BULLETIN

OF THE

GEOLOGICAL SOCIETY

OF

AMERICA

VOL. 26

JOSEPH STANLEY-BROWN, Editor

NEW YORK
PUBLISHED BY THE SOCIETY
1915

OFFICERS FOR 1915

ARTHUR P. COLEMAN, *President*

L. V. PIRSSON,
H. P. CUSHING, — *Vice-Presidents*
E. O. ULRICH,

EDMUND OTIS HOVEY, *Secretary*

WILLIAM BULLOCK CLARK, *Treasurer*

JOSEPH STANLEY-BROWN, *Editor*

F. R. VAN HORN, *Librarian*

Councilors

Class of 1917

CHARLES K. LEITH,
THOMAS L. WATSON,

Class of 1916

R. A. F. PENROSE, JR.,
W. W. ATWOOD,

Class of 1915

WHITMAN CROSS,
WILLET G. MILLER,

PRINTERS

JUDD & DETWEILER (INC.), WASHINGTON, D. C.

ENGRAVERS

THE MAURICE JOYCE ENGRAVING COMPANY, WASHINGTON, D. C.

CONTENTS

ILLUSTRATIONS

Plates

Figures

(27 plates; 41 figures.)

PUBLICATIONS OF THE GEOLOGICAL SOCIETY OF AMERICA

Regular Publications

The Society issues annually, in four quarterly parts, a single serial octavo publication entitled Bulletin of the Geological Society of America, the edition being 700 copies. A small supply of authors' separates of the longer articles is kept for sale by the Secretary at the prices quoted in each volume.

The Bulletin is sold at the uniform price of ten dollars ($10.00) per volume, with a discount of twenty-five (25) per cent to Fellows of the Society, persons residing elsewhere than in North America, and public and institutional libraries; carriage extra. Subscriptions are payable in advance. Regular subscribers within the United States of America and its possessions receive their parts, postage paid, as issued. Forty (40) cents per volume must be added to the subscription price to cover postage to other countries in the Postal Union.

The price of the index to volumes 1-10 is $2.25 and of the index to volumes 11-20 is $3.50; carriage extra. No reduction is made to dealers. Orders should be addressed to the Secretary, whose address is care of the American Museum of Natural History, New York, N. Y., and drafts and money orders should be made payable to *The Geological Society of America.*

Description of the Published Volumes

Volumes.	Pages.	Plates.	Figures.
Vol. 1, 1889	593 + xii	13	51
Vol. 2, 1890	622 + xiv	23	63
Vol. 3, 1891	541 + xi	17	72
Vol. 4, 1892	458 + xi	10	55
Vol. 5, 1893	655 + xii	21	43
Vol. 6, 1894	528 + x	27	40
Vol. 7, 1895	558 + x	24	61
Vol. 8, 1896	446 + x	51	29
Vol. 9, 1897	460 + x	29	49
Vol. 10, 1898	534 + xii	54	83
Index to volumes 1-10	209	..	..
Vol. 11, 1899	651 + xii	58	37
Vol. 12, 1900	538 + xii	45	28
Vol. 13, 1901	583 + xii	58	47
Vol. 14, 1902	609 + xii	65	43
Vol. 15, 1903	636 + x	59	16
Vol. 16, 1904	636 + xii	94	74
Vol. 17, 1905	785 + xiv	84	96
Vol. 18, 1906	717 + xii	74	59
Vol. 19, 1907	617 + x	41	31
Vol. 20, 1908	749 + xiv	111	35
Index to volumes 11-20	422	..	..
Vol. 21, 1909	823 + xvi	54	109
Vol. 22, 1910	747 + xii	31	66
Vol. 23, 1911	758 + xvi	43	44
Vol. 24, 1912	737 + xviii	36	60
Vol. 25, 1913	802 + xviii	28	47
Vol. 26, 1914	504 + xxi	27	41

Parts of Volume 26

	Pages.	Plates.	Figures	Price to Fellows.	Price to Public.
Number 1	1–204	1– 7	2	$2.60	$3.90
Number 2	205–294	8– 9	31	1.70	2.60
Number 3	295–388	10–24	6	1.90	2.75
Number 4 *	389–504	25–27	2	1.35	2.05

