps through the mountain.

Tertiary Baseleveling of the Cretaceous Overlap.—Frequent mention has been made of the former inland extension of the Cretaceous formation beyond its present bevelled edge, and special features have been found in the drainage of that part of the peneplain once covered by the inland extension of this formation. It has been noted also that while the harder rocks of the old peneplain still retain in great measure the form that they had when they were reduced to a lowland of denudation in the Cretaceous cycle, the softer rocks of the old peneplain have been reduced to a new lowland of denudation in the Tertiary cycle. The same is true of the remnant surface of the Cretaceous formation. Being generally of small resistance, it has been reduced to what I have called the "Tertiary baselevel," and thus is now to be classified, so far as date of origin of its surface is concerned, with the lowlands between the Appalachian ridges, the great valley, and the Triassic lowlands. Here and there some of its harder sandstones hold their edges at a slight height over the surrounding surface, and thus form a series of low hills on the line of their strike. Several of these are shown on the New Jersey maps. It is probable that the Long island hills, on which the rocky terminal moraines are laid, are homologous with these hills in New Jersey, and that similar hills occur in the south. I have not yet succeeded in tracing the southeastern border of this baseleveled area of the Cretaceous, for in that direction it approaches the sea-coast closely, and there, as has been explained in the introductory statement, the cutting and filling resulting from comparatively brief and trivial elevations and depressions make a record so complete and so complicated that its details encumber the problem and place its solution out of reach for the present. In the southern Atlantic states, where the fuller discussion of this part of the work will be possible, there is as yet little published material that can be used. The reports of the Gulf states, Alabama and Louisiana, are perhaps more complete than others in this respect; but as field investigations are now progressing there it is not advisable to attempt to study out the development of the region from maps and written descriptions, in whose preparation this aspect of its history was hardly considered.

Summary of Cretaceous and Tertiary Topography.—It has been found possible thus far to ascribe all the topographic forms of the Atlantic slope to one or the other of a few simple categories. The uplands and the even crest-lines of the ridges are parts of a Cretaceous peneplain of denudation, and are for the greatest part of subaërial denudation; occasional hills or submountainous elevations rise above this peneplain, these increasing to true mountain heights in New Hampshire and North Carolina. Taking these two elements together, and filling up the lowlands and valleys that have been sunk to a lower level, and depressing the peneplain surface close to sea-level, we have a restoration of the geography of our Atlantic border near the end of the Cretaceous period. The shore-line stood farther inland then than at present, while at the opening of Cretaceous time it had stood further out to sea. The change from one stage to the other was accomplished by a gentle depression, by which the Atlantic waters crept over the seaward border of the lowland. During the stand of the sea at its highest level, perhaps near the close of Cretaceous time, the larger rivers near their mouths appear to have reduced their valleys to broad lowlands, on which flood-plain or estuarine deposits were spread out; and in this area of the streams we may find at present a tendency of the side branches to turn downward before entering the master stream, a habit characteristic of flood-plained valleys in general. Several examples of this peculiarity in the Susquehanna tributaries have been mentioned in my essay on the Rivers and Valleys of Pennsylvania.*

The second large category of our topographic forms includes the slopes, valleys and open lowlands that have been sunk into the Cretaceous lowland after its elevation into an upland in Tertiary, probably early Tertiary time. It may be well to repeat that in assigning a geological time-name to date this change of level, it is not at present expected to reach a close accuracy of statement. Tertiary time was so long and witnessed changes of such magnitude in the west that our problem cannot be considered more than opened until a more definite date than "early Tertiary" is assigned for the time of the elevation of the Cretaceous peneplain.

We have in the foregoing paragraphs traced in some detail the development of the valleys and lowlands to a depth permitted by the altitude given to the old peneplain, and to a width allowed by the weakness of the rocks

* Nat. Geogr. Mag., vol. I, 1889, p. 241.

beneath. The great variation in the width of the valley lowlands that have been opened on the course of our greater rivers serves to emphasize the relatively small share of excavation actually performed by river action directly, and the large share that is to be ascribed to the slow processes of decaying, wasting, creeping, and wet-weather washing down hill. If one would picture the process in operation, he has only to conceive of time as passing quickly, and he may then in imagination see the waste of the land running down hill as fast as the snow-banks melt under a warm spring rain; or faster, up to any desired rate. This mental exercise has its use in bringing clearly to mind the sequence of forms through which a land-mass passes from its constructional youth to its baseleveled old age; and without it one can hardly become familiarly acquainted with the development of our topography.

The Tertiary valleys and lowlands mark an advance in the reduction of the uplifted Cretaceous peneplain towards baselevel, but the advance has not been nearly so complete as that of the long Jurassic-Cretaceous cycle. That cycle accomplished as nearly a complete baseleveling of a large area as any that I have yet found, although the post-Cretaceous baseleveling of the plains of the upper Missouri in Montana east of the mountains is of extraordinary perfection.* Our uplands of to-day in their relation to sea-level correspond to the hills that rose over the Cretaceous lowland, both being residuals not reduced to baselevel; but the present uplands are not so decrepit as were the Cretaceous residuals; the relief of the harder parts of the present uplands has indeed hardly reached maturity, hardly yet received so great a variety of form as it will if the process of sculpture is carried on farther. The valleys still have space to increase in number by ramifying into the uplands; the profile of the country is not yet so broken and varied as it may come to be.

The moderate advance in the development of the topography on the hard rocks of the uplands gives us warrant for regarding the hills that rise to higher levels than that of the uplifted peneplain as essentially still preserving the form that they had at the end of the Cretaceous cycle, for the dissection of the general upland has taken place only where the streams have trenched it and produced steep slopes on which its waste goes on with some rapidity. While the Cretaceous hills are in all cases avoided by the streams of the Tertiary cycle, their slopes are generally small, and their change of form in the Tertiary cycle may therefore be almost neglected; but in the White mountains of New Hampshire and the Black mountains of North Carolina, where the Cretaceous mountains remain, this statement is too moderate.

Post-Tertiary Topography.—There remains to be considered the work of

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*See my report on the "Relation of the Coal of Montana to the older Rocks," Tenth Census of the U. S., vol. XV, p. 710.

the late or post-Tertiary cycle, here again the name taken for the geological date of the uplift by which the cycle was opened being only roughly suggestive of the time of its beginning. The work of this young cycle is so evident that little time need be given here to its consideration. All the rivers are now at work trenching their lowlands to depths of one, two, or three hundred feet. In the course of the Susquehanna through the Appalachian lowlands, this is admirably shown at many points. The Delaware, Lehigh, Schuylkill, and Susquehanna all cross the great valley in trenches below its general surface, leaving it as an upland of low altitude—one, two, or three hundred feet—to be again surmounted by remnants of the older Cretaceous upland, higher still. The elevation of the Tertiary lowlands near the coast may be taken as a measure of their uplift, but in the interior their present altitude is certainly in part due to their imperfect reduction to baselevel in the Tertiary cycle: for example, the Berkshire valley in Massachusetts and the upper part of the Shenandoah valley in Virginia are now about 1,000 feet above sea-level, and part of this height may be ascribed to the altitude of the Tertiary lowland. The Delaware, Schuylkill, and Susquehanna traverse the Triassic lowland in the same way. When the traveler crosses the Delaware from New Jersey to Pennsylvania by the Bound Brook railroad (the so-called "New Line" between Philadelphia and New York), the trench cut by the river in the even surface produced on the Triassic area by Tertiary baseleveling is wonderfully well shown. At the time of the Tertiary baseleveling the Delaware appears to have been flood-plained and its side streams turned down the valley, as were those of the Susquehanna in the latter part of the Cretaceous cycle. The Doylestown, Pennsylvania, sheet of the Geological Survey topographic maps exhibits the evidence of this in great perfection, as well as some interesting results following from it in the reädjustment of the superimposed streams after the post-Tertiary elevation. The further search for downward deflected and partly reädjusted tributaries offers an attractive problem for students on the middle courses of our larger rivers.

The well-defined narrow and young trenches cut by the upper Ohio and its branches at the bottom of relatively wide open valleys, described by Chamberlin in his introduction to Bulletin 58 of the Geological Survey, seem to correspond with those of the post-Tertiary cycle nearer the seacoast.

During the post-Tertiary cycle the smaller streams have not sunk their valleys much below the general surface of the lowlands, except in the neighborhood of the larger rivers. In the belts of harder rocks the post-Tertiary cycle has hardly done more than to freshen up the slopes; thus, where the

Susquehanna crosses the Medina ridges above Harrisburg, the slopes are covered with a talus of loose rocks, indicative of a recently renewed attack on their bases by the river.

It must have been chiefly within this brief cycle that the fall-line displacement, as explained by McGee,* was initiated, for its effects are all young. The falls produced by it where the rivers cross the reefs of uplifted hard rocks are but little worn back, and the estuarine shores developed where the coastal plain was depressed are as yet but little filled by deltas. The displacement had an effect in turning the drainage westward on the peninsular areas between the rivers against the dip of the beds on which they flow, and in New Jersey this effect is noticeable even on the Triassic belt further inland than the fall-line is generally placed.† I am disposed to account for this by an additional displacement west of the fall-line, accompanied by the characteristic tilting of the displaced block, so that its formerly level surface now slants gently toward the northwest. In the case of small streams this was sufficient to determine the direction of their flow; but the larger streams, such as the Raritan, maintained their courses against it. It is worth noting that the displacement of this inner block and the tilting that accompanied it are in the same sense as those that must be inferred in accounting for the much more ancient faulted Triassic monocline of the New Jersey belt. It may also be noted in tracing out our geographic homologies that Long Island sound appears to correspond with the deflected parts of the Delaware, Susquehanna, Potomac and other rivers, being enclosed on the south by the retreating margin of the Cretaceous formation, and on the north by the old crystalline peneplain, laid bare of the Cretaceous cover that probably once stretched over its margin.

Further in this brief and imperfect cycle I shall not attempt to go. Changes of more modern date are marked by forms of such moderate emphasis that they must be deciphered by field-work rather than by map-work. The oscillations by which the deeper channels of the Connecticut and Hudson were carved beyond the present coast-line, by which the yellow gravel of New Jersey, the Columbia formation of McGee, was strewn over the lowlands, reaching an extraordinary development in the southern states, the latest changes indicated by the small estuarine mouths of many of the coastal rivers—all these require delicate observation on the ground on a scale of minuteness not reached by our maps, and of fullness not reached by the published accounts of our coastal geology.

*Seventh Ann. Rep. U. S. Geol. Surv., 1888, p. 616.

†Geographic Development of Northern New Jersey: Proc. Bost. Soc. Nat. Hist., vol. XXIV, 1889, p. 415.

Representation of the Dates of Topographic Forms by Colored Maps.

Having opened this account of the topography of the Atlantic slope with a statement of my conclusions, and having already made general review of the more important results attained, it remains now only to consider an application of the results that has been suggested to me by President Chamberlin. This is to represent the dates of the origin of topographic forms on maps by colors, just as the dates of the deposition of certain geological structures are indicated by colors. The suggestion seems to me particularly valuable at this time, when the meaning of topography and the natural sequence of the development of topographic forms are gaining much attention. Indeed, when once suggested, the plan appears to be so useful, so natural, and so needful that I can but wonder that it had not been proposed before.

We are well accustomed to representing the dates of formations by colors. We might indicate the dates of disturbances by colors also, and thus prepare maps of our orogenic history. We may certainly, at least for the better-studied parts of the world, indicate the geological dates of origin of our existent topographic forms, and, if not with entire certainty and accuracy, at all events with a useful approach to accuracy quite as correct as the coloring of the early geological maps. Take our Appalachian belt, for example, in Pennsylvania. Its geological representation is familiar enough, with its bands of many colors disposed in intricate zigzags. The representation of its orogenic disturbances would involve a greater share of doubt than in the ordinary geological coloring, although even that is at this day not free from question in all parts. There might be a strip of dull, dark color along the Archean to show that this part of the region had been deformed even in Archean times (the future student may subdivide this belt of color); another of lighter and clearer tint along the Cambrian to indicate, perhaps with some uncertainty, that there had been a Cambro-Silurian disturbance, not extending far northwestward. There might be a brighter, stronger, and more widely spread color to include all the area of the Appalachian folds, this being the chief feature of the map. Finally, there might be a faint overtint along the Triassic belts to mark the Jurassic monoclinal tilting; and this might extend to the northwest of the Triassic belts as far as the folds exhibit a prevailing overthrust in the direction of the Jurassic push.

Then the representation of the date of the topographic forms might be attempted. Its most striking feature would be the late date indicated by the colors; for while most of our rocks are Paleozoic, the dates of our forms are generally late Mesozoic or Tertiary. A wholesome result of this would be the increased attention that the eastern student would give to these later divisions of time on the Atlantic slope. At present he is disposed to neglect them, unless for special reasons he is particularly engaged in their study on the coastal plain, and even then their moderate thickness fails to give a properly impressive measure of the time that they represent. This would be better emphasized in the study of the denudation that these periods witnessed.

But the real value of a colored map showing the dates of the topographic forms would be found in the attention that it would call to the full meaning of the forms themselves. The current understanding of our Atlantic slope would certainly be greatly modified. Particularly in the case of our mountains, and the valleys among them, are current ideas vague and inaccurate. In the first place, it is too often tacitly assumed that the mountain ridges of the Appalachians are simply the unconsumed residuals of the original post-Carboniferous folding and upheaval. It may be asserted with much confidence that if there had been no uplift since that time there would be no mountains now. The Appalachians in Pennsylvania at least have been rubbed out once certainly, and perhaps twice; and what we now see may be truly likened to a cameo; a plateau and a series of ridges wrought out of a low, even surface by the wasting of its weaker parts after it had been moderately uplifted. Instead, then, of looking at our mountains as remnants of an unknown mass worked on by erosive forces during unknown times, they may be much more precisely understood. They are essentially the products of Tertiary erosion on an uplifted Cretaceous peneplain of moderate relief. The pre-Cretaceous forms are in nearly all parts lost; the post-Tertiary work is in nearly all places insignificant. Our topography is, for the most part, a Tertiary product.

A map of Pennsylvania colored to show the dates of origin of its topographic forms would possess a considerable area of Cretaceous greens, including here all the uplands. If any hills are found on the uplands they might be dotted green, to indicate that they were not completely worn down to baselevel in Cretaceous time. Another color of broad application would be the general Tertiary yellow. It would spread evenly over the lowlands, but would fall in dots or lines on the slopes descending from the Cretaceous uplands. Only the narrow trenches would be marked by strips of post-Tertiary color. With increase of scale, the more minute features might find recognition; and, in the end, the topographic map might be nearly as much of a patch-work of colors as the geological map is now. Nothing will contribute more to the realization of this end than the preparation of contoured topographic maps, such as those of the United States Geological Survey, so often referred to in this essay. Whether of final accuracy in all regions or not, they constitute so great an addition to our previous knowledge of the country that they are invaluable aids in geological or geographic study.

A result of interest that will be obtained from coloring maps by topographic dates is the relation of the origin of our geographic forms to their present settlement and to the occupations that they define. The Cretaceous uplands are largely forested, and support a scattered, rural population; the Tertiary valleys are lines of travel, the seats of towns and villages; the lowlands of the same date include our richest agricultural districts. The post-Tertiary trenches are as yet generally too narrow for occupation. Near the coast the oscillations of level have determined the harbors of New England, and the "fall-line" displacement is well known in locating many of the larger cities of the middle Atlantic states.

Harvard College, Cambridge, Mass.

Index of Localities and Abbreviations.

The greater number of the places named in the text are located on figures 1, 2, 3 and 4 by the abbreviations in the following list. The numbers after the names indicate the figures in the text where the places may be found. The page numbers give reference to accounts of the various localities.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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VARIATIONS IN THE CRETACEOUS AND TERTIARY STRATA OF ALABAMA.

BY DANIEL W. LANGDON, JR., A. M., F. G. S. A.

(*Read before the Society December* 30, 1890.)

CONTENTS.

The General Stratigraphy.

In the most recent and exhaustive authoritative publication concerning the Cretaceous and Tertiary strata of Alabama, Bulletin number 43 of the United States Geological Survey (1887), Professor Eugene A. Smith, State Gelogist of Alabama, and Lawrence C. Johnson, of the United States Geological Survey, have given the following classification, subdivision and thickness of these formations:

			Feet.
TERTIARY (EOCENE.)	*Upper* (*White Limestone.*)	Coral Limestone (Vicksburg?)	150
		Vicksburg (Orbitoidal)	140
		Jackson	60
	Middle	Claiborne	140–145
		Buhrstone	300
	Lower	Hatchetigbee	175
		Wood's Bluff or Bashi	80–85
		Bell's Landing or Tuscahoma	140
		Nanafalia	200
		Matthews' Landing or Naheola	130–150
		Black Bluff	100
		Midway	25
CRETACEOUS		Ripley	250–275
		Rotten Limestone	1,000
		Eutaw	300
CRETACEOUS (?)		Tuscaloosa	(?) 1,000

The measurements, actual and estimated, for the foregoing table are the result of careful observations made during boat trips down the Tombigbee, the Tuscaloosa, and the Alabama rivers, and wagon excursions through the regions embraced in the drainage of these streams. It was the privilege of the writer to be associated with Professor Smith in the greater part of this work, so that personal acquaintance with these formations as determined by Professor Smith under the auspices of the Alabama geological survey, in the western part of Alabama, renders it possible to compare them with those of the Georgia border with some degree of accuracy.

The summers of 1886 and 1887 were spent by the writer in tracing the Cretaceous and Tertiary rocks to the state line between Alabama and Georgia, and in determining the sections of strata exposed by Conecuh, Pea, and Chattahoochee rivers. It is the purpose to show in this paper the variations in the strata due to different conditions of sedimentation, as well as the faunal changes, together with unconformities brought about by the total absence in this region of groups well defined in the western part of the state.

The strata will be taken up in the order of their deposition, though the sections are in reverse order—*i. e.*, the latest stratum at the top.

CRETACEOUS STRATA.

The Tuscaloosa.—As early as 1846 the beds of pebbles with the associated deposits of clay were referred to the lower Cretaceous,* although Tuomey

* Quart. Jour. Geol. Soc. Lond., vol. 2, p. 280.

thought them newer than the Eocene white orbitoidal limestone.* Hilgard † embraced this group in his Eutaw, and called attention to the difficulty of distinguishing it from the Drift or Orange sand.

It is more than probable that much of Tuomey's Drift and Hilgard's Orange sand is properly referable to this formation. As a matter of fact, the discrimination is made with extreme difficulty, since the manner of deposition and the general character of the materials is quite similar, consisting of beds of more or less micaceous cross-bedded sands, water-worn pebbles of chert and hornstone, together with lenticular masses of clay of various colors. Tuomey ‡ has shown the tendency of the post-Tertiary Drift to appropriate materials from the rocks over which it passes. The same may be asserted of this, the Cretaceous Drift, and to this cause may be attributed the marked differences between the character of the deposits in eastern and western Alabama, since the conditions of sedimentation appear to have been the same.

From the Mississippi border to the water-shed between the Cahaba and Alabama rivers, Smith's description § of these measures holds good:

"The most conspicuous rocks are purple and mottled clays interstratified with white, yellowish-white, pink and light purple micaceous sands, and near the base of the formation dark gray, nearly black, thinly laminated clays, with sand partings."

But on leaving the Carboniferous rocks and the highly colored Paleozoic shales the lithological features of the formation become marked by the absence of beds of gray and purple clay, while the pebbles consist no longer of oölitic and fossiliferous chert, but of milky quartz, gneiss and schistose rocks. In lieu of the thousand feet of material estimated || as occurring on the Tuscaloosa and Alabama rivers, something less than a hundred feet is found on the Chattahoochee, as follows:

Section of Tuscaloosa Group; Chattahoochee River.

Base of the Eutaw group.

	Feet.
1—Strongly cross-bedded coarse sand and pebbles, with some few fragments of schist and just enough white clay to hold the mass together. The quartz pebbles are well water-worn, while the softer bits of schist are but slightly abraded. This stratum varies in color from white to lemon-yellow and in places green, while the upper part becomes mottled purple and yellow. This last phase is strongly developed at Thomas bluff, Georgia, due east of Fort Mitchell, Alabama	40

* 1st Bienn. Rep. on Geol. of Ala., 1850, p. 116.
† Rep. on Geol. and Agric. Miss., pp. 1860, 105-107, 66-68.
‡ 2d Bienn. Rep. on Geol. of Ala., 1858, p. 145.
§ Bull. 43, U. S. Geol. Survey, 1887, p. 95.
|| Ibid., plate XXI.

	Feet.
2—Red and gray variegated sandy clay; shows at water's edge, mouth of Bull creek, Georgia	6
3—Massive white coarse-grained sand, held together by white clay	15
4—Hard clay stained by ferruginous matter; breaks with conchoidal fracture	1
5—Light green, highly micaceous sand resembling weathered schist, for which it might be mistaken but for the occasional occurrence of water-worn quartz pebbles	3

Archean gneiss at Columbus, Georgia.

Whether this thinning out is due to erosion subsequent to deposition, or to less sedimentation originally, it is difficult to say. It is possible, however, that the subsidence of the coast-line in this vicinity took place subsequent to the deposition of the fossiliferous laminated gray clays occurring in the drainage of the Tuscaloosa and Cahaba rivers, so that only the younger or unfossiliferous member of this group is found on the Chattahoochee river.

The Eutaw.—However slight may be the differences between the Eutaw and the Tuscaloosa groups along the Tombigbee and Tuscaloosa rivers—so slight indeed that Hilgard does not discriminate them, and Smith draws the line with some misgivings because the mineral constituents and the conditions of sedimentation are about the same, except that the highly colored clays which are not found in the younger measures,—on the Chattahoochee river, and for some distance westward, the fossiliferous character of the Eutaw deposits makes them easily distinguishable.

Smith * has called attention to the absence of fossils in this group on the Tombigbee and Tuscaloosa rivers, except in the uppermost part of the measures. At Prattville, Alabama, which is near the base of this group, numerous univalve casts are found. On the Chattahoochee the line between the two groups is clearly marked by a bed of fossiliferous, laminated, sandy clay containing *Exogyra densata* and an *Anomia*, which bed rests conformably upon characteristic Tuscaloosa rocks. Scattered through the lower part of this clay there are a number of lignitized logs filled with calcified teredos, while in the upper part are numbers of casts as yet not identified but consisting in the main of lamellibranchs. These clays appear to have been deposited in undisturbed waters teeming with organic life, a condition of affairs quite different from that existing synchronously in the more western waters, where in ever-shifting, possibly very cold, currents cross-bedded sediments of sands, clays and pebbles, devoid of life, were deposited. Further eastward, beginning near Prattville, conditions more favorable to the existence of marine mollusks seem to have obtained along this Eutaw coast.

The thickness of the Eutaw is put by Smith † at 300 feet in his general section; and on the Chattahoochee it is practically the same, as follows:

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* Ibid., p. 88.
† Ibid., p. 18.

Section of Eutaw Rocks; Chattahoochee River.

Base of Ripley group.