Reprints from Volume 26

Reprints.	Pages.	Plates.	Figures	Price to Fellows.	Price to Public.
Proceedings of the Twenty-seventh Annual Meeting of the Geological Society of America, held at Philadelphia, Pennsylvania, December 29, 30, and 31, 1914. E. O. Hovey, *Secretary*	1–128	1– 7	1– 2	$1.60	$2 40
Proceedings of the Fifteenth Annual Meeting of the Cordilleran Section of the Geological Society of America, held at Seattle, Washington, May 21 and 22, 1914. G. D. Louderback, *Secretary*	129–140	....	....	20	30
Proceedings of the Sixth Annual Meeting of the Paleontological Society, held at Philadelphia, Pennsylvania, December 29, 30, and 31, 1914. R. S. Bassler, *Secretary*	141–170	...	....	35	55
Isostasy and radioactivity. G. F. Becker	171–204	...	....	45	65
Diastrophic importance of the unconformity at the base of the Berea grit in Ohio. H. P. Cushing	205–216	8	1– 2	20	30
Origin of the Red Beds of western Wyoming. E. B. Branson	217–230	9	....	25	40
Origin of thick gypsum and salt deposits. E. B. Branson	231–242	....	1– 5	20	30
Length and character of the earliest inter-Glacial period. A. P. Coleman	243–254	....	1– 3	20	30
Obsidian from Hrafntinnuhryggur, Iceland: its lithophysæ and surface markings. F. E. Wright	255–286	....	1–12	60	90
Post-Ordovician deformation in the Saint Lawrence Valley, New York. G. H. Chadwick	287–294	. .	1– 9	25	40
Close of Jurassic and opening of Cretaceous time in North America. H. F. Osborn †	295–302	....	1	15	20
Reasons for regarding the Morrison an introductory Cretaceous formation. W. T. Lee †	303–314	....	....	20	30
Origin and distribution of the Morrison formation. C. C. Mook †	315–322	....	1– 4	15	20

* Preliminary pages and index are distributed with number 4.

† Under the brochure heading is printed Proceedings of the Paleontological Society.

Reprints.	Pages.	Plates.	Figures.	Price to Fellows.	Price to Public.
Sauropoda and Stegosauria of the Morrison of North America compared with those of Europe and eastern Africa. R. S. Lull†	323–334	....	....	$0.20	$0.30
Paleobotanic evidence of the age of the Morrison formation. E. W. Berry†..	335–342	....	...	15	20
Invertebrate fauna of the Morrison formation. T. W. Stanton†......	343–348	....	....	10	15
Studies of the morphology and histology of the Trepostomata or Monticuliporoids. E. R. Cumings and J. J. Galloway†............	349–374	10–15	....	50	75
Present condition of the volcanoes of southern Italy. H. S. Washington and A. L. Day.......	375–388	16–24	1	45	65
Proceedings of the Summer Meeting of the Geological Society of America, held at the University of California and at Stanford University, August 3, 4, and 5, 1915. J. A. Taff, *Secretary pro tem.*	389–408	....	....	25	40
Proceedings of the Summer Meeting of the Paleontological Society, held at the University of California and at Stanford University, August 3, 4, 5, and 6, 1915. Chester Stock, *Secretary pro tem*.................	409–418	....	....	15	20
I. On the relationship of the Eocene lemur *Notharctus* to the Adapidæ and to other primates. II. On the classification and phylogeny of the Lemuroidea. W. K. Gregory†...	419–446	....	....	35	55
Problem of the Texas Tertiary sands. E. T. Dumble	447–476	25–27	1	50	75
A stratigraphic disturbance through the Ohio Valley, running from the Appalachian plateau in Pennsylvania to the Ozark Mountains in Missouri. J. H. Gardner...........	477–484	....	1	10	15

†Under the brochure heading is printed Proceedings of the Paleontological Society.