	Feet.
1—Light-yellow and white sands, containing beds of well-rounded quartzose pebbles; beds sometimes 20 feet thick. Lignitized logs can be seen protruding from the bluffs. The sands contain, at rare intervals, shells of a small *Exogyra*, probably the young of *E. densata*, Say	45
2—Yellow sands and gray clay, cross-bedded and containing bits of leaves. This bed and the preceding are seen at Chimney bluff, Georgia	60
3—Quartzose conglomerate much like that at Havana, Hale county, Alabama;* forms the shoal at Beden's rock and the bluff at Hatcher's lower landing; merges gradually into a yellow sand	50
4—Yellow and white sands, with seams of lignitic sand and an occasional "bunch" of gray laminated clay. This stratum is exposed in a bluff about 100 yards from the river, just south of Rooney's Mill creek, Georgia	50
5—Laminated dark-gray clays, with masses of yellow sands distributed at irregular intervals throughout the stratum; best developed just above Uchee creek, Alabama	25
6—Gray, calcareous, laminated sandy clay, containing calcite plates and some fossils in the lower part. The upper part of this stratum becomes more argillaceous and contains many fossil casts, mainly lamellibranchs; causes landslides like the Black Bluff clays (Eocene), which it resembles somewhat physically. These sandy clays give rise to the Uchee shoals	100
7—Dark-gray calcareous sand, pyritous and containing nodular masses 6 to 12 inches in diameter, with calcite nuclei. These nodules are arranged in strata about 12 inches thick. Fragments of lignite are scattered through this stratum, some of them filled with calcified teredos. The only other fossils seen are *Eogyra densata*, Say (young), and an *Anomia*, all poorly preserved; dip at this point, 40 feet to the mile southward	15

Tuscaloosa group.

The Rotten Limestone.—East of the drainage of the Alabama river the Rotten limestone, such as occurs in Marengo, Perry, Dallas, Lowndes, and Montgomery counties (Alabama), is not represented. The exact eastern limit of this group has not as yet been determined, but evidences of its decreasing thickness are seen in the narrow outcrop in the neighborhood of Pike road, Montgomery county, where its north-and-south extent is only five miles, as compared with thirty miles in Dallas county. Further than this decrease in thickness, present information does not warrant saying anything. As has been stated before, no rocks bearing any lithological resemblance to the Rotten limestone have been seen overlying the Eutaw group on the Chattahoochee river. Whether or not this group is represented by strata of different composition from the typical aluminous limestone it is difficult to

*Ibid., p. 111.

say, since no critical examination of the fossils of the several divisions of the Cretaceous has yet been undertaken. It is much to be regretted that the divisions have been made on such arbitrary grounds as mere lithological differences, since marked variations can be noted in almost any stratum of any of the groups, and experience in both the Tertiary and the Cretaceous of Alabama has proved the risk of creating groups on any but combined physical and faunal differences.

Noticeably absent from the Chattahoochee drainage is the probable Alabama representative of Hilgard's Tombigbee sands,* which marks so distinctly the boundary between the Rotten Limestone and Eutaw groups and is the source of extensive deposits of phosphatic nodules.† This horizon has not been traced east of Society Hill, Macon county, Alabama.

The Ripley.—Immediately overlying the Eutaw group in the Chattahoochee drainage is the Ripley group, characterized by gray calcareous sands filled with large shells of *Exogyra costata*, Say, and *Gryphæa mutabilis*, Mort. This group, reckoned at only 250 to 275 feet, with an outcrop barely ten miles across on the Alabama river, becomes nearly 1,100 feet thick and extends along the Chattahoochee river for thirty-five miles. Hilgard ‡ estimated its thickness in Mississippi at 350 feet. The estimate given below was carefully made under favorable circumstances, and is believed to be correct. The relative importance of this group is much changed. Instead of being the most insignificant group of the Cretaceous as in Mississippi and western Alabama, in eastern Alabama and Georgia it becomes the most important in extent and economic value—*i. e.*, as a soil-maker. On the Alabama river, where it has been studied to the best advantage, Smith § notes only four well-defined horizons, as follows:

Section of Ripley Group; Alabama River.‖

	Feet.
1—Yellowish micaceous sands (Ripley fossils)	55
2—Dark bluish-gray, sandy, micaceous clays, weathering into yellowish shales, with indurated sandy ledges projecting at intervals of 5 to 10 feet throughout; whole thickness	100
3—Bluish argillaceous limestone, with phosphatized shell-casts, etc.	30–35
4—Sands of various colors, dark blue to gray or white, traversed by indurated bands of calcareous fossiliferous sands; contains many shells of *Ostræa falcata*	60

Compare with this the great variations in the strata of this group along the Georgia border:

* Agric. and Geol. of Miss., 1860, p. 68.
† Bull. 5, Dep. Agric. of Ala., 1884, and Bull. 43, U. S. Geol. Survey, 1887, pp. 85, 86.
‡ Proc. Am. Assoc. Adv. Sci., vol. XX, 1871, p. 222; also Am. Jour. Sci., 3rd ser., vol. II, 1871, p. 391.
§ Bull. 43, U. S. Geol. Survey, 1886, pl. XXI, column 2.
‖ Ibid., p. 179.

Section of Ripley Group; Chattahoochee River.

Base of Eocene.

		Feet.
1	Massive blue clay; contains a few bits of teredo-eaten lignite	6
2	White coarse conglomerate, the matrix material being calcareous. The quartzose pebbles decrease in size toward the top, and the stratum becomes more argillaceous. There are many casts of fossils, but all too obscure for specific identification	18
3	Gray sand, with indurated ledges; no fossils seen; merges gradually in the upper part into a dark (almost black) sand, containing large nodular masses and interstratified with light-yellow sands	35
4	Hard sandy ledge; weathered surface jagged; light yellow in color, white when dry and unweathered; contains *Exogyra costata*, Say, and echinoids	30
5	Light-yellow sand, interstratified very irregularly with a gray micaceous sand filled with friable Ripley fossils; occurs at mouth of Pataula creek, Georgia	30
6	Brown laminated argillaceous sand; disappears at mouth of Pataula creek	5
7	Gray fossiliferous sands, with bowlder-like concretions. The sand is massive, and is fossil-bearing in the lowest 5 feet only	40
8	Yellow sands and indurated ledges filled with casts of *Exogyra costata*, Say, and echinoids set fast in the ledge. The sands are cross-bedded, and contain some lignitic streaks	35
9	Calcareous gray clays, with concretions	50
10	Light-yellow cross-bedded sands enclosed between indurated ledges	20
11	Calcareous sand filled with shells of *Exogyra costata*, Say, and *Gryphæa mutabilis*, Mort.; contains many indurated ledges, and gives rise to the first bar below Eufaula	70
12	A massive gray sand, with a few friable fossils and concretions. This sand is only slightly calcareous, and is more or less lignitic	40
13	Light-gray and yellow sands interlaminated with sand darker in color and more argillaceous than the preceding, and contains bits of lignitized dicotyledonous leaves and twigs; no other fossils seen; crops out in gullies of Eufaula, Alabama, next below the Orange sand	20
14	Gray calcareous sand, with indurated ledges, *E. costata*, Say; *G. mutabilis*, Mort.; *Hamulus onyx*, *Plicatula urticosa*, *Anomia*, sp. (?) *et als.*; forms the shoal at Frances bar and the bluff at Eufaula	190
15	Soft, slightly coherent sand, gray in color; appears at the mouth of Cowikee creek, Alabama	60
16	About the same in general character as the succeeding, but contains indurated ledges about a foot thick, which serve to indicate numerous rolls in the strata; ends just above the mouth of Cowikee creek, Alabama	170
17	Gray fossiliferous marl, shells much decomposed. An occasional lignitized log and numerous slightly phosphatic nodular masses containing fossils occur in this stratum	5
18	Gray, glauconitic calcareous sands, weathering into fucoidal shapes and containing a few white, soft phosphatic nodules	10
19	Fossiliferous marl; little or no lignite seen; the marl appearing to be somewhat glauconitic	2

	Feet.
20—Cross-bedded gray sands and clay	15
21—Sandy stratum, indurated and containing *Ostræa*, sp. (?)	1
22—Gray, highly fossiliferous marl. The fossils are nearly, if not quite, all bivalves, and are mostly comminuted as if they formed an ancient shore-line. There are numerous shark and sauroid teeth, mammalian bones, a hard black substance in sections resembling the under shell of a turtle, black coprolitic pebbles, and fragments of lignite	3
23—Gray and yellow sands resembling physically those of the Tertiary at Lower Peach Tree, Alabama *	30
24—Gray sand interlaminated with thin seams of more argillaceous sand, all of which is unfossiliferous	26
25—Gray sandy calcareous clay, with lines of bowlder-like concretions projecting from the bank; first seen at Lawson's wood-yard, Georgia. Few fossils except *E. costata*, Say, occur in the lower part of this stratum. A mile above Blufftown, Georgia, characteristic Ripley shells, mainly bivalves, are found in a much decomposed state throughout a stratum 6 to 8 feet thick, while the uppermost 10 feet of the entire stratum is very fossiliferous. Near Jernigan's Landing, Alabama, slight rolls in the strata are seen, involving about 20 feet of the sands. These miniature anticlinals and synclinals continue to within two miles of Florence, Georgia	120

Eutaw group.

Tertiary Strata.

Thickness and Divisions.—Hilgard † appears to be somewhat in doubt as to the exact thickness and characteristics of the Tertiary in Mississippi, placing it at about 620 feet, exclusive of the Grand Gulf, which is probably post-Eocene.

Smith ‡ divides the Eocene into three parts: the lower, consisting of the Midway, Black Bluff, Matthews' Landing or Naheola, Nanafalia, Bell's Landing or Tuscahoma, Wood's Bluff or Bashi, and Hatchetigbee; the middle, comprising the Buhrstone and Claiborne; and the upper, which includes the Jackson and Vicksburg; in aggregate thickness reaching about 1,700 feet. In the Chattahoochee water-shed the total thickness is not more than 1,200 feet, and many groups represented along the western border of the state are entirely lacking, while others are so attenuated as to have almost lost their identity.

The Midway or Clayton.—At the typical locality on the Alabama river, the Midway group consists of 10 feet of light gray, very argillaceous limestone, characterized by *Nautilus* (*Enclimatoceras*) *ulrichi*, Hyatt. Following the group eastward for 20 miles to the vicinity of Allenton, Alabama, this limestone has lost its argillaceous character, and is underlain by an additional 15

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* Ibid., p. 48.
† Agric. and Geol. of Miss., 1860, pp. 107–110.
‡ Bull. 43 U. S. Geol. Survey, 1886, p. 18.

feet of calcareous sands and sandy limestone filled with marine forms, mainly *Turritella* and *Cardita*.

In the northwestern part of Butler county, Alabama, about 20 miles east of the last-mentioned locality, this group becomes about 50 feet thick, the pure *Nautilus*-bearing limestone comprising the upper 30 feet, while the sandier phase containing *Turritella* has increased its thickness to 20 feet. From this point eastward the so-called *Nautilus* rock thins down, while the *Turritella* phase increases both in thickness and in faunal variety until the group is elevated from its insignificant place in the Alabama river section to the most important group of the Eocene on the Chattahoochee river. On this stream a section of this group is exposed, representing about 220 feet of rocks, as follows:

Section of Midway or Clayton Group; Chattahoochee River.

	Feet.
1—White calcareous sand, containing a few obscure casts and *Ostræa*, sp. (?). The sand sometimes becomes irregularly indurated, and is the source of numbers of small lime springs. It forms the lowest part of the bluff at Fort Gaines, Georgia, and in its uppermost 10 feet contains pockets of white sand enclosed by black clay, the clay resting in "potholes" in the limestone. Estimated at	200
2—Light-yellow, silicious limestone, containing a large *Ostræa* and numerous obscure casts	10
3—Massive, coarse-grained sandstone, almost a conglomerate	8

Ripley group.

The Black Bluff.—The identity of this group, in part at least, with Hilgard's Northern Lignitic is scarcely a matter of question, since the Alabama survey has taken it up on the Succarnochee river where he left off. In Mississippi this author notes the occurrence of lignitiferous sands and clays with leaf impressions to the extent of 400 to 500 feet, the marine life being confined to a limited area at or near the base and through not more than two feet of strata. The lack of lime in this group is clearly indicated by the analysis of the derived soil, which shows less than fifteen-one-hundredths of one per cent. In the vicinity of the type locality on the Tombigbee river the clays are but slightly calcareous, contain some marine forms, and are about 100 feet thick. In Wilcox county, Alabama, near Allenton, some 50 miles east of Black bluff, it is less than 65 feet. It contains a great variety of faunal remains and is very calcareous, the black-clay feature being subordinated to thin ledges of limestone. On the Chattahoochee this group is wanting entirely; in fact it has never been identified east of Wilcox county.

The Naheola.—Next succeeding the Black Bluff group in Smith's general section is the Matthews' Landing or Naheola series, composed of gray sands and sandy clays, containing at its base a fossiliferous stratum some 6 to 8 feet thick and abundant in variety of marine forms. The top of the series is marked by the most persistent and thickest stratum of lignite noticed in Alabama, an outcrop of 7 feet showing on Landrum's creek, Marengo county.

On the Tombigbee river this group is nearly 200 feet thick, and contains a limited, though characteristic, fauna; on the Alabama it is about 150 feet thick, and contains a most abundant variety of marine species; while at Oak hill, Wilcox county, it is only 125 feet thick. In the western part of Barbour county the thickness is barely 50 feet, the strata consisting mainly of slightly fossiliferous sands; and, like the foregoing member, it is lacking on the Chattahoochee.

The Nanafalia.—The Nanafalia series, marked by thick beds of *Gryphœa thirsæ*, Gabb, is the most abundant in organic remains of the lower Tertiary groups. So far as is known, it has not been noted in Mississippi. On the Tombigbee river the series is about 200 feet thick, the same on the Alabama, and 175 feet on the Chattahoochee. In the Tombigbee drainage the fossiliferous strata are composed of incoherent beds of *Gryphœa thirsæ*, *Venerecardia planicosta*, *Turritella mortoni*, *Osteodes caulifera*, and a few remains of *Ostrœa compressirostra*, the interstices between the shells being filled by sand and grains of glauconite. On the Alabama river and eastward the upper part of the group is marked by a gray aluminous rock containing numerous casts, and called, from its resemblance to a younger member of the Tertiary, "pseudo-Buhrstone."

On the Chattahoochee this series presents no particular features, except at Fort Gaines, Georgia, where it rests unconformably on the strongly eroded surface of the Midway or Clayton limestone. This was considered Claiborne by Loughridge.*

The Tuscahoma.—This series, consisting in the main of gray and yellow laminated and cross-bedded unfossiliferous sands and sandy clays, with one or two beds characterized by *Voluta newcombiana*, Whitf., and unusually large specimens of *Turritella mortoni*, *Venerecardia planicosta*, *Rostellaria trinodifera*, Con., and *Ostrœa compressirostra*, extends across the state practically unchanged, except that east of the typical locality on the Alabama river there is a paucity of fossils.

The Bashi.—One of the marked features of this series in western Alabama is a bed of lignite about 25 feet below the characteristic stratum of marl. The eastern limit of lignitiferous strata appears to be the head-waters of Sepulgah river, where the carbonaceous material is intermixed with the marl. Aldrich has pointed out the existence of fresh-water shells at the typical locality.

The thickness of this group on the Tombigbee is about 80 feet; on Pea river it increases to about 150 feet, and is highly fossiliferous; while on the

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* Rep. on Cotton Production of Ga., 10th Census U. S., vol. VI, 1884, p. 280.

Chattahoochee it thins down again to 44 feet, and is practically devoid of organic life, only a few casts being noted. Some difficulty is encountered in drawing the line between this and the underlying group because of the absence of the lignite which serves Smith* as a line of demarkation.

The Hatchetigbee.—The uppermost member of the lower Tertiary, limited by the Buhrstone on top and the Bashi at the bottom, is the Hatchetigbee. It is composed, at the typical locality and in the region investigated by Smith, of brown, purple, and gray laminated sandy clays and cross-bedded sands, containing round concretions of indurated sand; in all 175 feet thick. On Pea river this series thins down to 25 feet, and on Chattahoochee river to 10 feet, the lithological features remaining constant. No fossils have been found in this series except at Hatchetigbee bluff itself.

The Buhrstone.—The rocks of this series west of the Chattahoochee drainage consist of aluminous sandstones varying but slightly in composition and meagre in quantity and variety of fossils. In the eastern part of Alabama, however, the percentage of clay decreases, while the rocks become more calcareous and the fossils more abundant. In lieu of the silicified casts characterizing the Buhrstone on the Tombigbee and Alabama rivers, extensive beds of *Ostræa sellæformis* (var. *divaricata*) and an *Anomia* occur. The subterranean dissolution of the calcareous strata gives rise to numerous limesinks in Henry county.

On the Tombigbee the thickness of the series is estimated at 400 feet; on the Alabama, at about 300 feet; and on the Chattahoochee, 190 feet. The most noteworthy difference, however, is in the chemical composition of the constituent rocks.

The Claiborne.—In the western part of the region under consideration the Claiborne series is distinguishable into four sub-groups, viz., (*a*) the *Scutella* bed, (*b*) the Ferruginous sands or Claiborne proper, (*c*) the *Ostræa sellæformis* bed, and (*d*) the Lisbon bed.

The first sub-group is of minor importance, and serves mainly to mark the boundary between the White Limestone and the Claiborne.

The bed *b* has been more thoroughly studied by paleontologists than any other of the southern Tertiary formations. It is, however, of very limited extent, being confined exclusively to the region drained by the Tombigbee and Alabama rivers. Thirteen miles west of Bladen Springs, Alabama, is the westernmost outcrop of this stratum, which here consists of lignitic clays containing some greensand and *Crepidula lyrata*, *Corbula alabamensis* and *Voluta sayans*. About five miles east of this point the bed consists of very coarse-grained greensand with but few fossils; all, however, characteristic of this horizon. Eastward of this last locality the stratum is normal in appearance, except that the greensand is seldom decomposed as at the typ-

* Bull. 43, U. S. Geol. Survey, 1886, p. 43.

ical outcrop on the Alabama river. No stratum that could be referred to this horizon has been noted east of Monroe county, Alabama, or more than twenty miles from Claiborne.

Beneath the Claiborne sands lies a bed of gray calcareous sand characterized by numerous shells of *Ostrœa sellæformis.* Contrary to the opinion of A. Winchell,* this has proved to be the most persistent member of this group, having been traced by the writer personally from Suanlovey creek, near Garlandsville, Newton county, Mississippi, to the Georgia line. In general characters it does not vary throughout its extent, being about 75 feet thick on each of the three rivers.

The lowest division of this group appears to be confined to the region drained by the Alabama and Conecuh rivers. It is about 45 feet thick, and differs from the preceding mainly in a peculiar group of fossils that have as yet been but imperfectly studied.

The total thickness of this group, as given in Smith's general section,† is 145 feet, as compared with 75 on the Chattahoochee, where the *Ostrœa sellæformis* bed is the sole representative.

The White Limestone.—The youngest member of the Eocene in the Gulf embayment was considered Cretaceous until Lyell's second visit to this country, Morton ‡ having described the characteristic fossils and referred them to the Cretaceous. To facilitate comparison, the group may be subdivided into the Jackson and Vicksburg.

Hilgard § mentions the occurrence of lignitic clay between the Jackson and Vicksburg groups. Attention has already been called || to beds of lignitic sand intercalated between the calcareous Jackson clays exposed on Pearl river, Mississippi. At Red Bluff, Mississippi, near the Alabama line, the upper part of the lignitic clays contains an abundance of marine forms, while at the Alabama line these clays have become so calcareous and barren of fossils that they blend imperceptibly into the prairie-making rocks of the Jackson.

The Jackson sub-group, consisting of gray and white calcareous clays in a general way devoid of fossils except a few *Zeuglodon* vertebræ, has been traced from the Yazoo river to the Sepulgah, east of which it becomes more sandy and ferruginous until, on reaching the Chattahoochee, it is almost a counterpart of Smith's *Scutella* bed.

The Vicksburg, or orbitoidal limestone is, at its typical locality, rather a calcareous sand than a limestone, changing on Pearl river into occasional ledges of indurated subcrystalline limestone, and from the Mississippi–Alabama line to the Chattahoochee it assumes a white chalky phase which constitutes practically the entire group. The total thickness of the group is, in

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* Proc. Am. Assoc. Adv. Sci., vol. X, part II, 1856, p. 86.
† Op. cit., p. 18.
‡ "Synopsis," 1833.
§ Agric. and Geol. Miss., 1860, pp. 107–110.
|| Author, Am. Journ. Sci., 3d ser., 1886, vol. XXXI.

Mississippi 215 feet, in western Alabama 200 feet, and on the Chattahoochee 275 feet.

The uppermost or Salt Mountain division of this group is seen nowhere east of the typical locality, and so does not enter into the geological features of this section of Alabama. As a matter of fact, the characters of the Salt Mountain limestone—*i. e.*, corals and spines of echinoids—point rather to its being an atoll built up in Tertiary seas than any extensive deposit justifying the constitution of a group.

The Miocene.—The strata that are referable beyond queston to the Miocene are marine, and in Alabama and western Florida are confined practically to the drainage of the Chattahoochee, though Mr. L. C. Johnson, of the United States Geological Survey, has traced the Alum Bluff group as far west as Yellow river.

Résumé.

Probably the greatest difference between the geological features of eastern and western Alabama occurs in the Cretaceous.

The Tuscaloosa group of the Chattahoochee river is composed mainly of sand and pebble beds; no such accumulations are seen as on the Tuscaloosa river and in Bibb and Chilton counties. Conspicuously absent are the leaf-bearing clays, such as mark the lowest phase of the series further westward. In thickness it has become reduced from a thousand feet to less than one hundred.

The Eutaw remains approximately constant in thickness, but in faunal features a decided change takes place. From the Tombigbee river eastward to the vicinity of Prattville, Alabama, no marine life has been noted, except in what is termed the uppermost part of the measures, but what is really either the Tombigbee sands of Hilgard or a lower member of the Rotten limestone. From Prattville eastward molluscan remains increase in quantity and in vertical distribution, being found in lessening number and specific variety from the base of the measures to the top.

The Rotten limestone thins out gradually eastward until it disappears altogether on the Chattahoochee, causing the Ripley to rest directly and apparently unconformably on the Eutaw.

From the least important member of the Cretaceous formation in western Alabama the Ripley has become dignified into the most extensive.

The lower Tertiary, as a lignitiferous group, loses its identity in this region, since it is a noteworthy fact that there is not a single outcrop of lignite on the Chattahoochee river, and the black and dark colored clays so characteristic of this division of the Tertiary in western Alabama and Mississippi have disappeared entirely. The strata of the division become more calcareous, the faunal features more marine.

The division of the middle Tertiary into calcareous and silicious Claiborne seems more appropriate on the Chattahoochee than classification as Claiborne and Buhrstone, since the latter has become so closely related to the former in abundance and character of fossils that any division whatever is, in this region, purely arbitrary.

The White Limestone becomes a little thicker on the Chattahoochee, but loses its distinctiveness as Jackson and Vicksburg and may well be included under one head.

Apart from and *pari passu* with the faunal changes which have been indicated, it will be seen from the accompanying sections that there is a thinning out of the aggregate strata to the extent of some 500 feet in the Tertiary and 1,100 feet in the Cretaceous.

General Section Exposed on the Chattahoochee River.

The successive beds exposed on the Chattahoochee from Columbus, Georgia, to Alum bluff are as shown in the following table, in which the order of enumeration is that of historical succession, or the inverse of the stratigraphic succession. They are illustrated graphically, in connection with the Alabama and Tombigbee exposures, in plate 23.

	Feet.
1—Light green, highly micaceous sand, resembling weathered schist; but for occasional water-worn quartz pebbles might be mistaken for schist	3
2—Hard clay stained by ferruginous matter; breaks with conchoidal fracture	1
3—Hard, white, coarse-grained sand, held together by white clay	15
4—Red and gray variegated sandy clay (typical Tuscaloosa); shows at water's edge, mouth of Bull creek, Georgia	6
5—Strongly cross-bedded coarse sand and pebbles with some few fragments of schist and just enough white clay to hold the mass together. The quartzose pebbles are all well water-worn, while the softer bits of schist are but slightly abraded. This stratum varies in color from white to lemon yellow and in places green, while the upper part becomes mottled purple and yellow. This last phase is most strongly developed at Thomas' bluff, Georgia, due east of Fort Mitchell, Alabama	40
6—Dark-gray calcareous sand, pyritous and containing nodular masses 6 to 12 inches in diameter with calcite nuclei. These nodules are arranged in strata about two feet apart and terminate in an indurated stratum about 12 inches thick. Small fragments of lignite are scattered about through this stratum, and one or two large masses filled with calcified teredos were found. The only other fossils seen were an *Anomia* and an *Exogyra*, probably the young of *E. costata*, Say. The fossils are all poorly preserved. Dip at this point, 40 feet to the mile southward	15
7—Gray sands of the same nature as the preceding, only no nodules were seen, and the shells increase in quantity, particularly in the lower part. The upper part of this stratum becomes more argillaceous and contains many fossil casts, mainly lamellibranchs; causes landslides in the banks like the Black Bluff clays, which they resemble somewhat physically. These sandy clays give rise to Uchee shoals	100

	Feet.
8—Laminated dark gray clays, with masses of yellow sands distributed at irregular intervals throughout the stratum; best developed just above Uchee creek, Alabama	25
9—Yellow and white sands, with thin seams of lignitic sand and an occasional "bunch" of gray laminated clay. These sands are exposed in a bluff about 100 yards from the river, just south of Rooney's Mill creek, Georgia	50
10—Quartzose conglomerate much like that at Havana, Hale county, Alabama; forms the shoal at Beden's rock and the bluff at Hatcher's lower landing; merges gradually into a yellow sand	50
11—Yellow sand and gray clay, containing bits of leaves. This stratum and the following are seen at Chimney bluff, Georgia	60
12—Light-yellow and white sands, containing beds of well-rounded quartzose pebbles, sometimes 20 feet thick. Lignitized logs can be seen protruding from the bluffs. The sands contain a small *Exogyra* at rare intervals. The supposed top of the Eutaw group	45
13—Gray, sandy calcareous clay, with lines of bowlder-like concretions projecting from the bank; first seen at Lawson's wood-yard, Georgia. Few fossils occur in the lower part of this stratum, except *Exogyra costata*, Say, a mile above Blufftown, Georgia, where characteristic Ripley shells, mainly bivalves, are found in a much decomposed state throughout a stratum 6 to 8 feet thick. The uppermost 10 feet of the stratum is very fossiliferous. The river washes out little cave-like recesses in the banks. Near Jernigan's landing, Alabama, slight rolls in the strata are seen, involving about 20 feet of the sands, and these miniature anticlinals and synclinals continue to within two miles of Florence, Georgia. The dip, estimated from the line of bowlders, averages about 20 feet to the mile and is normal in direction	120
14—Two miles above Florence, Georgia, and making part of a bluff 50 feet high at that place, there is a gray sand interlaminated with thin seams of a more argillaceous sand, all of which is unfossiliferous. Dip here about 40 feet to the mile	26
15—Gray calcareous sands, containing a small, fragile *Anomia* and a line of hard, round concretionary bowlders	40
16—Gray and yellow sands, resembling in physical character those of the Tertiary at Lower Peach Tree, Alabama	30
17—Gray, highly fossiliferous marl. The fossils are nearly, if not quite, all bivalves, and are mostly comminuted as if they formed an ancient shore-line. There are numerous shark teeth and a hard black substance resembling in sections the under shell of a turtle, black coprolitic (?) pebbles, and fragments of lignite	3
18—Sandy stratum, indurated and containing *Ostræa*, sp	1
19—Cross-bedded gray sands and clay	15
20—Fossiliferous marl, about the same in general character as 17, only little or no lignite was seen, the marl appearing to be somewhat glauconitic. (The strata from 17 to 21, inclusive, form a bluff on the eastern bank five miles below Florence, Georgia.)	2
21—Gray, glauconitic, and calcareous sand, weathering into fucoidal masses and containing a few soft white phosphatic nodules	10

	Feet.
22—Gray fossiliferous marl, shells much decomposed. An occasional lignitized log and numerous slightly phosphatic nodular masses containing fossils occur in this stratum	5
23—About the same in general character as 21, but contains indurated ledges about a foot thick, which show the dip to average 40 feet to the mile, with numerous rolls; ends just above the mouth of Cowikee creek, Alabama	170
24—Soft, less coherent sand, gray in color; appears at the mouth of Cowikee creek, Alabama, from which the southern bank of the creek, composed of this stratum, may be seen to rise 50 feet from the water	60
25—Gray calcareous sand, with indurated ledges, containing *Exogyra costata*, Say; *Gryphœa mutabilis*, Mort.; *Hamulus onyx*, *Plicatula urticosa*, *Anomia*, sp.; forms the shoal at Frances bar and bluff at Eufaula, Alabama	190
26—Light-gray and yellow sands, interlaminated with sand darker in color, more argillaceous, and containing bits of lignitized leaves and twigs; no other fossils seen; crops out in the gullies of Eufaula next below the Orange sand	20
27—Massive gray sand, with a few fragile fossils and bowlders. This sand is only slightly calcareous, and is more or less lignitic; dip here about 100 feet to the mile	40
28—A more calcareous sand, filled with *Exogyra costata*, Say, and many indurated ledges, giving rise to the first bar below Eufaula	70
29—Light-yellow cross-bedded sands enclosed between indurated ledges	20
30—Calcareous gray sands, with bowlders	50
31—Yellow sands and indurated ledges filled with casts, *Exogyra costata*, Say, and echinoids set fast in the ledges. The sands are cross-bedded and contain some lignitic streaks	35
32—Gray fossiliferous sand, with bowlders. The sand is massive, and is fossil-bearing only in the lowest 5 feet	40
33—Brown laminated argillaceous sand; disappears at the mouth of Pataula creek, Georgia	5
34—Light-yellow sand, interstratified very irregularly with a gray micaceous sand filled with friable Ripley fossils; mouth of Pataula creek, Georgia	30
35—Hard sandy ledge; weathered surface jagged; contains *Exogyra costata*, Say, and echinoids; very light yellow in color, white when dry and not weathered	30
36—Gray sand, with indurated ledges; no fossils seen; merges gradually in the upper part into a dark, almost black, sand containing large nodular masses and interstratified with light-yellow sands	35
37—White coarse conglomerate, the matrix material being calcareous. The quartzose pebbles decrease in size toward the top, and the stratum becomes more argillaceous. There are many casts, but all too obscure for identification	18
38—Massive blue clay; contains a few bits of teredo-eaten lignite (probably top of Cretaceous)	6
39—Massive sandstone; coarse-grained and almost a conglomerate	8
40—Light-yellow silicious limestone, containing a large *Ostrœa* and numerous obscure casts; five miles above Fort Gaines, Georgia	10

	Feet.
41—White calcareous sand, containing a few obscure casts and an *Ostræa*. The sand sometimes becomes irregularly indurated, and is the source of numbers of small lime springs; forms the lowest part of the bluff at Fort Gaines, Georgia, and in its uppermost 10 feet contains pockets of white sand, enclosed by black clay, the clay resting in "potholes" in the limestone; estimated at	200
42—Glauconitic sand filled with *Gryphæa thirsæ*, Gabb; *Venericardia planicosta*, and *Crassatella tumidula*	8–12
43—Gray, calcareous sandy clay, containing bowlders of clay and a few decomposed shells of *Gryphæa thirsæ*	15
44—White and lignitic cross-bedded sands, and sandy gray clay containing one or two ledges of "pseudo-buhrstone"	50
45—Dark-gray argillaceous sand, with few fossils and fragments of water-worn clay balls. The lower part becomes more fossiliferous, containing *Osteodes caulifera*, *Venericardia planicosta*, and *Gryphæa thirsæ*, etc.	6
46—Greenish-gray, fine-grained calcareous sand; very firm, and holding decomposed shells, mainly bivalves	6
47—Coarse glauconitic sand filled with very large shells of *Ostræa compressirostra*, *Venericardia planicosta*, and a small pecten resembling the species occurring at Yellow bluff, on the Alabama	3
48—Cross-bedded yellow sands, the bedding planes being marked by streaks of gray clay	10
49—Yellow and gray sandy clays, containing occasional beds of *Ostræa compressirostra* and *Gryphæa thirsæ*. The indurated ledges (seldom over two feet thick) which sometimes occur are of the nature of "pseudo-buhrstone" and are filled with bivalves, the only exception noted being *Turritella mortoni* (large). This member disappears below the surface at the mouth of the first large creek flowing from the Georgia side below Fort Gaines	75
50—Light yellow and gray sandy clays, containing in the sandier portion bowlders much like those seen at Bell's landing; no fossils seen. These are undoubtedly the Lower Peach Tree clays and sands. They become more sandy on ascending	170
51—Light greenish-yellow sand filled with bits of decomposed shells and large specimens of *Ostræa compressirostra* and *Venerecardia planicosta*. (Interval of 50 yards.)	3
52—Gray sand filled with decomposed fossils. An irregular indurated ledge (non-fossiliferous) occurs in this stratum. This is probably Bashi, though the only fossil that could be determined with any degree of accuracy is the small oyster so common at the typical locality	18
53—Blue, slightly sandy clay	6
54—Light yellow, silicious (sandy) limestone filled with casts and containing pockets filled with shells of *Ostræa compressirostra*	18
55—Gray lignitic sandy clay (Hatchetigbee)	10
56—Coarse white sand, containing *Ostræa divaricata* and a few other friable shells in the upper part. (The first flexures since leaving Eufaula occur in this stratum.)	12
57—Plain buhrstone, rather sandy	40
58—Light yellowish-green sand containing numbers of small shells of *Ostræa sellæformis*	45

Feet.

59—Buhrstone 55

60—Greenish-yellow calcareous clay, with a few decomposed fossils and an occasional large shell of *Ostræa sellæformis* 12

61—White sandy limestone, with small shells of *Ostræa sellæformis* in abundance and pockets of larger sized shells. Makes capping ledge to island at mouth of Omussie creek, where the bluff is about twenty feet high. This stratum is made up of alternate beds of hard and soft strata, all containing more or less abundant remains of *Ostræa sellæformis.* The harder strata weather out into root-like shapes, and are sometimes rather argillaceous. Many return dips occur in this stratum, stringing it along the banks for many miles further than it would extend normally. The dips are all steep both ways, and many gaps in the succession are caused by the washing out of the softer strata. Owing to these gaps and return dips, it is rather difficult to estimate the thickness of this stratum with much accuracy. It dips below the surface of the river two miles below Gordon, Alabama, and is last seen on the Georgia bank. At Gordon there is a very pronounced return dip. Estimated at (and not exceeding) 60

62—The "*Scutella* bed;" weathers so as to make it not possible to "count up" its thickness. It is literally full of fossils, mainly *Scutella lyelli* (?) and *Pecten nuperus*, with a few smaller and thicker shells of *Scutella.* A bluff about 20 feet high occurs opposite the mouth of Cowhatchee creek, Georgia .... ~~25–30~~

63—White orbitoidal limestone, seen first at Dougherty's wood-yard (Georgia), on the Alabama bank, 9 miles by river from Neal's landing, Alabama. This limestone contains numbers of echinoids about 5 miles above Neal's. The limestone continues as far as Miriam's landing, at which place the thickness is 200

64—Argillaceous and sandy limestone, alternating with strata of purer character. Contains a pecten and an *Ostræa* very close to our recent *virginica.* This may be termed the Chattahoochee limestone. It is well developed there and in the eastern river bank for the succeeding 10 miles 25

65—Light yellow sand, containing pockets of fossils. Where there are no shells the sand is very calcareous. Fossils resemble those described by Conrad as Miocene from York county, Virginia, and Maryland 35

66—Gray sand, slightly calcareous 5

67—Gray calcareous sand filled with shells. The leading fossil is a *Mactra* .... ~~10–15~~

68—Black lignitic sand. This contains much pyrite, and from the efflorescence of ferrous sulphate arises the name Alum bluff; varies with preceding .... ~~10–15~~

Comparative Sections of eastern and western Alabama.

The following tables show the relative thickness of the Tertiary and Cretaceous strata as exposed along the Tombigbee and Chattachoochee rivers respectively:

Formations.

			General* section.	Chattahoochee section.
			Feet.	*Feet.*
Miocene		Alum Bluff	(Not seen)	65
		Chattahoochee	(Not seen)	250
Eocene	*Upper* (White Limestone.)	Salt Mountain	150	(Not seen)
		Vicksburg	140	250
		Jackson	60	25–30
	Middle	Claiborne	140–145	70–75
		Buhrstone	300	170–175
	Lower (Lignitic.)	Hatchetigbee	175	10
		Bashi	80–85	44
		Tuscahoma	140	173
		Nanafalia	200	175
		Naheola	130–150	(Wanting)
		Black Bluff	100	
		Midway	25	218
Cretaceous		Ripley	250–275	1031
		Rotten Limestone	1000	(Wanting)
		Eutaw	300	345
Cretaceous (?)		Tuscaloosa (or Potomac)	1000 (?)	65

* Bull. 43 U. S. Geol. Survey, 1886, p. 18.

Series.

	General section.	Chattahoochee section.
	Feet.	*Feet.*
Miocene	(Not seen)	315
Eocene	1,655±	1,145±
Cretaceous	2,560±	1,441
Total	4,215±	2,900±

DISCUSSION.

Dr. W. B. Clark: What grounds are there for correlating the beds exposed on the Chattahoochee with the Salt mountain beds?

Dr. C. A. White: I should like to ask about the correlation of the Eutaw group and the Tombigbee sands, which have been found to rest directly upon the equivalent of the Eutaw group?

Mr. Langdon: At Eutaw and in the upper part of the micaceous sands at the ferry bluff, casts of nautilii and ammonites as well as shark teeth have been found. Above the calcareous greensand, shark teeth have been found in what is believed to be the equivalent of the Tombigbee sands, seen below the Choctaw bluffs on the Chattahoochee. Here ambiguous fossil remains have been found, mostly casts, showing a great variety of species.

The Salt Mountain beds have been seen only at their typical locality. I do not regard them as constituting a group, but as coral islands in Tertiary seas.

Dr. C. A. White: I have found much difficulty in determining the upper delimitation of the Eutaw group of Tuomey and the lower delimitation of the marine upper Cretaceous series, as it is represented in Alabama and Mississippi. The lower part of the Eutaw group seems to be inseparable from the Tuscaloosa group, the strata of both being of non-marine origin. I regard the Tuscaloosa group of the Gulf-border region as equivalent to the Potomac group of the Atlantic-border region, and the marine upper Cretaceous series, which overlies those groups respectively in the two regions, are plainly equivalent.

It now seems improbable that the Potomac group is newer than the lower part of the lower Cretaceous, and it has even been referred to the Jurassic. In either case it is plain that there is a wide time-hiatus between the Potomac group and the lowermost of the marine Cretaceous strata that have been discussed by Mr. Langdon; and yet the conformity of the upper upon the lower series is usually so exact as to give no physical indication of such a hiatus as I have indicated.

GENERAL SECTIONS EXPOSED ON ALABAMA RIVERS.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 607-662 AUGUST 7, 1891

PROCEEDINGS OF THE THIRD ANNUAL MEETING, HELD AT WASHINGTON DECEMBER 29, 30 AND 31, 1890.

J. J. STEVENSON, *Secretary*.

CONTENTS.

SESSION OF MONDAY, DECEMBER 29.

The Society met in Columbian University at 2 o'clock p. m., Vice-President Alexander Winchell in the chair.

When the meeting was called to order, Mr. G. K. Gilbert, chairman of the Local Committee of Arrangements, introduced President J. C. Welling, of Columbian University, who gave a short address of welcome; and a brief reply on behalf of the Society was made by Vice-President Winchell.

The report of the Council was read by the Secretary as follows:

REPORT OF THE COUNCIL.

To the Fellows of the Geological Society of America:

The Council presents the following report: The number of Fellows now on the roll is 197, one having died since the last annual meeting. The election of five additional Fellows is announced at this meeting, so that the Society will begin 1891 with an enrollment of 202.

The permanent fund, made up of commutations of annual dues, now amounts to $1,800. The Treasurer reports a balance of $1,089 on November 30, the close of the fiscal year.

On January 18, 1890, the Council appointed Mr. W J McGee Editor of the publications. He has supervised the issue of volume 1 of the Bulletin, which contains 605 pages, with 13 plates and 51 figures. The actual cost of the volume is $1,665, and that of distribution is about $120; so that the edition of 530 copies has cost somewhat less than $1,800. The issue of the first part of volume 2 has been retarded by Mr. McGee's illness, but the matter is passing through the press and the brochure will soon be ready for distribution.

The edition of volume 1 consisted of only 530 copies, of which 30 went to the authors. After the necessary reserve of 75 copies for exchange and 150 copies for future needs, there remain 74 copies which can be placed on sale to Fellows at $4.35, an advance of 30 per cent. on the actual cost. A few volumes have been broken by supplying parts lost in mail. The separate parts of those volumes can be sold at a similar advance. It has been thought best to require persons not Fellows to pay not less than 50 per cent. advance upon the original cost, and in no case less than $10 per volume.*

The Council desires to call the attention of Fellows to the matter of publication. Volume 2 of the Bulletin will equal volume 1 in importance, and is likely to be much larger. The total income of the Society during 1891, making allowance for temporary defaults in payment of dues, will be somewhat more than $2,000. The expense of administration will be not far from $200, so that the amount available for publication will approximate $1,800. It is evident that until the permanent fund reaches $10,000 authors must be asked to bear a considerable part of the costs of plates, as the Society can do little more at present than pay for publishing the text, unless the Council resorts to an unpleasantly severe selection of papers for publication.

The Council recommends that the Treasurer be authorized to pay all bills for publication of the Bulletin, when certified to by the officer making the expenditure.

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* These prices were subsequently modified by the Council. See this volume, p. x.

As the sessions of the International Geological Congress begin in Washington on August 26, 1891, it will be well for the Society to hold sessions on the two days prior to that date. This is in strict conformity to the requirements of the constitution, as the American Association for the Advancement of Science will begin its meeting in Washington on August 19, 1891. The Council therefore recommends that when the Society adjourns, it adjourn to meet in Washington on August 24, 1891, at 10 a. m., and that the sessions continue during August 24 and 25.

By formal vote of the Society, the recommendations of the report were adopted.

ELECTION OF OFFICERS AND FELLOWS.

The Secretary announced the result of balloting for officers for 1891 as follows:

President:

ALEXANDER WINCHELL, Ann Arbor, Mich.

Vice-Presidents:

G. K. GILBERT, Washington, D. C.

T. C. CHAMBERLIN, Madison, Wis.

Secretary:

H. L. FAIRCHILD, Rochester, New York.

Treasurer:

HENRY S. WILLIAMS, Ithaca, New York.

Members-at-large of the Council:

Class of 1893:

GEORGE M. DAWSON, Ottawa, Canada.

JOHN C. BRANNER, Little Rock, Arkansas.

Class of 1892:

E. W. CLAYPOLE, Akron, Ohio.

CHAS. H. HITCHCOCK, Hanover, N. H.

Class of 1891:

I. C. WHITE, Morgantown, W. Va.

JOHN J. STEVENSON, New York City.

Editor:

W J McGEE, Washington, D. C.

The result of balloting for Fellows was announced by the Secretary as follows:

T. NELSON DALE, Newport, R. I. Assistant Geologist on the U. S. Geological Survey; now engaged on structural geology.

ORVILLE A. DERBY, M. S., present address Rio Janeiro, Brazil. Director of the Geographical and Geological Survey of the province of Sao Paulo, Brazil.

ULY. S. GRANT, B. S., Minneapolis, Minn. Now post-graduate student at Johns Hopkins University, engaged in study of crystalline rocks.

EDMUND JÜSSEN, Ph. D., Washington, D. C. Assistant Geologist on the U. S. Geological Survey and engaged on surface and crystalline geology.

WILL H. SHERZER, M. S., Saginaw, Mich. Teacher, and engaged in paleontological work.

The death of Richard Owen was announced by the Secretary, and authority was given to publish the following—

OBITUARY NOTICE.

Dr. Richard Owen, youngest brother of David Dale Owen and Robert Dale Owen, died at New Harmony, Indiana, on March 24, 1890, at the advanced age of somewhat more than eighty years. He was a native of Lanarkshire, Scotland. His education and training, prior to his settlement at New Harmony, Indiana, was partly at Lanark and at Hofwyl, Switzerland, and later at Glasgow, where he had a course of study with Dr. Andrew Ure. He was known as author, teacher, geologist, and soldier. His first geological work was done in association with his brother, David Dale Owen, on the United States survey of Wisconsin, Iowa, and Minnesota, where he was employed mainly on the northern shore of Lake Superior. He published in 1857 a work entitled "Key to the Geology of the Globe," and in 1862 his report on a "Geological Reconnoissance of Indiana." His later scientific publications relate to physical geography and seismism, and are principally published in the Proceedings of the American Association for the Advancement of Science and in the American Meteorological Journal. His two sons, Eugene and Horace, now reside at New Harmony.*

On motion of Mr. G. K. Gilbert, the thanks of the Society were unanimously voted to Professor J. J. Stevenson for his services as Secretary and for his efficient labors in organizing the Society.

Mr. G. K. Gilbert made some remarks in announcement of the illness of the President of the Society, Professor J. D. Dana, and Vice-President J. S. Newberry, and moved that the Secretary be instructed to communicate to President Dana and Vice-President Newberry the assurance of the sympathy of the Society in their illness, and hopes for their speedy recovery. The motion was unanimously voted.

* A sketch of the life and work of Dr. Owen, with a portrait, was published in the American Geologist, vol. VI, 1890, pp. 135-145.

After some general announcements the scientific work of the meeting was declared in order, and acting President Winchell announced the first paper upon the printed program:

THE STRUCTURE OF A PORTION OF THE SIERRA NEVADA OF CALIFORNIA.

BY GEORGE F. BECKER.

The communication was briefly discussed by George M. Dawson. It is printed among the memoirs of this volume, forming pages 49–74.

The second paper was—

NOTE ON THE GEOLOGICAL STRUCTURE OF THE SELKIRK RANGE.

BY GEORGE M. DAWSON.