Irregular Publications

In the interest of exact bibliography, the Society takes cognizance of all publications issued wholly or in part under its auspices. Each author of a memoir receives 30 copies without cost, and is permitted to order any additional number at a slight advance on cost of paper and presswork; and these reprints are identical with those of the editions issued and distributed by the Society; but the cover bears only the title of the paper, the author's name, and the statement [Reprinted from the Bulletin of the Geological Society of America, vol. —, pp. —, pl. — (Date)]. Contributors to the Proceedings and "Abstracts of Papers" are also authorized to order any number of separate copies of their papers at a slight advance on cost of paper and presswork; but such separates are bibliographically distinct from the reprints issued by the Society.

The following separates of parts of volume 26 have been issued:

Regular Editions

Pages	141–170,		165 copies.	March	31, 1915.
"	171–204,		90 "	"	31, 1915.
"	205–216,	plate 8,	140 "	June	15, 1915.
"	217–230,	" 9,	190 "	"	28, 1915.
"	231–242,		190 "	"	28, 1915.
"	243–254,		40 "	"	28, 1915.
"	255–286,		390 "	"	29, 1915.
"	287–294,		140 "	"	30, 1915.
"	295–302,*†		365 "	August	17, 1915.
"	303–314,*†		185 "	"	17, 1915.
"	315–322,*†		235 "	"	17, 1915.
"	323–334,*†		485 "	"	17, 1915.
"	335–342,*†		235 "	"	17, 1915.
"	343–348,*†		185 "	"	17, 1915.
"	349–374,*†	plates 10–15,	465 "	"	17, 1915.
"	375–388,	" 16–24,	340 "	September	3, 1915.
"	389–408,		40 "	November	22, 1915.
"	409–418,*		165 "	"	22, 1915.
"	419–446,*†		255 "	"	24, 1915.
"	447–476,	" 25–27,	60 "	December	4, 1915.
"	477–483,		110 "	"	4, 1915.

Special Editions ‡

Pages	4– 11,		40 copies.	March	31, 1915.
"	12– 18,	plate 1,	40 "	"	31, 1915.
"	18– 21,	" 2,	40 "	"	31, 1915.
"	21– 27,	" 3,	240 "	"	31, 1915.
"	27– 46,	" 4,	640 "	"	31, 1915.
"	47– 57,	plates 5–6,	40 "	"	31, 1915.
"	58– 60,		240 "	"	31, 1915.
"	70– 73,	plate 7,	240 "	"	31, 1915.
Page	75		290 "	"	31, 1915.
Pages	110–111,		540 "	"	31, 1915.
"	117–128,		40 "	"	31, 1915.
"	129–140,		40 "	"	31, 1915.

* Bearing on the cover

PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY.

[Reprinted from the Bulletin of the Geological Society of America, vol. ——, pp.——, pls. ——, (Date)].

† Under the brochure heading is printed PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY.

‡ Bearing imprint [From Bull. Geol. Soc. Am., Vol. 26, 1914].

CORRECTIONS AND INSERTIONS

All contributors to volume 26 have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 209, line 4 from top; *for* "Berea" *read* Bedford
" 232, line 17 from top; *for* "18" *read* 36
" 232, line 18 from top; *for* "127" *read* 137
" 236, line 21 from top; *for* ".3" *read* .8+
" 237, line 7 from bottom; *for* "75" *read* 225
" 247, line 18 from top; *omit* line 18
" 253, line 2 from bottom; *omit* line 2
" 253, line 1 from bottom; *omit* "Bay?"
" 289, line 10 from bottom; *for* "*beverleyensis*" *read* *beverleyense*
" 292, line 1 from top; *for* "examples" *read* example
" 294, line 11 from top; *after* "figure 9" *insert* before erosion

BULLETIN

OF THE

Geological Society of America

VOLUME 26 NUMBER 1

MARCH, 1915

JOSEPH STANLEY-BROWN, EDITOR

PUBLISHED BY THE SOCIETY

MARCH, JUNE, SEPTEMBER, AND DECEMBER

CONTENTS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

Subscription, $10 per year; with discount of 25 per cent to institutions and libraries and to individuals residing elsewhere than in North America. Postage to foreign countries in the postal union, forty (40) cents extra.

Communications should be addressed to The Geological Society of America, care of 420 11th Street N. W., Washington, D. C., or 77th Street and Central Park, West, New York City.