This was discussed by C. D. Walcott, J. W. Spencer, and G. K. Gilbert. It forms pages 165–176 of this volume. The discussion by Messrs. Spencer and Gilbert is appended to the paper. Mr. Walcott's remarks were as follows:

DISCUSSION ON THE GEOLOGICAL STRUCTURE OF THE SELKIRK RANGE.

BY C. D. WALCOTT.

Of the 25,000 to 40,000 feet of strata of the Castle Mountain and Bow River series included by Dr. Dawson in the Cambrian I have heretofore referred the lower portion, beneath the zone of the *Olenellus* fauna the Bow River series, to the Algonkian. While, as Dr. Dawson claims, there is no improbability that Cambrian life might be found in the lower series, yet the *Olenellus* fauna was the oldest known, and for convenience the strata beneath were referred to the Algonkian; still, from the fact that during the past summer I have found the *Olenellus* fauna to range through 1,000 feet of limestone and 250 feet of superjacent shales in Vermont, it is exceedingly probable that it had an extensive range in the quartzites of the Bow River series and also in the corresponding series of the Wasatch range, which was studied by the Fortieth Parallel survey and subsequently by myself. Owing to this I shall not offer serious objection to including the Bow River series in the Cambrian. A similar series has been described by Mr. Gilbert in Utah and by Dr. Peale in Montana.

The next paper was—

THE OVERTHRUST FAULTS OF THE SOUTHERN APPALACHIANS.

BY C. WILLARD HAYES.

It was discussed by G. K. Gilbert, C. D. Walcott, W. M. Davis, and Bailey Willis, and forms pages 141–154, with plates 2 and 3, of this volume.

The last paper of the afternoon session was—

POST-PLIOCENE SUBSIDENCE VERSUS GLACIAL DAMS.

BY J. W. SPENCER.

This was discussed by G. K. Gilbert. It is printed as pages 465–476, with plate 19, of this volume.

The Society adjourned, to meet at 8 o'clock p. m., in the same place.

Evening Session, Monday, December 29.

The Society convened at 8 p. m., President Winchell in the chair.

The first paper of the evening was entitled:

ILLUSTRATIONS OF THE STRUCTURE OF GLACIAL SAND-PLAINS.

BY W. M. DAVIS AND H. L. RICH.

Professor Davis described the form and structure of glacial sand-plains, and illustrated his remarks by a series of lantern views made from photographs taken by Mr. H. L. Rich, of Auburndale, Massachusetts, who has been associated with him in the study of these deposits during the past year. The text of Mr. Davis' remarks is given in his paper on this subject, read by title only at the New York meeting and published in the Bulletin volume 1, pages 195–202, plate 3.

The second paper of the evening was—

GLACIERS OF THE ST. ELIAS REGION, ALASKA.

BY. I. C. RUSSELL.

The glaciers of the St. Elias range and of the foothills and lowlands between the range and the Pacific ocean were described and illustrated. The glaciers were classified as (1) Alpine glaciers, or ice-rivers of the usual type; and (2) Piedmont glaciers, or broad ice-sheets lying at the bases of mountains and formed by the confluence of Alpine glaciers; and both classes were discriminated from continental glaciers.

The paper was illustrated by lantern views. It is published in full, with other matter, in The National Geographic Magazine, volume III, 1891, pages 53–204, plates 2–20.

The Society adjourned to meet in the same place on Tuesday, December 30, at nine o'clock a. m.

Session of Tuesday, December 30.

The Society was called to order at 9.30 a. m., acting President Alexander Winchell in the chair.

The first paper was—

VARIATIONS IN THE TERTIARY AND CRETACEOUS STRATA OF ALABAMA.

BY DANIEL W. LANGDON, JR.

It was discussed by W. B. Clark, C. A. White, and the author. The paper is printed among the memoirs of this volume as pages 587–606, plate 23.

The second paper was entitled—

THE COMANCHE SERIES OF THE TEXAS-ARKANSAS REGION.

BY R. T. HILL.

The paper was discussed by C. A. White, C. D. Walcott, E. T. Dumble, Cooper Curtice, and the author. It is printed as pages 505–528 of this volume.

The two following papers were read consecutively and discussed together:

A GEOLOGICAL SECTION ACROSS THE PIEDMONT PLATEAU IN MARYLAND.

BY CHARLES R. KEYES.

THE PETROGRAPHY AND STRUCTURE OF THE PIEDMONT PLATEAU IN MARYLAND.

BY GEORGE H. WIILLIAMS.

The papers were discussed by W. M. Davis, Jed. Hotchkiss, Charles S. Prosser and G. H. Williams. They are printed as pages 301–322, with plate 12, of this volume.

A recess was then taken until 1.30 o'clock p. m.

On reässembling, the following paper was read:

THE RELATION OF SECULAR ROCK-DISINTEGRATION TO CERTAIN TRANSITIONAL CRYSTALLINE SCHISTS.

BY RAPHAEL PUMPELLY.

This communication was discussed by Jed. Hotchkiss, G. K. Gilbert, H. S. Williams, B. K. Emerson, F. L. Nason and the author, and will be found, with the more considerable part of the discussion, on pages 209–224 of this volume.

The next two papers were read by title:

A PROPOSED SYSTEM OF CHRONOLOGIC CARTOGRAPHY ON A PHYSIOGRAPHIC BASIS.

BY T. C. CHAMBERLIN.

THE GEOLOGICAL DATES OF ORIGIN OF CERTAIN TOPOGRAPHIC FORMS ON THE ATLANTIC SLOPE OF THE UNITED STATES.

BY W. M. DAVIS.

The papers form pages 541–586 of this volume.

The following communication was then presented:

GRAPHIC FIELD NOTES FOR AREAL GEOLOGY.

BY BAILEY WILLIS.

It was discussed by G. F. Becker, Jed. Hotchkiss, P. H. Mell, and G. M. Dawson. It forms pages 177–188, with plate 6, of this volume.

The next communication was—

MESOZOIC AND CENOZOIC FORMATIONS OF EASTERN VIRGINIA AND MARYLAND.

BY N. H. DARTON.

It is printed as pages 431–450, with plate 16, of this volume.

The next two papers were read and discussed together:

THE CHAZY FORMATION IN THE CHAMPLAIN VALLEY.

BY EZRA BRAINERD.

Printed, with plate 11, as pages 293–300 of this volume.

ON THE LOWER CAMBRIAN AGE OF THE STOCKBRIDGE LIMESTONE AT RUTLAND, VERMONT.

BY J. E. WOLFF.

Printed as pages 331–338 of this volume.

The two papers were discussed by J. F. James, C. D. Walcott, C. H. Hitchcock, and the authors.

The Society then adjourned until 8 o'clock p. m. An auxiliary section, arranged to present papers on the Quaternary, adjourned early in the afternoon.

Following the session of the afternoon the Fellows and ladies partook of an informal dinner, without speeches, at Willard's Hotel.

Evening Session, Tuesday, December 30.

The Society reässembled at 8.10 p. m., and listened to a paper, illustrated with lantern views, entitled—

A CONTRIBUTION TO THE GEOLOGY OF GEORGIA.

BY P. H. MELL.

This was followed by—

ANTIQUITIES FROM UNDER TUOLUMNE TABLE MOUNTAIN IN CALIFORNIA.

BY GEORGE F. BECKER.

Remarks were made on this communication by G. F. Wright, E. D. Cope, H. W. Turner, and the author. The paper, with discussion, will be found as pages 189–200, with plate 7, of this volume.

Mr. J. S. Diller presented the report of the Committee on Photographs, which has been amended and enlarged to read as follows:

FIRST ANNUAL REPORT OF THE COMMITTEE ON PHOTOGRAPHS.

At the meeting of the British Association for the Advancement of Science in 1888, Mr. Osmund W. Jeffs presented a paper on local geologic photography which led, at the next meeting of the Association, in September, 1889, to the appointment of a committee to arrange for the collection, preservation, and systematic registration of photographs of geologic interest in the United Kingdom.

The success of this movement was afterwards brought to the attention of the International Geological Congress in London in 1889. Professor H. S. Williams suggested to Mr. J. F. Kemp the advisability of initiating a similar movement in the Geological Society of America. Mr. Kemp prepared a paper on this subject for the New York meeting of the Geological Society in 1890, but for the want of time it was crowded out. He urged the Secretary to bring the matter before the Council, and at the regular meeting of the Council, held in Washington in April, 1890, the following Fellows were appointed a committee on photographs: Professor J. F. Kemp, Cornell University, Ithaca, N. Y.; Professor W. M. Davis, Harvard University, Cambridge, Mass.; and Mr. J. S. Diller, U. S. Geological Survey, Washington, D. C.

The object of the movement is to make a photo-geologic survey, and secure for the Society a national collection of photographs illustrating the geology of the country. The demands for such a collection, already felt by the committee, are, first, to furnish to teachers better illustrations to use in teaching geology, and, second, to furnish to investigators material for comparative study.

The plan of the committee is: (1) To solicit donations of photographs of geologic phenomena, not only from Fellows of the Geological Society of America, but also from all other persons who can furnish them; (2) To exhibit the collection of photographs thus obtained at the annual meetings of the Society; and (3) To publish annually in the proceedings of the Society a report containing a register of the photographs received during the year.

The committee has issued three circulars. Number 1 was hektographed, and distributed in June, 1890. The same matter was printed and sent out in August, 1890, as circular number 2. The third circular was issued at the Washington meeting of the Society, and has since been distributed from Rochester by the Secretary. It contains a complete, but greatly abridged, list of the donations of photographs received before December 29, 1890.

At that time the committee had received 293 photographs, of which 21 were donated by Professor J. F. Kemp, of Ithaca; 269 by the Geological Survey, through the Director, Major J. W. Powell; and 3 by Professor W. B. Dwight, of Poughkeepsie.

To facilitate exhibition and examination at the annual meeting, and at the same time to ensure preservation, the photographs were classified and temporarily bound together in the form of books, as indicated in circular number 3.

Since December 29, 25 photographs have been received from Dr. George H. Williams, of Baltimore; Professor P. H. Mell, of Auburn, Alabama; and Mr. G. P. Merrill, of Washington, D. C. Professor W. M. Davis announces that he is preparing for the Society a collection of views illustrating the physical features of New England.

The expenses of the committee in printing the circulars and preparing the photographs for exhibition have been about $20.

The committee solicit the donation of good photographs which clearly illustrate important geologic phenomena, among which may be mentioned typical views of eruptive and sedimentary rocks, of dikes, bosses, contacts, transitions, folds, faults, jointing, cleavage, weathering, etc., of glaciers and other geologic agents, as well as of good exposures of definite geological horizons and of characteristic topographic forms, especially those which have a visible bearing upon the geologic history of the country.

Photographs may be sent to any member of the committee. Prints smaller than 4 by $4\frac{1}{4}$ inches are not desired. They should all be mounted; and for artistic effect, as well as ease of preservation, gray cards are preferred.

Each photograph should be plainly labeled, giving the subject, with a brief but explicit reference to what is illustrated by the photograph, its date, locality, and the name of the artist and donor, and a reference to its publication, if the photograph has been published, either in type or plate. The label should be placed, if in type, upon the front, beneath the photograph; if in script, upon the back.

The photographs should be accompanied by a statement whether duplicates and lantern slides can be furnished, and at what price, and the address of the person to whom application for them should be made. It is suggested that in order to save trouble to the donors, arrangements be made with local photographers, to whom the negatives may be intrusted, to fill orders.

Register of Photographs Received in 1890.

The following is a complete register of the photographs collected previous to the Washington meeting. It contains the running numbers of the photographs by which they can be ordered, their labels, sizes, dates, the cost of duplicates, as well as the names of the photographers and the donors; also directions as to where duplicates and lantern slides may be obtained.

Professor J. F. Kemp presented 21 photographs, numbered from 1 to 21 inclusive. All but 18–21 were photographed by Mr. Kemp. Their size is 5 by 7 inches. They may be ordered of him at $0.10 unmounted, $0.12 mounted, postage extra.

1. Boss or knob of so-called porphyrite, associated with the elæolite-syenite near Beemerville, New Jersey. (Am. Jour. Sci., 3d ser., vol. XXXVIII, p. 130.) June, 1888.
2. The Sopris coal mines, near Trinidad, Colorado. The mines enter the hill just in the rear of the engine-house. September, 1888.
3. Coal mines and butte at Rouse, near Walsenburg, Colorado. Characteristic scenery of the eastern foothills. September, 1888.
4. View of Mount Sopris, western Colorado, from the Spring Gulch coal mines across Jerome park. The point of view is on the Laramie. The intervening upturned strata are Mesozoic and Paleozoic. August, 1888.
5. The Sunshine coal mines, Jerome park, northwestern Colorado. The Laramie sandstones show in section on the right, dipping westward. September, 1888.
6. Open cut and stopes at Pilot Knob, Missouri, showing the relations of the specular hematite to the porphyry, and also the thickness of the ore body. September, 1888.
7. Open cut at Pilot Knob, Missouri, showing the specular hematite interbedded in porphyry and slate. September, 1888.
8. Open cut at Iron Mountain, Missouri. Photograph taken on a very cloudy day. September, 1888.
9. Red Cambrian quartzite, as exposed in the quarries at Willard's ledge, Burlington, Vermont. Dip 10°–15° E. July, 1889.
10. Trap dike in red Cambrian quartzites at the Willard's ledge quarries, Burlington, Vermont. July, 1889.
11. Red Cambrian quartzite at the Red Rocks, just south of Burlington, Vermont. Dip 15°–20° E. The water is Lake Champlain. July, 1889.
12. Overthrow of Cambrian sandstone on Utica slate, Lone Rock point, just north of Burlington, Vermont. The water is Lake Champlain. July, 1889.

13. Cambrian sandstone overlying Utica slate, which is not visible in this view, having dipped out of sight. Lone Rock point, just north of Burlington, Vermont. July, 1889.
14. Au Sable chasm in Potsdam quartzite near Lake Champlain, New York. July, 1889. 1st view.
15. The same. 2d view.
16. The same. 3d view.
17. The Adirondacks, looking eastward from the summit of Mount Marcy. July, 1889.
18. Portage sandstone at Enfield gorge, near Ithaca, New York. Photographed by V. F. Marsters. 1890.
19. Section of Portage shaly sandstone at the Buttermilk falls, near Ithaca, New York. Photographed by V. F. Marsters. 1890.
20. Vertical schists, quartzites, etc., with trap dikes at Bald cliff, Maine. Photographed by Harris Kennedy, 1888. Size, $6\frac{1}{2}$ x $8\frac{1}{2}$ inches.
21. Schists and dikes at Kennebunkport, Maine. Photographed by Harris Kennedy, 1888. Size, $6\frac{1}{4}$ x $8\frac{1}{2}$ inches. (Amer. Geol., vol. V, 1890, p. 129.)

The United States Geological Survey, through the Director, Major J. W. Powell, has contributed 269 photographs. These bear numbers from 22 to 290, inclusive, and have been classified. Prices are stated at close of list.

STRUCTURAL FEATURES OF ROCKS.

Folds.

22. Anticlinal in Lévis terrane, on roadside leading up the bluff above Lévis railway station, Province of Quebec, Canada. Size, 6 x 8 inches. Photographed by C. D. Walcott, 1889.
23. Southern shore of St. Lawrence river, 9 miles below Quebec, Canada. Plication of shales and sandstones of Sillery terrane. Size, 6 x 8 inches. Photographed by C. D. Walcott, 1889.
24. Anticlinal fold in Sillery shales and sandstones, 9 miles below Quebec, Canada, on southern shore of St. Lawrence river. Size, 6 x 8 inches. Photographed by C. D. Walcott, 1889.
25. Section of anticlinal ridge in railway cut one mile east of Dunkirk, New York. The rock is a black shale of Devonian age. The anticlinal structure was imposed after the retreat of the Pleistocene ice sheet. Size, 4 x $4\frac{3}{4}$ inches. Photographed by G. K. Gilbert, 1886.
26. Arched strata on Chesapeake and Ohio canal, probably near Hancock, West Virginia. Size, 8 x 10 inches. Photographed by H. R. Geiger, 1886.
27. Fold in brown sandstone on Chesapeake and Ohio canal, 2 miles above Hancock, West Virginia. Size, 8 x 10 inches. Photographed by H. R. Geiger, 1886.

Faults.

28. Fault in sandstone and shale of the Newark system, Bogan cut, near Wadesborough, North Carolina. Hade toward the west. Size, 8 x 10 inches. Photographed by I. C. Russell, 1885.
29. Fault between Archean gneiss and Trenton limestone and Utica shale, just south of Montmorency falls, Canada. Size, 8 x 10 inches. Photographed by C. D. Walcott, 1889.
30. Contact of rocks of lower Cambrian and lower Ordovician age, on the line of the great fault, about $2\frac{1}{2}$ miles northeast of Highgate springs, Vermont, Size, 6 x 8 inches. Photographed by C. D. Walcott, 1889.

Contacts, etc.

31. Unconformable contact of gneiss and Trenton limestone; ½ mile from Montmorency falls, Canada. Size, 6 x 8 inches. Photographed by C. D. Walcott, 1889.

32.* Base of first Watchung trap-sheet in gorge of Passaic river at Paterson, New Jersey, showing both basaltic columns and bedded trap in the same sheet and contact with Newark shales. Size, 5 x 7 inches.

33. Lateral ascent of base of palisade trap across Newark shales at King's point, Weehawken, New Jersey. Shore of the Hudson river. Size, 5 x 7 inches.

34. Cross-section exposure of base of palisade trap-sheet, showing its contact with the Newark shales. West Shore railroad tunnel, Weehawken, New Jersey. Size, 5 x 7 inches.

35. Seams in limestone filled with calc-spar. Calciferous formation near Limekiln point, Highgate Springs, Vermont. Size, 6 x 8 inches. Photographed by C. D. Walcott, 1889. 1st view.

36. The same. 2d view.

37. Brecciated limestone conglomerate. Calciferous zone, 1 mile south of Highgate falls, Vermont. Size, 6 x 8 inches. Photographed by C. D. Walcott, 1889.

Jointing.

38. Obsidian columns, Obsidian cliff, Yellowstone National Park. Size, 6 x 8 inches. Photographed by J. P. Iddings and described in the 7th Ann. Rep. of the U. S. Geol. Survey, 1888, pp. 249–295.

39. The same, near view, showing horizontal lamination of obsidian columns.

40. The same, showing lithoidal portion.

41. Columnar basalt, O'Rourke's quarry, Orange mountain, New Jersey. Converging columns in middle of quarry. Size, 6 x 8 inches. Photographed by J. P. Iddings and described in Am. Jour. Sci., 3d ser., vol. XXXI, 1886, pp. 321–331.

42. The same, northern end of quarry.

43. The same. Southern end, showing the curved, tapering ends of vertical columns and the junction of two groups of small columns.

44. The same, showing converging columns and large vertical columns.

45. The same, showing large vertical columns with spheroidal parting and transverse, chiseled structure.

46. The same.

47. Table mountain, Golden, Colorado. Shows effect of unequal, horizontal, tabular jointing in dense part of a thick basalt sheet. Size, 8 x 10 inches. Photographed by Whitman Cross, 1886.

48. Cliffs in Topman's gulf, Jefferson county, New York. Lorraine rocks; Utica shale with interbedded sandstone of the Lorraine series coming in above. Size, 6 x 8 inches. Photographed by C. D. Walcott, 1889.

49. Joints in granite, Mount Lyell, California. Size, 8 x 10 inches. Photographed by I. C. Russell, September, 1883.

CLEAVAGE and WEATHERING.

50. Middle quarry of the Penrhyn slate company, Middle Granville, Washington county, New York. Illustration of the bedding of the roofing slate. It is coincident with the line of cleavage. Size, 6 x 8 inches. Photographed by C. D. Walcott, September, 1890.

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*32, 33 and 34 photographed by N. H. Darton, 1887, Bull. 67, U. S. Geol. Survey, 1890.

51. Old quarry north of the Penrhyn slate company's quarries, Middle Granville, Washington county, New York. Illustration of the dip of the slate. Size, 6 x 8 inches. Photographed by C. D. Walcott, 1890.
52. Same as 50; the light-colored stratum is a brecciated limestone conglomerate in a massive layer coincident with the cleavage of the roofing slate. Northern and eastern sides of quarry.
53. Same as 52.
54. Spherical sundering in cliff of basalt, northern Table mountain, Golden, Colorado. The most distinct spheres are from one to two feet in diameter, with several concentric shells. Size, 8 x 10 inches. Photographed by C. Whitman Cross, 1883.
55. Decomposed trap rock in Newark system at Wadesborough, North Carolina. Size, 8 x 10 inches. Photographed by I. C. Russell.
56. Typical field of gabbro bowlders in northern Delaware and southeastern Pennsylvania, 3 miles west of Claymont, Delaware. Size, 6 x 8 inches. By W J McGee, 1888.
57. Cherty layers interbedded in Sillery shales, 8 miles below Quebec, Canada, on the southern side of St. Lawrence river. Size, 6 x 8 inches. Photographed by C. D. Walcott, 1889.

EROSION and DEPOSITION.

Cañons of the *Colorado*, *Yellowstone*, etc.

58. Grand cañon of the Colorado at the foot of the Toroweap, in Arizona. The outer cañon, of which only the northern wall in seen, is here 5 miles wide and 2,000 feet deep. The inner gorge cut in the floor of the outer one is 3,000 feet deep and from 3,500 to 4,000 feet wide from crest to crest. Size, 10 x 13 inches. Photographed by J. K. Hillers, 1882. Published in Tertiary History of the Grand Cañon District by Captain C. E. Dutton, p. 86.
59. Shinimo altar from the brink of Marble cañon of the Colorado river, Arizona. Size, 10 x 13 inches. Photographed by J. K. Hillers, 1882.
60. Upper falls and Upper cañon of the Yellowstone, Yellowstone National Park. Size, 10 x 13 inches. Photographed by W. H. Jackson.
61. Grand cañon of the Yellowstone, Yellowstone National Park. Size, 10 x 13 inches. Photographed by W. H. Jackson.
62. Cañon de Chelly, Arizona. Size, 10 x 13 inches. Photographed by J. K. Hillers, 1885.
63. Oak cañon, Arizona. Bedding and cross-bedding. Ruins of cliff dwellings on the left. Size, 10 x 13 inches. Photographed by J. K. Hillers, 1885.
64. Lava-capped river bed of the ancient Sacramento, near Delta, California. The embankment midway between the river below and its ancient bed beneath the lava above is occupied by a railroad. The lava stream is from Mount Shasta and it follows the cañon of the Sacramento for nearly 50 miles. Size, 8 x 10 inches. Photographed by J. S. Diller, 1888.
65. Navajo church, near Fort Wingate, New Mexico. Prominent columns of erosion, cross-bedding. Size, 10 x 13 inches. Photographed by J. K. Hillers, 1885.

Gorges of the Potomac and Susquehanna. (Photographed under the direction of W J McGee, 1889. Size, 6 x 8 inches.)

66. Junction of the Shenandoah and Potomac. Photographed by E. P. Hough.
67. The Shenandoah near Harper's ferry. Photographed by E. P. Hough.
68. The Potomac near Harper's ferry. Photographed by E. P. Hough.
69. The Great falls of the Potomac. Photographed by E. P. Hough, 1888.
70. The gorge of the lower Susquehanna. Published in Seventh Ann. Rept. U. S. Geol. Survey, pl. LVI, 1888. Size, 10 x 13 inches. Photographed by C. C. Jones, 1886.

Waterfalls.

71. The rapids above Niagara falls, seen from the Canadian side. Size, 10 x 13 inches. Photographed by J. K. Hillers, 1886.
72. The rapids and Canadian falls of Niagara, seen from Goat island. Size, 10 x 13 inches. Photographed by J. K. Hillers, 1886.
73. Niagara falls, from the American side. Size, 10 x 13 inches. Photographed by J. K. Hillers, 1886.
74. The American portion of Niagara falls, from Goat island. Size, 10 x 13 inches. Photographed by J. K. Hillers, 1886.
75, 76. The American portion of Niagara falls, from the Canadian side. Size, 10 x 13 inches. Photographed by J. K. Hillers, 1886.
77. Falls of the Passaic at Paterson, New Jersey. Edge of first Watchung trap-sheet. Size, 5 x 7 inches. Photographed by N. H. Darton, 1887.
78. Highgate falls, Vermont. Size, 6 x 8 inches. Photographed by C. D. Walcott, 1889.
79. Falls on Manuel's brook, Conception bay, Newfoundland. Size, 6 x 8 inches. Photographed by C. D. Walcott, 1888.
80. Falls in Black creek, near Gadsden, Alabama. A synclinal stream flowing over Carboniferous sandstone with shale underneath. Height of fall, 100 feet. Size, 8 x 10 inches. Photographed by I. C. Russell, 1885.
81. Burney falls, Shasta county, California. The upper portion of the falls is over basalt and the lower portion over infusorial earth. Size, 8 x 10 inches. Photographed by J. S. Diller, 1885.
82. Lower falls of the Yellowstone, 308 feet high. Size, 10 x 13 inches. Photographed by W. H. Jackson.
83. Upper falls of the Yellowstone, 112 feet high. Size, 10 x 13 inches. Photographed by W. H. Jackson.

Forms of tilted Strata and residual Deposits.

84. Triassic sandstone, Garden of the Gods, Colorado. Size, 6 x 8 inches. Photographed by I. C. Russell, 1888.
85. Triassic sandstone, Red valley, an extension of the Garden of the Gods, Colorado. Size, 6 x 8 inches. Photographed by I. C. Russell.
86. Same as 84.
87. Jurassic rocks, Como (Aurora), Wyoming. Size, 6 x 8 inches. Photographed by I. C. Russell, 1888.
88. Monoclinal ridge, Colorado City, Colorado. Triassic and Jurassic. Size, 6 x 8 inches. Photographed by I. C. Russell, 1888.
89. Algonkian rocks in cut on the D. & H. Railway, Putnam station, Washington county, New York. Size, 8 x 10 inches. Photographed by C. D. Walcott, 1887.
90. Fields of residual clay near Natural bridge, Virginia. Published in Bulletin 52, U. S. Geol. Survey. Size, 8 x 10 inches. Photographed by I. C. Russell, 1885.

Glacial Phenomena of the Sierra Nevada, California. (Photographed by I. C. Russell, summers of 1882 and 1883. Size, 8 x 10 inches.)

91. Gibb's cañon, from Williams butte, Mono valley, California. Published in Eighth Ann. Rep. U. S. Geol. Survey, pl. XXXIV.
92. Bloody cañon, south of Mono lake, California.
93. Lake cañon, near Mono lake, California. Partially refilled after being glaciated. Published in Eighth Ann. Rep. U. S. Geol. Survey, pl. XXXIII.

Nos. 94, 95, 96, 97, 99, 100, 101 are published in Fifth Ann. Rep. U. S. Geol. Survey, with plate numbers as below.

94. Mount Lyell, from the Tuolumne meadows, California. Pl. XXXVIII.
95. Tuolumne valley, California, showing upper limit of ancient glacier. Pl. LXI.
96. Mount Dana, California, from the west. A small glacier on northern slope, glaciated country to the right. Pl. XXXIV.
97. Mount Dana glacier, northern side of Mount Dana, California. Pl. XXXV.
98. Mount Dana glacier, northern side of Mount Dana, California.
99. Mount Dana glacier, northern side of Mount Dana, California. Pl. XXXVII.
100–101. Double plate. Mount Lyell glacier, northern side of Mount Lyell, California. Pl. XXXIX.
102. Leevining cañon, near Mono lake, California. A glaciated cañon with small terminal moraine in the foreground.

Glacial Phenomena of Mount Shasta, California. (Excepting 103 and 112 photographed by J. S. Diller, chiefly in July and August, 1884, Size, 8 x 10 inches.)

103. Mount Shasta from the western base, near the railroad station at Sissons. Size, 8 x 10 inches. Photographed by C. E. Dutton, July, 1885.
104. Mount Shasta from the north, after the first snowfall of September, 1884.
105. Near view of Mount Shasta from the north. Mount Shasta on the left is 2,000 feet higher than Shastina on the right The gray pile at the foot of the snow between them is the terminal moraine of the Whitney glacier. To the left of this is the terminal moraine of the Bulam glacier.
106. Whitney glacier, crevasses and moraine, northwestern slope of Mount Shasta.
107. Bulam glacier and moraine, northern slope of Mount Shasta.
108. Mount Shasta from the east.
109. Hotlum glacier and moraine, eastern slope of Mount Shasta.
110. Glaciated rocks, southeastern slope of Mount Shasta.
111. Moraine of late glacial field at western base of Lassen peak, California. Photographed August, 1885.
112. Glacial striæ, north Yallo Bally mount, Coast range, California. Photographed by J. Stanley-Brown, August, 1889.

Glacial Striæ, Bowlders, Avalanche.

113. Striated limestone bowlder from loess, one-half natural size, Norway, Iowa. Published in Eleventh Ann. Rep. U. S. Geol. Survey, pl. XLVI. Size, 8 x 10 inches. Photographed by W J McGee, 1888.
114. Perched bowlder, near Jura lake, Mono valley, California. Published in Eighth Ann. Rep. U. S. Geol. Survey, pl. XXXVIII. Size, 8 x 10 inches. Photographed by I. C. Russell, 1883.
115. Shore of Lake Ontario, at Pillar point, New York. Removal of glacial deposits by the waves has exposed a typical glaciated surface traversed by a few scratches ascribed to the grounding of icebergs. Same subject as No. 116. Published by T. C. Chamberlin, Seventh Ann. Rept. U. S. Geol. Survey, p. 166. Size, 4 x 4¾ inches. Photographed by G. K. Gilbert, 1885.
116. Shore of Lake Ontario at Pillar point, New York. The aberrant scratches are ascribed to the grounding of icebergs. Same subject as No. 115. Size, 4 x 4¾ inches. Photographed by G. K. Gilbert, 1885.
117. Bowlders in foreground, loess hills in background. S. E. ¼ S. E. ¼ sec. 3, T. 93 N., R. VIII W., Fayette county, Iowa. Size, 6 x 8 inches. Published in Eleventh Ann. Rep. U. S. Geol. Survey, pl. XLV. Photographed by W J McGee, 1888.

118. View on Brush creek, Gunnison county, Colorado, to show the swath cut by a snow-slide through a dense growth of spruce. Size, 8 x 10 inches. Photographed by C. Whitman Cross, October 3, 1885.

Wind Erosion. (Photographed by I. C. Russell, 1887. Size, 8 x 10 inches.)

119. Eolian erosion in rhyolite, Mono valley, California.
120. Sand dunes near Sleeping Bear bluff, eastern shore of Lake Michigan.
121. Forest formerly buried beneath drifting sand and now exposed by eolian erosion. High part of South Manitou island, Lake Michigan.

Topographic Features of Lake Shores, ancient and modern, Ontario Basin. (Photographed by G. K. Gilbert, 1885. Size, 4 x $4\frac{3}{4}$ inches.)

122. Shore of Lake Ontario, Griffin bay, New York. The waves have excavated a cliff from bowlder clay, but have not been able to remove the larger bowlders.
123. Shore of Lake Ontario, Griffin bay, New York. A barrier of shingle separates a lagoon from the lake.
124. On western shore of Cayuga lake, at East Varick, New York. A delta modified in outline through deflection of shore currents by a projecting pier.
125. Views of Iroquois shore, near Wolcott, New York. A sea-cliff, cut from a drumlin, appears just to the right of the center, and a spit running to the left bears a house and barn.
126. Portion of Iroquois shore, near Wolcott, New York. The camera stands on a spit and is turned toward a sea-cliff cut from a drumlin.
127. Iroquois shore, near Constantia, New York. The camera stands on a beach ridge of gravel. Compare modern beach in No. 123.
128. Iroquois shore, near Pierrepont manor, New York. Excavation of till by the waves left a cut terrace set with large bowlders. Compare with No. 122.
129. Iroquois shore, near Pierrepont manor, New York. Excavation of till by the waves left a cut terrace set with large bowlders. Compare with No. 122.
130. Iroquois shore, section of spit, 3 miles east of Watertown, New York. The open lake lay at the left, a bay at the right. The spit was accumulated by additions on the landward side.
131. Wall composed of limestone blocks rounded by wave action on an ancient shore of Lake Ontario, 5 miles east of Watertown, New York. 1890.

Topographic Features of Lake Shores, Michigan and Superior. (Photographed by I. C. Russell, 1887. Size, 8 x 10 inches.)

132. Sea-cliff in limestone, Mackinaw island, Michigan.
133. Sea-cliff in sandstone, small island near Marquette, Michigan.

Nos. 134, 135, 139, 142, 144, 145, 147 are published by G. K. Gilbert in Fifth Ann' Rep. U. S. Geol. Survey, with plate numbers as below.

134. Sea-cliff in hard sandstone, with beach beyond, Au Train island, Lake Superior. Pl. V.
135. Sea-cliff in bowlder clay, with beach in foreground, South Manitou island, Lake Michigan. Pl. III.
136. Sea-cliff in sand, with beach, Sleeping Bear point, eastern shore of Lake Michigan.
137. Sea-cliff in bowlder clay, South Manitou island, Lake Michigan.
138. Sea-cliff in bowlder clay, North Manitou island, Lake Michigan.
139. Beach of limestone pebbles, Mackinaw island, Michigan. Pl. VII.
140. Gravel spit, with driftwood, near Mackinaw island, Michigan.

141. A spit forming under water, western end of Bois Blanc island, Michigan. Mackinaw island in the distance.

142. Spit of shingle, Au Train island, Lake Superior. Pl. XIII.

143. Curved sand spit, southern channel, Strait of Mackinaw.

144. A recurved spit, "Duck point," Grand Traverse bay, Lake Michigan. Pl. IX.

145. Bar joining Empire and Sleeping Bear bluffs, eastern shore Lake Michigan. Pl. VIII.

146. Ancient sea-cliff of Lake Michigan, near Glen Arbor, Michigan.

147. Ancient sea-cliff of Lake Michigan, South Manitou island, Lake Michigan. Pl. VI.

Lacustrine Deposits, Sedimentary.

148. Sediments of Lake Lahontan, Humboldt valley near Rye Patch, Nevada. Published in Monograph No. XI, U. S. Geol. Survey, pl. XXII. Size, 8 x 10 inches. Photographed by I. C. Russell, 1882.

149. Lahontan lake-beds, bank of Humboldt river, Nevada. Size, 8 x 10 inches. Photographed by I. C. Russell, 1882.

150. Contorted lake-beds near southern margin of Mono lake, California. Published in Eighth Ann. Rep. U. S. Geol. Survey, pl. XXIV. Size, 8 x 10 inches. Photographed by I. C. Russell, 1883.

151. Deposit of infusorial earth 110 feet thick near Great bend of Pitt river, Shasta county, California. Size, 8 x 10 inches. Photographed by J. S. Diller, 1885.

Lacustrine Deposits, Chemical. (Photographed by I. C. Russell, 1883. Size, 8 x 10 inches.)

152. Lithoid, thinolitic and dendritic tufa deposited from the waters of Lake Lahontan, shore of Pyramid lake, Nevada.

153. Towers of calcareous tufa formed by sub-lacustral springs, shore of Mono lake, California. Published in Eighth Ann. Rep. U. S. Geol. Survey, pl. XXV.

154. Hillside coated with calcareous tufa deposited from Lake Lahontan, shore of Pyramid lake, Nevada.

155. Calcareous tufa deposited from the waters of Lake Lahontan, shore of Pyramid lake, Nevada.

156. Rocks coated with calcareous tufa, beach of oölitic sand. Shore of Pyramid lake, Nevada. Published in Monograph XI, U. S. Geol. Survey, pl. XIII.

157. Tufa domes formed by sub-lacustral springs. Published in Eighth Ann. Rep. U. S. Geol. Survey, pl. XXI.

158. An island of calcareous tufa deposited from the waters of Lake Lahontan, Pyramid lake, Nevada. Published in Monograph XI, U. S. Geol. Survey, pl. XXXVIII.

159. Pyramid island, Pyramid lake, Nevada; an island coated with calcareous tufa. Published in Monograph XI, U. S. Geol. Survey, pl. XI.

Spring Deposits.

160. Upper geyser basin, Yellowstone National Park. Crater of Old Faithful in the foreground at the right. In the distance the Castle and Grand geysers are in eruption. The formation is silicious sinter. Size, 10 x 13 inches. Photographed by W. H. Jackson.

161. Crater of the Castle geyser, Upper geyser basin, Yellowstone National Park. Silicious sinter. Size, 10 x 13 inches. Photographed by W. H. Jackson.

162. Crater of the Grotto geyser. Silicious sinter. Yellowstone National Park. Size, 10 x 13 inches. Photographed by W. H. Jackson.

163. Old Faithful in eruption. Upper geyser basin, Yellowstone National Park. Size, 10 x 13 inches. Photographed by W. H. Jackson.

164. Calcareous tufa bank, Cement creek, Gunnison county, Colorado. Face seen is 40 to 50 feet high, overhanging in places, forming grottoes. Size, 8 x 10 inches. Photographed by C. Whitman Cross, July 28, 1885.

165. Calcareous tufa deposit, near view of central portion of bank shown in No. 164. Size, 8 x 10 inches. Photographed by C. Whitman Cross, July 28, 1885.

166. Mammoth hot springs, Yellowstone National Park. Size, 10 x 13 inches. Photographed by W. H. Jackson.

167. Mammoth hot springs, Yellowstone National Park. Size, 10 x 13 inches. Photographed by W. H. Jackson.

Dismal Swamp Series. (Photographed by I. C. Russell, April, 1889. Size, 6 x 8 inches.)

Nos. 168, 169, 170, 171, 176, 178, 180, 183 published by Professor N. S. Shaler in Tenth Ann. Rep. U. S. Geol. Survey, with plate numbers as below.

168. View showing the general aspect of the swamp in the district where the forest is relatively dense. In the foreground a single elevated root arch of the black gum is plainly shown, also a great number of cypress knees. Pl. XXIX.

169. Southern margin of Dismal Swamp, 12 miles west of Elizabeth City, North Carolina, showing the general aspect of the swamp in the month of May. The spur-like projections in the foreground are the knees belonging to the roots of the large cypress on the left hand. The gnarled excrescences at its base exhibit one type of root arches. In the center of the picture is a single root arch of the common type. Pl. VIII.

170. View showing general aspect of the wide, swampy channels which connect the main Dismal swamp with the tributary morasses lying to the west. Pl. XV.

171. View of the swamp about a mile and a half east of Drummond lake, showing the ordinary condition of the wetter parts of the swamp in the growing season. Pl. IX.

172. Southern margin of the swamp near Elizabeth City, North Carolina.

173. View near the southern border of the main swamp near Elizabeth City, North Carolina.

174. View of Jericho ditch.

175. Cypress trees in the eastern part of Lake Drummond.

176. Cypress trees in the eastern part of Lake Drummond. Pl. X.

177. View of the western shore of Lake Drummond, showing the wall-like character of the forest growth.

178. View of Jericho ditch. The foliage on the right hand represents a cane-brake. The trees on the left hand of the picture are of second growth.

179. View of Jericho ditch.

180. View showing thinly wooded portion of the main swamp area. The trees are mostly of second growth; the surface bears a scanty growth of cane. Pl. XVI.

181. View showing the general aspect of the wide, swampy channels connecting the main Dismal swamp with tributary morasses lying to the west of that area.

182. View of Jericho ditch.

183. Dismal Swamp canal, looking southward from the village of Wallaceton. The land on either side has been reclaimed from the original condition of swamp. Pl. VII.

SEISMIC PHENOMENA.

Effects of the Charleston Earthquake. (Photographed under the direction of W J McGee by C. C. Jones, September 3-7, 1886. Size, 10 x 13 inches.)

Nos. 185, 188, 189, 199, 202, and 203, published by C. E. Dutton in Ninth Ann. Rep., U. S. Geol. Survey, with plate numbers as below.

184. Worst wreck in Charleston. East Bay street, near Chalmers, looking south.
185. Displaced coping and portico of old guard-house, southwest corner of Meeting and Broad streets, looking southwest, Charleston. Pl. XV.
186. Displaced gable, southeast corner of Queen and Mazyck streets, looking south-southeast, Charleston.
187. Displaced towers and coping of City hospital, southwest corner of Logan and Magazine streets, looking west, Charleston.
188. The same, looking west-southwest, Charleston. Pl. XVIII.
189. St. Philip's church, Church street, between Queen and Cumberland streets, looking north, Charleston. Pl. XVI.
190. Displaced chimney, southwest corner of Beaufin and Archdale streets, looking east-northeast, Charleston.
191. Thrown gable and twisted chimney, residence of late Bishop Lynch, Broad street opposite Orange, looking northeast, Charleston.
192. Thrown portico, Hibernian hall, Meeting street opposite Chalmers, looking north-northwest, Charleston.
193. Fissure in front of 167 Tradd street, between Council and Rutledge, looking east-southeast, Charleston.
194. Characteristic wreck, 167 Tradd street, between Council and Rutledge, looking southeast, Charleston.
195. Displaced portico, Synagogue, Hasel street, between King and Meeting, looking north-northwest, Charleston.
196. Thrown house, looking south, Lincolnville.
197. Displaced monument, First Presbyterian church, southwest corner of Meeting and Tradd streets, looking east, Charleston.
198. Displaced monument, St. John's Lutheran church, Archdale street, between Clifford and King, looking north, Charleston.
199. Derailed locomotive, looking west, Ten-mile Hill. Pl. XIX.
200. Sink, Ten-mile Hill.
201–204. Craterlets, Ten-mile Hill. 202, pl. XXI; 203, pl. XX.

SANDSTONE DIKES.

(Photographed by J. S. Diller, 1888 and 1889. Size, 8 x 10 inches.)

Nos. 205 to 212 are published in Bull. Geol. Soc. Am., vol. 1, 1889, on pages given below.

205. Sandstone dike penetrating Cretaceous shales, Dry creek, Tehama county, California. The dike is 18 inches thick and has well-developed parallel and transverse joints. p. 416.
206. Great sandstone dike on Roaring river, $\frac{3}{4}$ mile above Drews. The dike is 5 feet thick and can be traced for about $9\frac{1}{3}$ miles. p. 418.
207. Great sandstone dike on Roaring river, $\frac{1}{2}$ mile above Drews. The dike is 5 feet thick and can be traced about $9\frac{1}{3}$ miles. p. 414.
208. Lateral view of a wall-like sandstone dike on Crow creek, Shasta county, California. The transverse joints in the dike are parallel to plane of bedding in the shales seen at the right. The exposure is 20 feet high. p. 416.
209. Sandstone dikes cutting Cretaceous shales on Roaring river, Shasta county, California. The larger dike is 12 inches and the other 6 inches thick. p. 414.
210. Group of sandstone dikes on north fork of Cottonwood creek, 1 mile above Gas point, Shasta county, California. The largest dike is 4 inches thick. p. 414.
211. Sandstone dike occupying a joint in Cretaceous shales, 1 mile above Gas point, on the north fork of Cottonwood creek, Shasta county, California. The dike is 4 inches thick. p. 416.

212. Lateral view of sandstone dike, Dry creek, Tehama county, California. p. 414.

213. Sandstone dike penetrating Cretaceous sandstones and shales, Dry creek, Tehama county, California. The dike is 10 inches thick below.

214. Four small sandstone dikes penetrating Cretaceous shales on Dry creek, Tehama county, California. The dikes are each about 4 inches thick. Some are regular and others very irregular.

VOLCANIC PHENOMENA.

Scene of a late Volcanic Eruption in Northern California. (Photographed by J. S. Diller, 1888 and 1890. Size, 8 x 10 inches.)

Nos. 215–226, published in Bulletin 79, U. S. Geol. Survey, with the designations given below.

215. Model of cinder cone, lava field and ash-covered slopes. The cinder cone is 640 feet high, the crater is 240 feet deep, and the lava field is about 3 miles long. Snag lake, at the left end of the lava field, was formed by the lava dam. Fig. 1.

216. Lava field and cinder cone looking southwest across Lake Bidwell, Lassen peak in the distance. Pl. II.

217. The cinder cone from the south, earlier lava partly covered by volcanic sand. The dead trees extend down 7 feet through the volcanic sand to the original soil beneath. Pl. III.

218. The cinder from the east. Earlier lava near the cone is covered by volcanic sand; later lava in the foreground uncovered. Pl. IX.

219. Volcanic bombs at the base of cinder cone; the largest is 8 feet in diameter. Pl. IV.

220. The lava field looking southeast from the base of the cinder cone towards Snag lake. Pl. VIII.

221. Surface of lava field; breaking of the lava crust. Photographed by W. B. Smith. Pl. VII.

222. The tree projecting from beneath the lava was pushed over by the advancing lava. The dead tree on the left extends 10 feet down through the coating of volcanic sand to the original soil beneath. The living trees, some of which are about 200 years old, have grown up entirely since the eruption. Pl. XIV.

223. Lava dam which formed Snag lake at the time of the eruption and drowned the trees whose stumps are seen in the lake. Pl. XIII.

224. Snag lake, with lava dam in the distance and the stumps of drowned trees in the foreground. Pl. XII.

225. Lava front at the corner of Snag lake. Pl. VI.

226. Near view of lava blocks on edge of lava field. The lava is basalt, which is remarkable in containing numerous phenocrysts of quartz, which are uniformly distributed throughout the mass. The white spots seen in the lava are quartz. Pl. XVI.

227. Hand specimen of quartz basalt from lava field near Snag lake. The white spots are quartz.

Laccolitic Domes and Plugs of the Black Hills. (Photographed by I. C. Russell, 1888. Size, 6 x 8 inches.)

228. Little Sun Dance hill, South Dakota. A dome of Carboniferous limestone, with Jurassic and Triassic rocks on the outer bench. The upheaval is due to volcanic rocks injected far beneath.

229. Little Sun Dance hill, from the top of Sun Dance hill, South Dakota.

230. Little Sun Dance hill, South Dakota. Near view.

231. Sun Dance hill, South Dakota. The volcanic rock injected from beneath exposed by erosion.

232, 233, 234. Mato Tepee, Wyoming. Plug of columnar volcanic rock exposed by erosion. Height of column above the river, about 1,100 feet.

Craters, Table Mountains, Peaks and Domes. (Size, 8 x 10 inches.)

235. Mono crater, Mono valley, California, from the south. Photographed by I. C. Russell, 1883.
236. End of Obsidian flow, Mono craters, Mono valley, California. Published in Eighth Ann. Rep. U. S. Geol. Survey, pl. XLIII. Photographed by I. C. Russell, 1883.
237. Mount Wilkinson (or Table mountain), Gunnison county, Colorado. A remnant of a complex basalt sheet, resting upon Cretaceous sandstones. "Mesa" type of mountain. Photographed by C. Whitman Cross, July 25, 1885.
238. Castle rock, near Golden, Colorado. A point projecting from the basalt sheet of Table mountain. Represents a confused mingling of dense and scoriaceous lava, presumably near edge of flow. Photographed by C. Whitman Cross, 1886.
239. Mount Wheatstone, Gunnison county, Colorado (12,543 feet). Upper two-thirds of mountain a single mass of coarse porphyry, a laccolite from which all overarching strata have been eroded away. Glacial amphitheatres in upper part. Photographed by C. Whitman Cross, October 15, 1885.
240. Teocalli mountain, West Brush creek, Gunnison county, Colorado (13,220 feet). Structure caused by beds of Carboniferous rocks, much metamorphosed by a large diorite mass behind the mountain. Photographed by C. Whitman Cross, October 4, 1885.
241. Typical scenery in the Elk mountains, Gunnison county, Colorado. Pearl mountain in the center, 13,484 feet. Brush creek valley. Timber line at 12,000 feet. Photographed by C. Whitman Cross, October 2, 1885.
242. Glaciated dome in Tuolumne valley, California. Photographed by I. C. Russell.

MISCELLANEOUS.

Columbia and Potomac Formations. (Photographed under the direction of W J McGee by C. C. Jones, 1886. Size, 10 x 13 inches.)

Nos. 243, 244, 245, 246, 247, 248, 249, 250 are published in the Seventh Ann. Rep. U. S. Geol. Survey, with plate numbers as below.

243. Wild Duck bluff. Pl. LXI.

244, 245. Unconformity between Columbia and Potomac formations. Pls. LXIII, LXIV.

246. Turkey point. Pl. LXV.
247. Southeastern extremity of Grove point. Pl. LXVI.
248. Center of Grove point. Pl. LXVII.
249. Upper terrace at Ordinary point. Pl. LXXI.
250. Section at Howell's point. Pl. LXIX.
251. Near East Capitol street, between Sixteenth and Seventeenth, Washington, D. C. Columbia loam, as excavated for brick-clay, and terrace plain formed by it. Natural surface. Looking southwest. 1887.
252. Columbia and Potomac formations, Forest place, north side of Chase street, Baltimore, Maryland. 1885.
253. Formation of gravel from vein quartz. South side of Oakland street, 200 yards west of Columbia road, Kalorama heights, Washington, D. C. 1888.

Experiments of Bailey Willis in 1890 *in Folding Loaded Strata by Horizontal Thrust.*

The photographs in series 254 to 284, inclusive, are part of a series representing models of folded strata.

The folds are the results of horizontal pressure applied to the ends of flat strata which were confined on four sides and at the bottom, and could rise only by lifting a load of bird shot.

The materials composing the models were mixtures of plaster of Paris and beeswax and Venice turpentine in varied proportions, which resulted in strata of varied plasticity.

Each pile of strata was compressed from two to five times and photographed at each stage of compression. The photographs therefore represent successive stages in the development of folds and faults.

254. The vertical datum lines, continuous in the left end of the model, were broken across, as the strata near the right-hand end slipped past each other in folding. Size, 6 x 8 inches.

255. Further compression of No. 254, resulting in a fault which follows the plane of inflexion between the anticline and syncline, but which was not preceded by thinning or stretching of the strata. Size, 6 x 8 inches.

256. A series of thinly laminated beds above conform closely to the flexure of a massive bed below. The former was incompetent to lift the load of shot; the latter is competent to do so. Size, 6 x 8 inches.

257. Second stage of experiment with No. 256. Size, 6 x 8 inches.

258. Third stage of experiment begun with No. 256. Size, 8 x 10 inches.

259. Another view of third stage of experiment with No. 256, showing mammillated surface induced by pressure of shot. Size, 8 x 10 inches.

260, 261, 262, 263, 264. Five stages of development of folds in a pile composed of a massive layer (white) overlaying a series of thin layers. Size, 6 x 8 inches.

265, 266, 267, 268, 269. Five stages of development of folds in a pile composed of strata differing less markedly than in series 260 to 264 in thickness and consequent differences of rigidity. The load was uniformly distributed and the three folds similar in dimensions. Size, 5 x 7 inches.

270, 271, 272, 273, 274. Five stages of development of folds and faults in a pile of strata composed of a thick bed above and many thin ones below. Differential folding within the principal anticline led to faulting within the fold, and the displacement was deflected upward into the axial planes. Size, 5 x 7 inches.

275, 276, 277, 278, 279. Five stages in the development of folds in a pile composed of a hard bed above and more plastic, thinner layers below. The latter thinned where the upper stratum and load rested heavily and thickened where the upper stratum carried the load. Size, 5 x 7 inches.

280. Complex folds and indirect faults produced in an asymmetrical mass. Strata on the left massive, strata on the right thinly laminated. Size, 6 x 8 inches.

281, 282, 283, 284. Anticlines developed at base and top of an assumed monocline, and modified by cutting off the tops of the arches between each two stages of compression. The last stage of this model was exhibited at the Washington meeting, in December, 1890. Size, 5 x 7 inches.

Unclassified.

285. Conception bay, Newfoundland. Size, 6 x 8 inches. Photographed by C. D. Walcott, 1888.

286. Hydraulic mining, Cherokee Flat, Butte county, California. Size, 8 x 10 inches. Photographed by J. S. Diller, 1885.

287. Characteristic timber-line growth of stunted spruces, at an elevation of 12,100 feet, head of Cement creek, Gunnison county, Colorado. Size, 8 x 10 inches. Photographed by C. Whitman Cross, September 20, 1885.

288. Snow-storm in Elk mountains, Gunnison county, Colorado. Lake in foreground, at 11,500 feet, is just south of Maroon pass. The storm is rapidly descending to lake. Size, 8 x 10 inches. Photographed by C. Whitman Cross, October 9, 1886.

289. Meridian lake, near Crested Butte, Gunnison county, Colorado. One mile long, 200 to 500 feet wide. Occupies the crest of a ridge of soft Cretaceous shales. Crested Butte mountain in background. Size, 8 x 10 inches. Photographed by L. G. Eakins, September 2, 1887.

290. Sandstone in Hudson shales, town of Argyle, Washington county, New York. Size, 6 x 8 inches. Photographed by C. D. Walcott, 1887.

Fellows of the Geological Society who desire to obtain copies of any of the above photographs, or lantern-slides from the same negatives, should apply to the Director of the United States Geological Survey, Washington, D. C. The photographs are not kept in stock, but will be printed as ordered with such promptness as the regular work of the photographic laboratory of the Survey will permit.

PRICES.

	4 x $4\frac{3}{4}$	5 x 7	6 x 8	8 x 10	10 x 13
Unmounted prints	$0 05	$0 08	$0 10	$0 12	$0 20
Mounted prints	06	10	12	15	30

Lantern-slides, $0.30.

Professor W. B. Dwight, of Poughkeepsie, New York, presented three photographs of his rock-slicer. They are numbered 291 to 293.

No. 291. General view of the machine, of which the label contains a full description.

No. 292. Special view of parts of the machine, of which the label contains a full description.

No. 293. View of drawings, illustrating special features of the machine.

The above report was by vote accepted, the committee continued, and an appropriation of twenty-five dollars ($25.00) made to defray expenses.

The last paper of the evening session, illustrated with lantern views, was

OBSERVATIONS UPON THE LAVA DEPOSITS OF THE SNAKE RIVER VALLEY, IDAHO.

BY G. F. WRIGHT.

The Society then adjourned to the following day at 9 o'clock a. m.

Session of Wednesday, December 31.

Two sections were organized. The First Section was called to order at 9.35 o'clock a. m., by acting President Winchell, with W. M. Davis as acting Secretary.

The Auditing Committee, Messrs. J. S. Diller and E. T. Dumble, reported that the Treasurer's accounts had been examined and found correct.

The report was adopted and the committee discharged.

It was moved and voted that the Secretary should communicate to Dr. G. Brown Goode, in charge of the National Museum, the thanks of the Society for furnishing and operating the stereopticon used at this meeting.

Professor Raphael Pumpelly was called to the chair, and the first paper of the day was read by the acting President.

A LAST WORD WITH THE HURONIAN.

BY ALEXANDER WINCHELL.

There was no discussion of the paper, which will be found printed in full among the memoirs as pages 85–124 of this volume.

The next paper was—

COMPOSITION OF CERTAIN MESOZOIC IGNEOUS ROCKS OF VIRGINIA.

BY H. D. CAMPBELL AND W. G. BROWN.

It was discussed by W. M. Davis, J. E. Wolff, F. L. Nason, B. K. Emerson, and G. H. Williams. It is printed, with the discussion, as pages 339-348 of this volume.

The following paper was then presented:

THE STRUCTURE OF THE BLUE RIDGE NEAR HARPER'S FERRY.

BY H. R. GEIGER AND ARTHUR KEITH.

It was discussed by Bailey Willis, C. H. Hitchcock, G. K. Gilbert, C. D. Walcott, and Jed. Hotchkiss; and, with the discussion and plates 4 and 5, is printed as pages 155–164 of this volume.

The next paper was—

ON THE GEOLOGY OF QUEBEC AND ENVIRONS.

BY HENRY M. AMI.

The paper gave rise to a discussion in which C. D. Walcott and H. S. Williams took part, and a note was read from A. R. C. Selwyn. The communication is printed, with plate 20, as pages 477–502 of this volume.

The following communication was read by title:

GEOLOGY OF THE ENVIRONS OF QUEBEC.

BY JULES MARCOU.

The Section then took a recess until 2 o'clock p. m.

The Second Section was called to order by Professor Edward Orton, who was made chairman, and Professor F. R. Carpenter was made Secretary.

The first paper in this Section was—

THE NICKEL AND COPPER DEPOSITS OF SUDBURY DISTRICT, CANADA.

BY ROBERT BELL.

Remarks were made by W. H. Weed and E. V. D'Invilliers. This communication was followed by an appendix on—

THE SILICIFIED GLASS-BRECCIA OF VERMILION RIVER, SUDBURY DISTRICT.

BY GEORGE H. WILLIAMS.

The paper and appendix are printed on pages 115–140 of this volume.

The second paper was—

PHOSPHATE DEPOSITS ON THE ISLAND OF NAVASSA.

BY E. V. D'INVILLIERS.

Remarks were made by C. H. Hitchcock. The paper forms pages 75–84 of this volume.

The third paper was—

THE COAL FIELDS OF ALABAMA.

BY HENRY MCCALLEY.

It was discussed by I. C. White, C. W. Hayes, E. V. D'Invilliers, G. F. Becker, and J. R. Procter. An abstract of this paper, mainly relating to the wealth of the coal fields, is published in the Scientific American Supplement, vol. XXXI, pp. 12530–12531.

The fourth paper was—

THE CINNABAR AND BOZEMAN COAL FIELDS OF MONTANA.

BY W. H. WEED.

It was the subject of remarks by G. M. Dawson, and is published as pages 349–364, with plate 13, of this volume.

The fifth paper was on—

THE GEOLOGY OF MOUNT DIABLO, CALIFORNIA.

BY H. W. TURNER.

It was discussed by G. F. Becker. It is supplemented by notes on—

THE CHEMISTRY OF THE MOUNT DIABLO ROCKS.

BY W. H. MELVILLE.

The paper and supplement are printed, with plate 15, as pages 383–414 of this volume.

The sixth paper was read, in the absence of the author, by G. M. Dawson:

THE CARBONIFEROUS FLORA OF NEWFOUNDLAND.

BY SIR WILLIAM DAWSON.

The communication is printed as pages 529–540, plates 21 and 22, of this volume.

The seventh paper was entitled—

NOTES ON THE EARLY CRETACEOUS OF CALIFORNIA AND OREGON.

BY GEORGE F. BECKER.

It was discussed by G. M. Dawson, J. S. Diller and C. A. White. It forms, with the discussion, pages 201–208 of this volume.

The Section voted a recess until 2 o'clock p. m.

At 2 o'clock in the afternoon the Society reässembled, acting President Winchell in the chair.

The first paper read was the following:

THE POST-ARCHEAN AGE OF THE WHITE LIMESTONES OF SUSSEX COUNTY, NEW JERSEY.

BY F. L. NASON.

The paper was discussed by J. E. Wolff, H. M. Ami and G. H. Williams. It is published in full in the Annual Report of the State Geologist of New Jersey for 1890.

The following paper was then presented:

TWO BELTS OF FOSSILIFEROUS BLACK SHALE IN THE TRIASSIC FORMATION OF CONNECTICUT.

BY W. M. DAVIS AND S. W. LOPER.

It is printed as pages 415–430 of this volume.

A brief oral communication was made:

ON THE GEOLOGY OF LITTLE FALLS, NEW YORK.

BY H. S. WILLIAMS.

Afterward the following paper was read:

ON THE TRIASSIC OF MASSACHUSETTS.

BY B. K. EMERSON.

This is printed as pages 451–456, with plate 17, in this volume.

The next paper is represented in the following abstract:

ON THE OCCURRENCE OF *MEGALONYX JEFFERSONI* IN CENTRAL OHIO.

BY EDWARD ORTON.

(*Abstract.*)

In digging a county ditch in Berlin township, Holmes county, Ohio, six miles east and a little north of Millersburg, a number of bones of *Megalonyx jeffersoni*, Harlan, were found during the month of December, 1890. Among the bones found up to the present date, there may be named the two femurs, one tibia, two fibulas (the first representatives of this bone yet reported, so far as my knowledge goes), two calcaneums; almost complete series of the tarsal, metatarsal and phalangeal bones, and many of the carpal and metacarpal series as well; eleven claws, including several larger than any figured before; one radius, one clavicle, five perfect vertebræ from the dorsal or lumbar region, three teeth, and the hyoid bone. Exploration will be resumed as soon as the weather will permit, and the prospect is excellent for recovering at least the pelvic bones; probably numerous others will be exhumed. The state of preservation of the bones is in the main excellent, and the series thus far found is undoubtedly by far the finest yet obtained from any one station.

The bones were found at a depth of about six feet below the surface. They were mostly imbedded in about a foot of shell marl, which is overlain by five or more feet of black muck. Such as projected into the muck were in an inferior state of preservation.

The area of the swamp which the ditch is designed to drain is about 300 acres. The altitude is about 1,050 feet above tide. The latitude is approximately 40° 35′ north. The swamp lies within and owes its origin to the terminal moraine of the Glacial period. Crescentic piles of sand, gravel and clay have in many places obstructed the natural drainage of the district, leaving behind them shallow lakes, now converted into swamps.

This discovery is the first, so far as known, of this remarkable fossil north of the Ohio river and west of the mountains. The most northerly station, up to the present find, in the Ohio valley is Big Bone lick, Kentucky. East of the mountains, along the seaboard, *Megalonyx* has been reported as far north as the Holmes county specimen.

In the recovery and subsequent preservation of the bones much is due to W. S. Hanna, Esq., lately county surveyor. It was chiefly to his sagacity, also, that the first identification of the remains as belonging to *Megalonyx jeffersoni* is due.

Remarks upon Professor Orton's communication were made by H. C. Hovey and Josua Lindahl; and, upon motion, the Society tendered a vote of thanks to Mr. W. S. Hanna, of Millersburg, Holmes county, Ohio, for his efforts to preserve the remains of this animal.

The following paper was read by title:

STRATIGRAPHY OF THE CARBONIFEROUS IN CENTRAL IOWA.

BY CHARLES R. KEYES.

The paper forms, with plates 9 and 10, pages 277–292 of this volume.

The next paper also was read by title:

GEOLOGICAL AGE OF THE SAGANAGA SYENITE.

BY H. V. WINCHELL.

It is published in the American Journal of Science, 3d series, volume XLI, 1891, pages 386–390.

The following paper was read by title:

THE RAILROADS AND THE GEOLOGY CLASSES IN ALABAMA.

BY E. A. SMITH.

The following abstract represents a communication presented by title:

ON THE FAMILY ORTHIDÆ OF THE BRACHIOPODA.

BY JAMES HALL.

(Abstract.)

In the paper the author has carried out the revision of the genus *Orthis* as begun in the preceding volume of the Bulletin of the Society (page 19), making some farther subdivisions, which are founded on important characters, and recognizing in all, including the subdivisions of other authors and himself, fourteen distinct genera or subgenera, each one characterized by a number of well marked and, for the most part, well known species of the genus *Orthis* as recognized in its broadest acceptation by authors generally. It has long been recognized that this genus embraced heterogeneous material, and several generic names have been proposed and accepted as applicable to certain groups of species. The very great number of species which are currently referred to the genus *Orthis*, and the constant reference of new species, of varied character, to the same generic term are sufficient evidence of a want of homogeneity in the group; and it has for a long time been the object of the writer to present some scheme for the basis of a classification resting primarily upon the internal characters, and also considering the relations of the external form, surface markings, and minute shell structure, to the more vital manifestations.

The paper presented at the Toronto meeting was a preliminary attempt toward the accomplishment of this object, but the record of the work up to that date had not been fully incorporated. The studies since that time have enabled the writer to give a more definite limitation to some of the groups and to recognize the necessity of a farther subdivision in others. Under each group a generic or subgeneric term has been proposed. These terms will not only be found useful to the student in arranging and classifying his collections, but will serve to give him some knowledge of their geological range. The commencement and continuance of each generic group in geological time will be indicated in the text and illustrated by a diagrammatic arrangement under the geological series. A list of the known and verified species will be given under each subdivision of the family.

The following paper was then read:

GLACIAL LAKES IN CANADA.

BY WARREN UPHAM.

It is printed, with remarks by G. M. Dawson, on pages 243–276 of this volume.

The papers remaining upon the program were read by title only. They are as follows:

NOTES ON TWO MORAINES IN THE CATSKILL MOUNTAINS, NEW YORK.

BY J. C. SMOCK.

THE MELTING OF THE NORTHERN ICE-SHEET IN NORTHEASTERN IOWA.

BY W J MCGEE.

(This communication, with much other matter, appears in full in the Eleventh Annual Report of the Director of the United States Geological Survey, 1891, pages 187–577, with plates II–LXI.)

THE QUATERNARY FORMATIONS OF THE SOUTHWEST.

BY E. W. HILGARD.

GLACIAL GROOVES AT THE SOUTHERN MARGIN OF THE DRIFT.

BY P. MAX FOSHAY AND R. R. HICE.

This paper is printed as pages 457–464, with plate 18, of this volume.

TERTIARY AND POST-TERTIARY CHANGES OF THE ATLANTIC AND PACIFIC COASTS.

BY JOSEPH LE CONTE.

A NOTE ON THE MUTUAL RELATIONS OF LAND ELEVATION AND ICE ACCUMULATION DURING THE QUATERNARY PERIOD.

BY JOSEPH LE CONTE.

These two papers are printed as pages 323–330 of this volume.

ON A JOINTED EARTH AUGER FOR GEOLOGICAL EXPLORATION IN SOFT DEPOSITS.

BY N. H. DARTON.

The instrument exhibited is a modification of the form proposed by McGee in the Ninth Annual Report of the Director of the United States Geological Survey, for 1887-'88, pages 106-107. It consists of an ordinary carpenter's auger, 1¼ inches in diameter, welded to a short length of iron bar; a number of 3-foot lengths of ¼-inch iron pipe with threads and couplings, and a cross-head of ½-inch iron bar for a handle. In clays and sands borings have been made with this instrument to a depth of 40 feet, samples being secured at about each 6 inches. A detailed description of the instrument is given in American Geologist, volume VII, 1891, page 117.

ON THE OCCURRENCE OF DIAMONDS IN WISCONSIN.

BY GEORGE FREDERICK KUNZ

In October, 1890, Mr. G. H. Nichols, of Minneapolis, Minnesota, wrote to the editors of the "Engineering and Mining Journal"* stating that in a review of "Gems and Precious Stones of North America"† published in that journal no mention had been made of the finding of diamonds in Wisconsin, and adding that he had found several small ones there. The matter having been referred to me, I immediately put myself in communication with Mr. Nichols, and from him obtained the information which I now give.

In the summer of 1887 Mr. Nichols, in company with Mr. W. W. Newell and Mr. C. A. Hawn, of Rock Elm, prospected for gold on Plum creek, in Rock Elm township, Pearce county, Wisconsin. They employed some help, and, while sluicing for gold, one of their workmen detected a bright stone, which proved to be a diamond. This was in gravel which had been taken from the bank of the stream at a depth of some feet below water-level. Bad weather prevented the continuance of the work then, but as soon as favorable weather came they resumed their search, and Mr. Newell found one, while several were found by other members of the party. No more work was done in 1887, but in panning three miles further up the stream Mr. Newell found another diamond, which was very much distorted and off color.

In the summer of 1888 actual sluicing for gold was begun, and in the gravel that occurred at the washout four diamonds were found in three weeks' time. One was found on the surface of the gravel bed, and another came from material taken out of a pit some thirty rods from where the other was found, at a depth of five or six feet below the water-level. The most perfect stone was found by a workman, who secreted it. In 1889 prospecting was again resumed on the western branch of Plum creek, where Mr. Nichols found another diamond in a shovelful of gravel taken from the sluice. Two or three small ones were also found in the tailings.

Gold is found all along the main branches of Plum creek, as well as all along the smaller runs of their extreme headwaters from two to five miles from their confluence. From Mr. Nichols I received a series of specimens both of the gold-bearing sands in

* December 13, 1890, page 686.
† New York, 1890, page 336, plate 24.

which the diamonds sent me for examination are said to have been found and three of the diamonds, weighing, respectively, $\frac{25}{32}$ of a carat (160.5 milligrammes), $\frac{7}{16}$ of a carat (46 milligrammes) and $\frac{3}{32}$ of a carat (19.25 milligrammes). The largest of these only would cut into a stone of any value. It is a hexoctahedral crystal, with rounded faces, white, with a slight grayish-green tinge. It could be cut into a perfect brilliant of about $\frac{6}{16}$ of a carat. On one side there is an L-shaped depression, with rounded faces, in which there are minute grains of sand. The second in size is a slightly yellowish elongated hexoctahedron. The surface of the crystal is not so smooth as that of the larger crystal, and the entire surface is covered with small crystalline markings. The third in size is an elliptical hexoctahedral twin. The surface is dull and the color white with a tinge of yellow.

The sand which Mr. Nichols sent me I submitted to a microscopical examination, and found that it contained, in addition to the quartz grains, magnetic iron; titanic iron; almandite garnet, in grains and in minute perfect dodecahedrons; small, transparent, brilliant crystals, none more than one-third the size of a pin's head, of what appeared to be spessarite or essonite garnet; a number of grains and rolled crystals of monazite, and one small grain, said to be of platinum, which was lost before I could examine it; thus resembling in many particulars the gold-bearing sands of Burke county, North Carolina, and Hall county, Georgia.

Interesting as this is, since it is a new locality for diamonds, it is very doubtful if these sands will be more prolific or whether the discovery will have any more commercial value than the gold sands of North Carolina and Georgia have proved to possess up to the present time.

ON THE OCCURRENCE OF FIRE OPAL IN A BASALT IN WASHINGTON STATE.

BY GEORGE FREDERICK KUNZ.

During the month of August, 1890, James Allen, a jeweler of Yonkers, New York, detected fire opal among a pile of rocks that had been taken out of a well at a depth of twenty-two feet on the farm of William Leosure, near Whelan, near the state line of Washington, twenty miles southwest of Colfax, Washington state, and adjoining Moscow, Idaho, in latitude 47°, longitude 117°, midway between the Cœur d'Alene and the Nez Percés Indian reservation. It was found more or less plentifully, as the last four feet of the rock contained cavities filled with fire opal.

The opal occurs in altered and also in unaltered basalt. In the former most, if not all, of the feldspar and pyroxene, as well as the green mass, appears to be altered. Some original constitutent may have changed, but whether or not it is olivine is difficult to determine because of the crystal aggregate character of the pseudomorph. The pieces varied from the size of a half pea to that of a hen's egg. The material is found in a vesicular lava. The smaller nodules are very rich in color, but the larger ones often have little or no play of colors.

The opal may have been formed simultaneously with the formation of the rock, or rather at a time that would be favorable to the formation of zeolites. The quality of some of the small specimens examined was very fine, and if the material is so extensive as supposed and is properly worked it is likely to be one of the most promising of our precious stones, from a financial point of view.

A FALLEN FOREST AND PEAT LAYER UNDERLYING AQUEOUS DEPOSITS IN DELAWARE.

BY HILBORNE T. CRESSON.

Since the announcement that paleolithic implements have been discovered in post-glacial deposits at Trenton, New Jersey, by Dr. C. C. Abbott and other distinguished scientists, the attention of geologists has been drawn to these gravels, and they have endeavored to ascertain approximately the relative geological time in which they were deposited. It is not the intention of the author of this paper to make more than a brief allusion to archeological details, simply referring to those indications of early man's presence that have an intimate relationship with the various geological deposits which are to be discussed. Further southward, in the lower portion of the Delaware valley, aqueous deposits of a less recent origin than those of Trenton have also yielded rude stone implements of quartz, quartzite, and argillite, the two former materials predominating over the latter. In this connection, it must be said that Dr. Abbott and his son, Richard Abbott, since the discovery of paleoliths at Carpenter station, on the Baltimore and Ohio railroad, near Wilmington, Delaware, have likewise found implements of stone flaked by the hand of man in the older geological deposits at Trenton, upon which lie the post-glacial gravels in which their first important finds were made.

A few remarks upon the aqueous deposits at Trenton will be necessary, together with a brief description of the somewhat older formations at and for some distance south of Philadelphia, so that the exact geological position of the organic remains denominated the "fallen forest and peat layer," underlying the Philadelphia brick-clay and gravels on Naaman's creek, may be more easily understood.

It will hardly be necessary to recall that at Trenton we find a well known glacial deposit bearing the name of that place, and that it is generally a horizontal deposit of sand and gravel confined to the flat borders of the Delaware river, resting within channels cut through the Philadelphia brick-clay, lying upon a narrow belt of steeply inclined gneissic rocks, Triassic shales, and Cretaceous plastic clay. Overlooking the level plain are hilltops on which appear older yellow and red gravels and the brick-clay just referred to. The yellow gravel of these hilltops, probably the remains of some old Tertiary sea, covers nearly the whole of southern New Jersey and a portion of Pennsylvania, and may even, we think, be traced into certain portions of northern Delaware. It is composed of water-worn pebbles of quartz and quartzite, with occasional pebbles of flint and a fossiliferous hornstone and chert. Resting upon this yellow deposit is a more recent gravel, the Philadelphia red gravel, generally confined to the immediate vicinity of the Delaware valley. Highly colored by rich peroxides of iron, it forms a striking contrast to the more clayey yellow gravel just mentioned. It lies at a lower level than the other gravel, is stratified, and contains smooth, water-worn pebbles. Resting upon the red gravel is the Philadelphia brick-clay already referred to, generally of a yellow color, but varying somewhat in this respect at places as we approach Mason and Dixon's line. It is a bowlder clay lying within a fixed limit of 150 to 180 feet above the Delaware river. Where the clay and gravel are present it rests upon the red gravel in depressions and on slight elevations. In northern Delaware it is much less stony than at Trenton, and still further northward, near the terminal moraine, it contains so many stones that it might readily be mistaken for true glacial till.

At Philadelphia the Trenton gravel lies near the Delaware river, enveloped by older gravels rising but a few feet above its waters. It is not so coarse as at Trenton, and south of Philadelphia forms a fine river gravel and sand, difficult to trace in places, and often reäppearing in deposits of considerable thickness. It will not be necessary to say anything more upon the geological disposition of the aqueous gravel at Philadelphia and Trenton, already so well described by competent authorities upon the subject, but special attention is directed to a point just across Mason and Dixon's line, on the headwaters of Naaman's creek, near Claymont, Delaware.

It is not our intention to enter into a controversy in regard to the age of the geological deposits lying around the site of the prehistoric stations in northern Delaware, but rather to call the attention of scientists to interesting facts in regard to the superposition of the ancient aqueous deposits in that vicinity. Along the Delaware river at Claymont, in Newcastle county, we find extending backward in a northwesterly direction toward Elam and the hills on the Bradywine creek a series of enormous benches marking different periods of erosion; and these are thinly covered by old river gravels and clays resting upon pre-glacial deposits, supported by beds of decomposed schistose rock. These aqueous deposits are the Philadelphia red gravel and brick-clay of Lewis and Wright, similar to those underlying the city of Philadelphia and its immediate vicinity, classed by McGee as part of the Columbia formation. It is in all probability an aqueo-glacial formation of an earlier date than the Trenton gravels, and has been connected (by Professor G. F. Wright) with the ice when at its maximum extension and the level of the region was depressed one hundred feet or more. Authorities upon the subject who have examined this deposit agree that it is evidently older than the deposits farther up the valley at Trenton, New Jersey. Since, as already suggested, implements of stone worked by early man have been found in the gravels covering these benches, their relation to the Trenton gravels will be an exceedingly interesting study.

Eastward toward the Delaware river, on the lowest bench, we find that the Philadelphia brick-clay predominates in thickness over the red gravel, and that the bowlder clay in certain places rests upon a gray plastic clay, probably of lower Cretaceous or Wealden age, as we find it further northward. Six to twelve miles further southward beyond Wilmington the trend of the Cretaceous may be marked as it cuts across Delaware in a southwesterly direction from the state of New Jersey toward the Maryland line.

Interspersed between layers of Philadelphia red gravel and brick-clay at various depths are organic remains, consisting of branches of oak, sycamore, willow and pine trees, which I have designated as the "fallen forests and peat layers." Within a radius of several miles from Carpenter station, east, west, north and south, we have this peculiar evidence of a quite recent disturbance. Some of the organic material is well preserved; even the leaves of the trees composing it can be recognized. In places the peat layer comes to the surface of the ground, as at Lobdell's car-wheel works, near the mouth of Christiana river toward the southwest, but this may be the result of the disappearance by erosion of formerly overlying layers. Excavations at Lobdell's works indicated that the peat layers also dip beneath clay and alluvial deposits from the Delaware; and in this connection it may be stated that traces of man's presence were found beneath the alluvial deposits, intermingled with and on top of the peat bed. At Richmond's brick yard, mouth of Naaman's creek, we find this same peat layer, rising to the surface on one side of the creek; and on the north side it is found beneath 10 to 18 feet of Philadelphia brick-clay resting on red gravels

(Lewis). Fishermen of Marcus Hook, a small village just above the Delaware state line, in Pennsylvania, who understand the bed of the Delaware river northward and eastward toward the mouth of Christiana river, state that they prefer the eastern channel of the river to the western on account of the tree ends, which catch and destroy their heavy nets in sturgeon fishing. These supposed remains of submerged farms under the Delaware's waters have proved to be but portions of the fallen forests and peat layers, which have been laid bare by the water of the Delaware river in cutting its way through the old clay and gravel deposits. Traces of early man's presence, as at Lobdell's, have also been found in this peat layer at Naaman's creek and near Grubb's landing, southwest of the last-named place. As the peat and fallen forest layer seems to trend southeastward across the Delaware into New Jersey, it will be interesting in the future to see if it has any connection with the well known deposits in the southern portion of that state.

A thorough study of the peat and forest layer underlying the aqueous deposits in northern Delaware is extremely difficult, for in some cases they are covered by quite heavy deposits of brick-clay and gravel. Much information can be obtained from well-diggers, from railroad excavations, and from creek beds which have cut their way through the clays and gravels. An interesting problem is suggested for the future study of our geologists, as the presence of these organic remains and the disturbed appearance of the deposits in some cases suggest that it is not impossible that in the last melting of the great ice-sheet the older deposits were disarranged in the localities referred to, and are not so old as we have hitherto considered them.

The following resolution was moved by Professor W. M. Davis and unanimously voted:

Resolved, That the thanks of the Geological Society of America are tendered to the President and Board of Regents of Columbian University for the generous accommodations given during the present meeting.

On motion of Professor H. L. Fairchild, the following was unanimously adopted:

Whereas, The success and pleasure of this meeting of the Geological Society of America has been due in large measure to the skillful plans and hearty labor of the Local Committee: Therefore—

Resolved, That the earnest thanks of the Society be hereby extended to the Local Committee as a body and to each individual member thereof.

Responding in behalf of the Local Committee, Mr. G. K. Gilbert named the following subcommittees, to whom credit is due:

On Rooms: Bailey Willis; I. C. Russell.
On Magic Lantern: J. S. Diller.
On Reception: J. P. Iddings; G. H. Eldridge.
On Entertainment: W J McGee; F. H. Newell; Arthur Keith.
On Printing: W. H. Weed; C. Willard Hayes; G. P. Merrill.

For reporting discussions of the papers credit is hereby given as follows:

Reporting discussion on Archean, H. W. Turner; on Cambrian and Silurian, N. H. Darton; on Devonian and Carboniferous and on Paleobotany, C. S. Prosser; on Mesozoic and Tertiary, W. H. Weed; on Quaternary, C. Willard Hayes; on Petrography, J. E. Wolff.

Vice-President Winchell, the President-elect, made some closing remarks, and the Society adjourned, to meet in Washington, D. C., on August 24, 1891, at 10 o'clock a. m.

Register of the Washington Meeting, 1890.

The following Fellows were in attendance at the meeting:

Henry M. Ami.
George H. Barton.
George F. Becker.
Robert Bell.
Ezra Brainerd.
Walter A. Brownell.
Henry D. Campbell.
Franklin R. Carpenter.
J. H. Chapin.
William B. Clark.
Edward D. Cope.
C. Whitman Cross.
Nelson H. Darton.
William M. Davis.
George M. Dawson.
Joseph S. Diller.
Edward V. D'Invilliers.
Edwin T. Dumble.
George H. Eldridge.
Benjamin K. Emerson.
Samuel F. Emmons.
Herman L. Fairchild.
G. K. Gilbert.
Arnold Hague.
C. Willard Hayes.
Robert T. Hill.
Charles H. Hitchcock.
Jed. Hotchkiss.
Horace C. Hovey.
Edwin E. Howell.
Joseph P. Iddings.
Joseph F. James.
Arthur Keith.
Charles R. Keyes.
Frank H. Knowlton.
Daniel W. Langdon, Jr.
Josua Lindahl.
Henry McCalley.
W J McGee.
Othniel C. Marsh.
P. H. Mell.
George P. Merrill.
Henry B. Nason.
Edward Orton.
J. W. Powell.
John R. Procter.
Charles S. Prosser.
Raphael Pumpelly.
Israel C. Russell.
J. W. Spencer.
John J. Stevenson.
Henry W. Turner.
Warren Upham.
Charles D. Walcott.
Walter H. Weed.
David White.
Israel C. White.
Charles A. White.
George H. Williams.
Henry S. Williams.
Bailey Willis.
Alexander Winchell.
Newton H. Winchell.
John E. Wolff.
Robert S. Woodward.
G. Frederick Wright.

Total attendance, 66.

LIST OF

OFFICERS AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA.

OFFICERS FOR 1891.

President.

ALEXANDER WINCHELL, Ann Arbor, Mich.

Vice-Presidents.

G. K. GILBERT, Washington, D. C.
T. C. CHAMBERLIN, Madison, Wis.

Secretary.

H. L. FAIRCHILD, Rochester, New York.

Treasurer.

HENRY S. WILLIAMS, Ithaca, New York.

Councillors.

Class of 1893.

GEORGE M. DAWSON, Ottawa, Canada.
JOHN C. BRANNER, Little Rock, Arkansas.

Class of 1892.

E. W. CLAYPOLE, Akron, Ohio.
CHAS. H. HITCHCOCK, Hanover, N. H.

Class of 1891.

I. C. WHITE, Morgantown, W. Va.
JOHN J. STEVENSON, New York City.

Editor.

W J MCGEE, Washington, D. C.

FELLOWS, JULY 1, 1891.

* Indicates Original Fellow (see article III of Constitution).
† Indicates decedent.

*Charles C. Abbott, M. D., Trenton, N. J.

Frank Dawson Adams, Montreal, Canada; Lecturer on Geology at McGill College. December, 1889.

Victor C. Alderson, 6721 Honore St., Englewood, Ills. December, 1889.

Truman H. Aldrich, M. E., 92 Southern Ave., Cincinnati, Ohio. May, 1889.

Henry M. Ami, A. M., Geological Survey Office, Ottawa, Canada; Assistant Paleontologist on Geological and Natural History Survey of Canada. December, 1889.

*† Charles A. Ashburner, M. S., C. E. (Died December 24, 1889.)

George H. Barton, B. S., Boston, Mass.; Instructor in Geology in Massachusetts Institute of Technology. August, 1890.

William S. Bayley, Ph. D., Waterville, Maine; Professor of Geology in Colby University. December, 1888.

*George F. Becker, Ph. D., San Francisco, Cal.; U. S. Geological Survey.

Charles E. Beecher, Ph. D., Yale University, New Haven, Conn. May, 1889.

Robert Bell, C. E., M. D., LL. D., Ottawa, Canada; Assistant Director of the Geological and Natural History Survey of Canada. May, 1889.

Albert S. Bickmore, Ph. D., American Museum of Natural History, 77th St. and Eighth Ave., N. Y. City; Curator of Anthropology in the American Museum of Natural History. December, 1889.

Stephen Bowers, A. M., Ph. D., Mineralogical and Geological Survey of California, Ventura, California. May, 1889.

Amos Bowman, Anacortes, Skagit Co., Wash. State. May, 1889.

Erza Brainerd, LL. D., Middlebury, Vermont; President of Middlebury College. December, 1889.

*John C. Branner, Ph. D., Little Rock, Ark.; State Geologist of Arkansas.

*Garland C. Broadhead, Columbia, Mo.; Professor of Geology in the University of Missouri.

*Walter A. Brownell, Ph. D., 905 University Ave., Syracuse, N. Y.

*Samuel Calvin, Iowa City, Iowa; Professor of Geology and Zoology in the State University of Iowa.

Henry Donald Campbell, Ph. D., Lexington, Va.; Professor of Geology and Biology in Washington and Lee University. May, 1889.

Franklin R. Carpenter, Ph. D., Rapid City, South Dakota; Professor of Geology in Dakota School of Mines. May, 1889.

Robert Chalmers, Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada. May, 1889.

*T. C. Chamberlin, LL. D., Madison Wis.; President University of Wisconsin.

Henry M. Chance, M. D., Philadelphia, Pa.; Geologist and Mining Engineer. August, 1890.

*J. H. Chapin, Ph. D., Meriden, Conn.; Professor in St. Lawrence University.

Frederick D. Chester, M. S., Newark, Delaware; Professor of Geology and Botany in Delaware College. May, 1889.

*William B. Clark, Ph. D., Baltimore, Md.; Instructor in Geology in Johns Hopkins University.

* EDWARD W. CLAYPOLE, D. Sc., Akron, O.; Professor of Geology in Buchtel College.

AARON H. COLE, A. M., Hamilton, N. Y.; Lecturer on Biology and Geology in Colgate University. December, 1889.

* JOHN COLLETT, A. M., Ph. D., Indianapolis, Ind.; lately State Geologist.

* THEODORE B. COMSTOCK, Tucson, Ariz.; Director Arizona School of Mines.

† GEORGE H. COOK, Ph. D., LL. D. (Died September 22, 1889.)

* EDWARD D. COPE, Ph. D., 2102 Pine St., Philadelphia; Professor of Geology in the University of Pennsylvania.

* FRANCIS W. CRAGIN, B. S., Topeka, Kansas; Professor of Geology and Natural History in Washburne College.

* ALBERT R. CRANDALL, A. M., Lexington, Kentucky; Professor of Geology in Agricultural and Mechanical College of Kentucky.

* WILLIAM O. CROSBY, B. S., Boston Society of Natural History, Boston, Mass.; Assistant Professor of Mineralogy and Lithology in Massachusetts Institute of Technology.

CHARLES WHITMAN CROSS, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

* MALCOLM H. CRUMP, Bowling Green, Kentucky; Professor of Natural Science in Ogden College.

* HENRY P. CUSHING, M. S., 786 Prospect St., Cleveland, Ohio.

T. NELSON DALE, Newport, R. I.; Assistant Geologist, U. S. Geological Survey. December, 1890.

* JAMES D. DANA, LL. D., New Haven, Conn.; Professor of Geology in Yale University.

* NELSON H. DARTON, United States Geological Survey, Washington, D. C.

* WILLIAM M. DAVIS, Cambridge, Mass.; Professor of Physical Geography in Harvard University.

GEORGE M. DAWSON, D. Sc., A. R. S. M., Geological Survey Office, Ottawa, Can.; Assistant Director of Geological and Natural History Survey of Canada. May, 1889.

Sir J. WILLIAM DAWSON, LL. D., McGill College, Montreal, Canada; Principal of McGill University. May, 1889.

FREDERICK P. DEWEY, Ph. B., 621 F St. N. W., Washington, D. C. May, 1889.

ORVILLE A. DERBY, M. S., Sao Paulo, Brazil; Director of the Geographical and Geological Survey of the Province of Sao Paulo, Brazil.

* JOSEPH S. DILLER, B. S., United States Geological Survey, Washington, D. C.

EDWARD V. D'INVILLIERS, E. M., 711 Walnut St., Philadelphia, Pa. December, 1888.

* EDWIN T. DUMBLE, Austin, Texas; State Geologist.

* WILLIAM B. DWIGHT, M. A., Ph. B., Poughkeepsie, N. Y.; Professor of Natural History in Vassar College.

* GEORGE H. ELDRIDGE, A. B., United States Geological Survey, Washington, D. C.

ROBERT W. ELLS, LL. D., Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada. December, 1888.

* BENJAMIN K. EMERSON, Ph. D., Amherst, Mass.; Professor of Geology in Amherst College.

* SAMUEL F. EMMONS, A. M., E. M., U. S. Geological Survey, Washington, D. C.

* HERMAN L. FAIRCHILD, B. S., Rochester, N. Y.; Professor of Geology and Natural History in University of Rochester.

J. C. FALES, Danville, Kentucky; Professor in Centre College. December, 1888.

P. J. FARNSWORTH, M. D., Clinton, Iowa; Professor in the State University of Iowa. May, 1889.

MORITZ FISCHER, 721 Cambridge St., Cambridge, Mass. May, 1889.

* ALBERT E. FOOTE, M. D., 4116 Elm Ave., Philadelphia, Pa.

WILLIAM M. FONTAINE, A. M., University of Virginia, Va.; Professor of Natural History and Geology in University of Virginia. December, 1888.

* P. MAX FOSHAY, M. S., M. D., Beaver Falls, Pa.

* PERSIFOR FRAZER, D. Sc., 1042 Drexel Building, Philadelphia, Pa.; Professor of Chemistry in Franklin Institute.

* HOMER T. FULLER, Ph. D., Worcester, Mass.; Professor of Geology in Worcester Polytechnic Institute.

* GROVE K. GILBERT, A. M., United States Geological Survey, Washington, D. C.

ADAMS C. GILL, A. B., Northampton, Mass. December, 1888.

N. J. GIROUX, C. E., Geological Survey Office, Ottawa, Canada; Assistant Field Geologist, Geological and Natural History Survey of Canada. May, 1889.

ULY. S. GRANT, B. S., Minneapolis, Minn.; Assistant Geologist, Geological Survey of Minnesota. December, 1890.

* GEORGE B. GRINNELL, Ph. D., 318 Broadway, New York city.

* WILLIAM F. E. GURLEY, Danville, Illinois.

ARNOLD HAGUE, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

* CHRISTOPHER W. HALL, A. M., 803 University Ave., Minneapolis, Minn.; Professor of Geology and Mineralogy in University of Minnesota.

* JAMES HALL, LL. D., State Hall, Albany, N. Y.; State Geologist and Director of the State Museum.

HENRY G. HANKS, 1124 Greenwich St., San Francisco, Cal.; lately State Mineralogist. December, 1888.

JOHN B. HASTINGS, M. E., Ketchum, Alturas Co., Idaho. May, 1889.

* ERASMUS HAWORTH, Ph. D., Oskaloosa, Iowa; Professor of Natural Sciences in Penn College.

* ROBERT HAY, Box 562, Junction City, Kansas; Geologist, U. S. Department of Agriculture.

C. WILLARD HAYES, Ph. D., U. S. Geological Survey, Washington, D. C. May, 1889.

* ANGELO HEILPRIN, Academy of Natural Sciences, Philadelphia, Pa.; Professor of Paleontology in the Academy of Natural Sciences.

CLARENCE L. HERRICK, M. S., 324 Hamilton Ave., North Side, Cincinnati, Ohio; Professor of Geology and Biology in the University of Cincinnati. May, 1889.

* LEWIS E. HICKS, Lincoln, Nebraska.

* EUGENE W. HILGARD, Ph. D., LL. D., Berkeley, Cal.; Professor of Agriculture in University of California.

FRANK A. HILL, 208 S. Centre St., Pottsville, Pa.; Geologist in Charge of Anthracite District, Second Geological Survey of Pennsylvania. May, 1889.

* ROBERT T. HILL, B. S., U. S. Department of Agriculture, Washington, D. C.

* CHARLES H. HITCHCOCK, Ph. D., Hanover, N. H.; Professor of Geology in Dartmouth College.

* LEVI HOLBROOK, A. M., P. O. Box 536, New York city.

* JOSEPH A. HOLMES, Chapel Hill, North Carolina; State Geologist and Professor of Geology in University of North Carolina.

MARY E. HOLMES, Ph. D., 201 S. First St., Rockford, Illinois. May, 1889.

† DAVID HONEYMAN, D. C. L. (Died October 17, 1889.)

*JEDEDIAH HOTCHKISS, 346 E. Beverly St., Staunton, Virginia.

*EDMUND O. HOVEY, Ph. D., Waterbury, Conn.

*HORACE C. HOVEY, D. D., Bridgeport, Conn.

*EDWIN E. HOWELL, A. M., 18 College Ave., Rochester, N. Y.

SAMUEL B. HOWELL, M. D., 1513 Green St., Philadelphia, Pa.; Professor of Mineralogy and Geology in University of Pennsylvania. May, 1889.

THOMAS STERRY HUNT, D. Sc., LL. D., Park Avenue Hotel, New York city. December, 1889.

*ALPHEUS HYATT, B. S., Bost. Soc. of Nat. Hist., Boston, Mass.; Curator of Boston Society of Natural History.

JOSEPH P. IDDINGS, Ph. B., U. S. Geological Survey, Washington, D. C. May, 1889.

A. WENDELL JACKSON, Ph. B., Berkeley, Cal.; Professor of Mineralogy, Petrography and Economic Geology in University of California. December, 1888.

THOMAS M. JACKSON, C. E., Morgantown, W. Va.; Professor of Civil and Mining Engineering in West Virginia University. May, 1889.

*JOSEPH F. JAMES, M. S., United States Geological Survey, Washington, D. C.

*LAWRENCE C. JOHNSON, United States Geological Survey, Gainesville, Fla.

*W. D. JOHNSON, United States Geological Survey, Washington, D. C.

ALEXIS A. JULIEN, Ph. D., Columbia College, New York city; Instructor in Columbia College. May, 1889.

EDMUND JÜSSEN, Ph. D., Washington, D. C.; Assistant Geologist, U. S. Geological Survey. December, 1890.

ARTHUR KEITH, A. M., U. S. Geological Survey, Washington, D. C. May, 1889.

*JAMES F. KEMP, A. B., E. M., Ithaca, N. Y.; Assistant Professor of Geology and Mineralogy in Cornell University.

CHARLES R. KEYES, A. M., Johns Hopkins University, Baltimore, Md. August, 1890.

CLARENCE KING, 18 Wall St., New York city; lately Director of the U. S. Geological Survey. May, 1889.

FRANK H. KNOWLTON, M. S., U. S. National Museum, Washington, D. C.; Assistant Curator of Botany in U. S. National Museum. May, 1889.

*GEORGE F. KUNZ, 402 Garden St., Hoboken, N. J.

R. D. LACOE, Pittston, Pa. December, 1889.

J. C. K. LAFLAMME, M. A., D. D., Quebec, Canada; Professor of Mineralogy and Geology in University Laval, Quebec. August, 1890.

LAWRENCE M. LAMBE, Ottawa, Canada; Artist and Assistant in Paleontology on Geological Survey of Canada. August, 1890.

ALFRED C. LANE, Ph. D., Houghton, Michigan; Assistant on Geological Survey of Michigan. December, 1889.

DANIEL W. LANGDON, Jr., A. B., University Club, Cincinnati, Ohio; Geologist of Chesapeake and Ohio Railroad Company. December, 1889.

ANDREW C. LAWSON, Ph. D., Berkeley, Cal.; Assistant Professor of Geology in the University of California. May, 1889.

*JOSEPH LE CONTE, M. D., LL. D., Berkeley, Cal.; Professor of Geology in the University of California.

*J. PETER LESLEY, LL. D., 1008 Clinton St., Philadelphia, Pa.; State Geologist.

FRANK LEVERETT, B. S., Madison, Wisconsin; Assistant Geologist, U. S. Geological Survey. August, 1890.

JOSUA LINDAHL, Ph. D., Springfield, Ills.; State Geologist. August, 1890.

WALDEMAR LINDGREN, U. S. Geological Survey, Washington, D. C.

ROBERT H. LOUGHRIDGE, Ph. D., Berkeley, Cal.; Assistant Professor of Agricultural Chemistry in University of California. May, 1889.

THOMAS H. MCBRIDE, Iowa City, Iowa; Professor of Botany in the State University of Iowa. May, 1889.

HENRY MCCALLEY, A. M., C. E., University, Tuscaloosa County, Ala.; Assistant on Geological Survey of Alabama. May, 1889.

RICHARD G. MCCONNELL, A. B., Geological Survey Office, Ottawa, Canada; Field Geologist on Geological and Natural History Survey of Canada. May, 1889.

* W J MCGEE, United States Geological Survey, Washington, D. C.

WILLIAM MCINNES, A. B., Geological Survey Office, Ottawa, Canada; Assistant Field Geologist, Geological and Natural History Survey of Canada. May, 1889.

PETER MCKELLAR, Fort William, Canada. August, 1890.

JULES MARCOU, 42 Garden St., Cambridge, Mass. December, 1888.

OLIVER MARCY, LL. D., Evanston, Cook Co., Illinois; Professor of Natural History in Northwestern University. May, 1889.

OTHNIEL C. MARSH, Ph. D., LL. D., New Haven, Conn.; Professor of Paleontology in Yale College. May, 1889.

P. H. MELL, M. E., Ph. D., Auburn, Ala.; Professor of Geology and Natural History in the State Polytechnic Institute. December, 1888.

* FREDERICK J. H. MERRILL, Ph. D., State Museum, Albany, N. Y.; Assistant State Geologist and Assistant Director of State Museum.

GEORGE P. MERRILL, M. S., U. S. National Museum, Washington, D. C.; Curator of Department of Lithology and Physical Geology. December, 1888.

JAMES E. MILLS, B. S., 2106 Van Ness Ave., San Francisco, Cal. December, 1888.

* ALBRO D. MORRILL, A. M., M. S., Athens, Ohio; Professor of Biology and Geology in Ohio University.

THOMAS F. MOSES, M. D., Urbana, Ohio; President of Urbana University. May, 1889.

* FRANK L. NASON, A. B., 5 Union St., New Brunswick, N. J.; Assistant on Geological Survey of New Jersey.

* HENRY B. NASON, Ph. D., M. D., LL. D., Troy, N. Y.; Professor of Chemistry and Natural Science in Rensselaer Polytechnic Institute.

* PETER NEFF, A. M., 401 Prospect St., Cleveland, Ohio.

* JOHN S. NEWBERRY, M. D., LL D., Columbia College, New York city; Professor of Geology and Paleontology in Columbia College.

FREDERICK H. NEWELL, B. S., U. S. Geological Survey, Washington, D. C. May, 1889.

* EDWARD ORTON, Ph. D., LL. D., Columbus, Ohio; State Geologist and Professor of Geology in the State University.

* AMOS O. OSBORN, Waterville, Oneida Co., N. Y.

*† RICHARD OWEN, LL. D. (Died March 24, 1890.)

* HORACE B. PATTON, Ph. D., New Brunswick, N. J.; Assistant Professor of Geology and Mineralogy in Rutgers College.

RICHARD A. F. PENROSE, Jr., Ph. D., Little Rock, Arkansas; Assistant on Arkansas Geological Survey. May, 1889.

JOSEPH H. PERRY, Worcester, Mass.; Professor of Natural Sciences in the Worcester High School. December, 1888.

* WILLIAM H. PETTEE, A. M., Ann Arbor, Mich.; Professor of Mineralogy, Economical Geology, and Mining Engineering in Michigan University.

* FRANKLIN PLATT, 615 Walnut St., Philadelphia, Pa.

* JULIUS POHLMAN, M. D., University of Buffalo, Buffalo, N. Y.
WILLIAM B. POTTER, A. M., E. M., St. Louis, Mo.; Professor of Mining and Metallurgy in Washington University. August, 1890.
* JOHN W. POWELL, Director of U. S. Geological Survey, Washington, D. C.
* JOHN R. PROCTER, Frankfort, Ky.; State Geologist.
* CHARLES S. PROSSER, M. S., U. S. National Museum, Washington, D. C.
* RAPHAEL PUMPELLY, U. S. Geological Survey, Newport, R. I.
WILLIAM N. RICE, A. M., Ph. D., LL. D., Middletown, Conn.; Professor of Geology in Wesleyan University. August, 1890.
* EUGENE N. S. RINGUEBERG, M. D., Lockport, N. Y.
CHARLES W. ROLFE, M. S., Urbana, Champaign Co., Illinois, Professor of Geology in University of Illinois. May, 1889.
* ISRAEL C. RUSSELL, M. S., U. S. Geological Survey, Washington, D. C.
* JAMES M. SAFFORD, M. D., LL. D., Nashville, Tenn.; State Geologist; Professor in Vanderbilt University.
* ROLLIN D. SALISBURY, A. M., Madison, Wis.; Professor of General and Geographic Geology in University of Wisconsin.
* CHARLES SCHAEFFER, M. D., 1309 Arch St., Philadelphia, Pa.
HENRY M. SEELY, M. D., Middlebury, Vt.; Professor of Geology in Middlebury College. May, 1889.
ALFRED R. C. SELWYN, C. M. G., LL. D., Ottawa, Canada; Director of Geological and Natural History Survey of Canada. December, 1889.
* NATHANIEL S. SHALER, LL. D., Cambridge, Mass.; Professor of Geology in Harvard University.
WILL H. SHERZER, M. S., Ann Arbor, Mich.; Instructor in Geology and Paleontology, University of Michigan. December, 1890.
* FREDERICK W. SIMONDS, Ph. D., Austin, Texas; Professor of Geology in University of Texas.
* EUGENE A. SMITH, Ph. D., University, Tuscaloosa Co., Ala.; State Geologist and Professor of Chemistry and Geology in University of Alabama.
* JOHN C. SMOCK, Ph. D., New Brunswick, N. J.; State Geologist.
* J. W. SPENCER, A. M., Ph. D., Atlanta, Georgia; State Geologist.
* JOHN J. STEVENSON, Ph. D., University of the City of New York; Professor of Geology in the University of the City of New York.
ORESTES H. ST. JOHN, Topeka, Kansas. May, 1889.
GEORGE C. SWALLOW, M. D., LL. D., Helena, Montana; State Geologist; lately State Geologist of Missouri, and also of Kansas. December, 1889.
RALPH S. TARR, Vermilion, S. D. Professor of Geology and Mineralogy, University of South Dakota. August, 1890.
* WILLIAM E. TAYLOR, Peru, Nemaha Co., Neb.; Teacher of Geology and Natural History in Nebraska State Normal School.
MAURICE THOMPSON, Crawfordsville, Ind.; lately State Geologist. May, 1889.
*ASA SCOTT TIFFANY, 901 West Fifth St., Davenport, Iowa.
* JAMES E. TODD, A. M., Tabor, Iowa; Professor of Natural Sciences, Tabor College.
* HENRY W. TURNER, United States Geological Survey, Valley Springs, Cal.
JOSEPH B. TYRRELL, M. A., B. Sc., Geological Survey Office, Ottawa, Canada; Geologist on the Canadian Geological Survey. May, 1889.
* EDWARD O. ULRICH, A. M., Newport, Ky.
* WARREN UPHAM, A. B., 36 Newbury St., Somerville, Mass.; Assistant on the U. S. Geological Survey.

*Charles R. Van Hise, M. S., Madison, Wis.; Professor of Mineralogy and Petrography in Wisconsin University; Geologist U. S. Geological Survey.

*Anthony W. Vogdes, Fort Canby, Astoria, Or.; Captain Fifth Artillery, U. S. Army.

Charles Wachsmuth, M. D., Burlington, Iowa. May, 1889.

*Marshman E. Wadsworth, Ph. D., Houghton, Mich.; State Geologist; Director of Michigan Mining School.

*Charles D. Walcott, U. S. National Museum, Washington, D. C.; Paleontologist U. S. Geological Survey.

Lester F. Ward, A. M., U. S. Geological Survey, Washington, D. C.; Paleontologist U. S. Geological Survey. May, 1889.

Walter H. Weed, M. E., U. S. Geological Survey, Washington, D. C. May, 1889.

David White, U. S. Geological Survey, Washington, D. C. May, 1889.

*Israel C. White, Ph. D., Morgantown, W. Va.; Professor of Geology in West Virginia University.

*Charles A. White, M. D., U. S. National Museum, Washington, D. C.; Paleontologist U. S. Geological Survey.

*Robert P. Whitfield, Ph. D., American Museum of Natural History, 77th St. and Eighth Ave., New York city; Curator of Geology and Paleontology in American Museum of Natural History.

*Edward H. Williams, Jr., A. C., E. M., 117 Church St., Bethlehem, Pa.; Professor of Mining Engineering and Geology in Lehigh University.

*George H. Williams, Ph. D., Johns Hopkins University, Baltimore, Md.; Professor of Inorganic Geology in Johns Hopkins University.

*Henry S. Williams, Ph. D., Ithaca, N. Y.; Professor of Geology and Paleontology in Cornell University.

*J. Francis Williams, Ph. D., Salem, N. Y.

*Samuel G. Williams, Ph. D., Ithaca, N. Y.; Professor in Cornell University.

Bailey Willis, U. S. Geological Survey, Washington, D. C. December, 1889.

*† Alexander Winchell, LL. D. (Died February 19, 1891.)

*Horace Vaughn Winchell, 10 State St., Minneapolis, Minn.; Assistant on Geological Survey of Minnesota.

*Newton H. Winchell, A. M., Minneapolis, Minn.; State Geologist; Professor in University of Minnesota.

*Arthur Winslow, B. S., Jefferson City, Mo.; State Geologist.

John E. Wolff, Ph. D. Harvard University, Cambridge, Mass.; Instructor in Petrography, Harvard University. December, 1889.

Robert Simpson Woodward, C. E., U. S. Coast and Geodetic Survey, Washington, D. C. May, 1889.

*G. Frederick Wright, D. D., Oberlin, Ohio; Professor in Oberlin Theological Seminary.

Lorenzo G. Yates, M. D., Santa Barbara, Cal. December, 1889.

Summary.

Original Fellows	112
Elected Fellows	96
Aggregate	208
Deceased Fellows	5
Membership July 1, 1891	203

INDEX TO VOLUME 2.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 1-30.

PROCEEDINGS OF THE SEMI-ANNUAL MEETING HELD AT INDIANAPOLIS

AUGUST 19, 1890

J. J. STEVENSON, *Secretary*

NEW YORK
PUBLISHED BY THE SOCIETY
JANUARY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 31-48, PL. 1

THE CUYAHOGA SHALE AND THE PROBLEM OF THE OHIO WAVERLY

BY

C. L. HERRICK

NEW YORK
PUBLISHED BY THE SOCIETY
JANUARY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 49-74

THE STRUCTURE OF A PORTION OF THE SIERRA NEVADA OF CALIFORNIA

BY

GEO. F. BECKER

NEW YORK
PUBLISHED BY THE SOCIETY
JANUARY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 75-84

PHOSPHATE DEPOSITS OF THE ISLAND OF NAVASSA

BY

EDWARD V. D'INVILLIERS

NEW YORK
PUBLISHED BY THE SOCIETY
JANUARY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 85-124

A LAST WORD WITH THE HURONIAN

BY

ALEXANDER WINCHELL, LL. D., F. G. S. A.

ROCHESTER
PUBLISHED BY THE SOCIETY
FEBRUARY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 125-140.

THE NICKEL AND COPPER DEPOSITS OF SUDBURY DISTRICT, CANADA

BY

ROBERT BELL, B. A. SC., M. D., LL. D.

ASSISTANT DIRECTOR OF THE GEOLOGICAL SURVEY OF CANADA

With an Appendix on

THE SILICIFIED GLASS-BRECCIA OF VERMILION RIVER, SUDBURY DISTRICT

BY

GEORGE H. WILLIAMS

ROCHESTER
PUBLISHED BY THE SOCIETY
FEBRUARY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 141-154, PLS. 2, 3

THE OVERTHRUST FAULTS OF THE SOUTHERN APPALACHIANS

BY

C. WILLARD HAYES

ROCHESTER
PUBLISHED BY THE SOCIETY
FEBRUARY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 155-164, PLS. 4, 5

THE STRUCTURE OF THE BLUE RIDGE NEAR HARPER'S FERRY

BY

H. R. GEIGER AND ARTHUR KEITH

ROCHESTER
PUBLISHED BY THE SOCIETY
FEBRUARY 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 165-176

NOTE ON THE GEOLOGICAL STRUCTURE OF THE SELKIRK RANGE

BY

GEORGE M. DAWSON
ASSISTANT DIRECTOR OF THE GEOLOGICAL SURVEY OF CANADA

ROCHESTER
PUBLISHED BY THE SOCIETY
FEBRUARY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
· VOL. 2, PP. 177-188, PL. 6

GRAPHIC FIELD NOTES FOR AREAL GEOLOGY

BY

BAILEY WILLIS

ROCHESTER
PUBLISHED BY THE SOCIETY
FEBRUARY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 189-200, PL. 7; PP. 201-208

ANTIQUITIES FROM UNDER TUOLUMNE TABLE MOUNTAIN IN CALIFORNIA

NOTES ON THE EARLY CRETACEOUS OF CALIFORNIA AND OREGON

BY

GEORGE F. BECKER

ROCHESTER
PUBLISHED BY THE SOCIETY
FEBRUARY 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 209-224

THE RELATION OF SECULAR ROCK-DISINTEGRATION TO CERTAIN TRANSITIONAL CRYSTALLINE SCHISTS

BY

RAPHAEL PUMPELLY

ROCHESTER
PUBLISHED BY THE SOCIETY
FEBRUARY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 225-242, PL. 8

THE GEOTECTONIC AND PHYSIOGRAPHIC GEOLOGY OF WESTERN ARKANSAS

BY

ARTHUR WINSLOW

ROCHESTER
PUBLISHED BY THE SOCIETY
FEBRUARY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 243-276

GLACIAL LAKES IN CANADA

BY

WARREN UPHAM

ROCHESTER
PUBLISHED BY THE SOCIETY
MARCH, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 277-292, PLS. 9, 10

STRATIGRAPHY OF THE CARBONIFEROUS IN CENTRAL IOWA

BY

CHARLES R. KEYES

ROCHESTER
PUBLISHED BY THE SOCIETY
MARCH, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 293-300, PL. 11

THE CHAZY FORMATION IN THE CHAMPLAIN VALLEY

BY

EZRA BRAINERD

ROCHESTER
PUBLISHED BY THE SOCIETY
MARCH, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
Vol. 2, pp. 301-322, pl. 12

THE PETROGRAPHY AND STRUCTURE OF THE PIEDMONT PLATEAU IN MARYLAND

BY

GEORGE HUNTINGTON WILLIAMS OF JOHNS HOPKINS UNIVERSITY

WITH A SUPPLEMENT ON

A GEOLOGICAL SECTION ACROSS THE PIEDMONT PLATEAU IN MARYLAND

BY

CHARLES R. KEYES

ROCHESTER
PUBLISHED BY THE SOCIETY
March, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 323-330

TERTIARY AND POST-TERTIARY CHANGES OF THE ATLANTIC AND PACIFIC COASTS

WITH A NOTE ON

THE MUTUAL RELATIONS OF LAND-ELEVATION AND ICE-ACCUMULATION DURING THE QUATERNARY PERIOD

BY

JOSEPH LE CONTE

ROCHESTER
PUBLISHED BY THE SOCIETY
MARCH, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
Vol. 2, pp. 331-338

ON THE LOWER CAMBRIAN AGE OF THE STOCKBRIDGE LIMESTONE

BY

J. E. WOLFF

ROCHESTER
PUBLISHED BY THE SOCIETY
March, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 339-348

COMPOSITION OF CERTAIN MESOZOIC IGNEOUS ROCKS OF VIRGINIA

BY

H. D. CAMPBELL AND W. G. BROWN

ROCHESTER
PUBLISHED BY THE SOCIETY
MARCH, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 349-364, PL. 13

THE CINNABAR AND BOZEMAN COAL FIELDS OF MONTANA

BY

WALTER HARVEY WEED

ROCHESTER
PUBLISHED BY THE SOCIETY
MARCH, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 365-382, PL. 14

ON THE RECOGNITION OF THE ANGLES OF CRYSTALS IN THIN SECTIONS

BY

ALFRED C. LANE

ROCHESTER
PUBLISHED BY THE SOCIETY
MAY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 383-414, PL. 15

THE GEOLOGY OF MOUNT DIABLO, CALIFORNIA

BY

H. W. TURNER

WITH A SUPPLEMENT ON

THE CHEMISTRY OF THE MOUNT DIABLO ROCKS

BY

W. H. MELVILLE

ROCHESTER
PUBLISHED BY THE SOCIETY
MARCH, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 415-430

TWO BELTS OF FOSSILIFEROUS BLACK SHALE IN THE TRIASSIC FORMATION OF CONNECTICUT

BY

W. M. DAVIS AND S. WARD LOPER

ROCHESTER
PUBLISHED BY THE SOCIETY
APRIL, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 431-450, PL. 16

MESOZOIC AND CENOZOIC FORMATIONS OF EASTERN VIRGINIA AND MARYLAND

BY

N. H. DARTON, U. S. GEOLOGICAL SURVEY

ROCHESTER
PUBLISHED BY THE SOCIETY
APRIL, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 451-456, PL. 17

ON THE TRIASSIC OF MASSACHUSETTS

BY

BENJAMIN K. EMERSON

ROCHESTER
PUBLISHED BY THE SOCIETY
APRIL, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 457-464, PL. 18

GLACIAL GROOVES AT THE SOUTHERN MARGIN OF THE DRIFT

BY

P. MAX FOSHAY AND RICHARD R. HICE

ROCHESTER
PUBLISHED BY THE SOCIETY
APRIL, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 465-476, PL. 19

POST-PLEISTOCENE SUBSIDENCE VERSUS GLACIAL DAMS

BY

J. W. SPENCER, M. A., PH. D., F. G. S. (L. AND A.)

ROCHESTER
PUBLISHED BY THE SOCIETY
APRIL, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 477-502, PL. 20

ON THE GEOLOGY OF QUEBEC AND ENVIRONS

BY

HENRY M. AMI, OF THE GEOLOGICAL SURVEY OF CANADA

ROCHESTER
PUBLISHED BY THE SOCIETY
APRIL, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 503-528

THE COMANCHE SERIES OF THE TEXAS-ARKANSAS REGION

BY

ROBERT T. HILL

ROCHESTER
PUBLISHED BY THE SOCIETY
MAY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 529-540, PLS. 21, 22

CARBONIFEROUS FOSSILS FROM NEWFOUNDLAND

BY

SIR J. WILLIAM DAWSON, F. R. S., ETC.

ROCHESTER
PUBLISHED BY THE SOCIETY
MAY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 541-586

A PROPOSED SYSTEM OF CHRONOLOGIC CARTOGRAPHY ON A PHYSIOGRAPHIC BASIS

BY

PRESIDENT T. C. CHAMBERLIN

WITH

THE GEOLOGICAL DATES OF ORIGIN OF CERTAIN TOPOGRAPHIC FORMS ON THE ATLANTIC SLOPE OF THE UNITED STATES

BY

WILLIAM MORRIS DAVIS

ROCHESTER
PUBLISHED BY THE SOCIETY
JULY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 2, PP. 587-606, PL. 23

VARIATIONS IN THE CRETACEOUS AND TERTIARY STRATA OF ALABAMA

BY

DANIEL W. LANGDON, JR., A. M., F. G. S. A.

ROCHESTER
PUBLISHED BY THE SOCIETY
JULY, 1891

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

VOL. 2, PP. 607-662

PROCEEDINGS OF THE THIRD ANNUAL MEETING, HELD AT WASHINGTON DECEMBER 29, 30 AND 31, 1890

J. J. STEVENSON, SECRETARY

(WITH INDEX. ALSO CONTENTS, ETC., OF VOLUME 2, PP. i–xiv.)

ROCHESTER
PUBLISHED BY THE SOCIETY
AUGUST, 1891