NOTICE.—In accordance with the rules established by Council, claims for non-receipt of the preceding part of the Bulletin must be sent to the Secretary of the Society within three months of the date of the receipt of this number in order to be filled gratis.

Entered as second-class matter in the Post-Office at Washington, D. C., under the Act of Congress of July 16, 1894

PRESS OF JUDD & DETWEILER, INC., WASHINGTON, D. C.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 1-128, PLS. 1-7 MARCH 31, 1915

PROCEEDINGS OF THE TWENTY-SEVENTH ANNUAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT PHILADELPHIA, PENNSYLVANIA, DECEMBER 29, 30, AND 31, 1914.

EDMUND OTIS HOVEY, *Secretary*

CONTENTS

Session of Tuesday, December 29

The first general session of the Society was called to order at 9.55 o'clock a. m., Tuesday, December 29, in the lecture hall of the Academy of Natural Sciences, Philadelphia, Pennsylvania, by First Vice-President Lindgren in the absence of President Becker, who was detained at home by illness. Professor Lindgren introduced Dr. Samuel G. Dixon, who in turn welcomed the visiting geologists and paleontologists in the name of the Academy.

The report of the Council for the year ending November 30, 1914, was presented as follows:

REPORT OF THE COUNCIL

To the Geological Society of America, in twenty-seventh annual meeting assembled:

The regular annual meeting of the Council was held at Princeton, New Jersey, in connection with the meeting of the Society, December 30 and 31, 1913, and January 1, 1914.

The details of administration for the twenty-sixth year of the existence of the Society are given in the following reports of the officers:

Secretary's Report

To the Council of the Geological Society of America:

Meetings.—The proceedings of the annual general meeting of the Society held at Princeton, N. J., December 30 and 31, 1913, and January 1, 1914, have been recorded in volume 25, pages 1-118; of the Cordilleran Section, pages 119-126, and of the Paleontological Society, pages 127-156, of the Bulletin.

Membership.—During the past year the Society has lost four Fellows[1] by death—Alfred E. Barlow, Albert S. Bickmore, Horace C. Hovey, and Newton H. Winchell; and three Correspondents, H. Rosenbusch, Eduard Suess, and Th. Tschernyschew. One resignation has become effective. The names of the twelve Fellows elected at the Princeton meeting have been added to the list, all of them having completed their membership according to the rule. The present enrollment of the Society is 363. Nineteen candidates for Fellowship are before the Society for election and several applications are under consideration by the Council.

Distribution of Bulletin.—There have been received during the year 8 new subscriptions to the Bulletin, and 5 subscriptions have been discontinued, making the number of subscribers 118.

The irregular distribution of the Bulletin during the past year has been as follows: Complete volumes sold to the public, 16; sold to Fel-

[1] Since the meeting the Secretary has received notice of the death of Arthur B. Willmott on May 8, 1914.

lows, 1; sent out to supply deficiencies, 1, and delinquents, 7; brochures sent out to supply deficiencies, 5, and delinquents, 67; sold to Fellows, 14; sold to the public, 53.

Bulletin sales.—The receipts from subscriptions to and sales of the Bulletin during the past year are shown in the following table:

Bulletin Receipts, December 1, 1913–November 30, 1914

	Complete volumes.			Brochures.			Grand total.
	Fellows.	Public.	Total.	Fellows.	Public.	Total.	
Volume 1	....	$7.50	$7.50	....	....	....	$7.50
Volume 2	....	7.50	7.50	....	$0.40	$0.40	7.90
Volume 3	....	7.50	7.50	....	....	....	7.50
Volume 4	....	7.50	7.50	....	....	....	7.50
Volume 5	....	7.50	7.50	....	.20	.20	7.70
Volume 6	....	7.50	7.50	....	.65	.65	8.15
Volume 7	....	7.50	7.50	....	....	....	7.50
Volume 8	....	7.50	7.50	....	.30	.30	7.80
Volume 9	....	7.50	7.50	$0.70	....	.70	8.20
Volume 10	....	7.50	7.50	.80	3.40	4.20	11.70
Volume 11	....	15.00	15.00	.60	....	.60	15.60
Volume 12	....	7.50	7.50	....	....	....	7.50
Volume 13	....	7.50	7.50	35	1.50	1.85	9.35
Volume 14	....	7.50	7.50	....	2.70	2.70	10.20
Volume 15	....	15.00	15.00	.10	.30	.40	15.40
Volume 16	....	15.00	15.00	....	.90	.90	15.90
Volume 17	....	7.50	7.50	.40	....	.40	7.90
Volume 18	....	7.50	7.50	....	.55	.55	8.05
Volume 19	....	15.00	15.00	....	....	....	15.00
Volume 20	....	30.00	30.00	....	1.20	1.20	31.20
Volume 21	....	30.00	30.00	....	....	....	30.00
Volume 22	....	15.00	15.00	8.35	.90	9.25	24.25
Volume 23	....	22.50	22.50	2.00	5.00	7.00	29.50
Volume 24	$7.50	68.50	76.00	6.35	20.33	26.68	102.68
Volume 25	....	821.00	821.00	....	.25	.25	821.25
Volume 26	....	30.00	30.00	....	....	....	30.00
Total	$7.50	$1,198.50	$1,206.00	$19.65	$38.58	$58.23	$1,264.23
Index 1–10	....	6.75	6.75	....	....	....	6.75
Index 11–20	....	17.50	17.50	....	....	....	17.50
Total	$7.50	$1,222.75	$1,230.25	$19.65	$38.58	$58.23	$1,288.48

Receipts for the fiscal year	$1,288.48
Previously reported	17,012.41
Total receipts to date	$18,300.89
Charged, but not yet received: On 1911 account	7.50
On 1912 account	9.40
On 1914 account	89.35
Total sales to date	$18,407.14

One subscription to volume 25 is still to be paid for and 6 of the regular subscribers have not yet sent in their orders for the volume. No volumes are sent out now except on definite orders.

Expenses.—The following table gives the cost of administration and of Bulletin distribution during the past year:

EXPENDITURE OF SECRETARY'S OFFICE DURING THE FISCAL YEAR ENDING NOVEMBER 30, 1914

Account of Administration

Postage	$72.16	
Post-cards	17.40	
Printing (including annual meetings of 1913 and 1914)	85.00	
Labor at sundry times	6.24	
Typewriter	72.90	
Typewriter ribbons	1.50	
Messenger service	.75	
Telephone charges	1.30	
Telegrams	.85	
Express	4.57	
Expenses of trip to Philadelphia to arrange for annual meeting	6.35	
Collection charges on checks	.20	
Addressograph plates	.04	
Letter-heads, envelopes, etcetera	50.25	
Binding three copies of Bulletin	6.40	
Cordilleran Section (1914)	40.05	
Total		$365.96

Account of Bulletin

Postage	$20.01	
Express	28.84	
Telegrams	.82	
Wrapping paper	3.87	
Messenger service	1.90	
Labor at sundry times	9.00	
Rubber stamp	.40	
Jurat	.50	
Collection charges on checks	1.25	
Bulletin envelopes	34.30	
Purchase of back numbers of Bulletin	18.00	
Total		$118.89
Total expenditures for the year		$484.85

Respectfully submitted, EDMUND OTIS HOVEY,
Secretary.

Treasurer's Report

To the Council of the Geological Society of America:

The Treasurer herewith submits his annual report for the year ending November 30, 1914.

One Fellow—Robert T. Hill—taking advantage of the new provision of the By-laws, has commuted for life during the year by the payment of one hundred dollars, thus increasing the total Life Commutations, since the organization of the Society, to 104, which, with the 4 Honorary Life Members, makes a total of 108. One Life Member died during the year, which, with the 14 previous deaths, leaves 93 living Life Members.

The membership of the Society at the present time is 363, of whom 270 pay annual dues. Twelve new members were elected at the last annual meeting, all of whom qualified. There have been 4 deaths during the year and 1 resignation. Fifteen members are delinquent in the payment of dues—1 for five years, 3 for three years, and are therefore liable to be dropped from the roll—and 11 for one year.

With the advice of the Investment Committee, the Treasurer bought during the year two Southern Bell Telephone and Telegraph Company five per cent bonds, with interest, at a cost of $2,008.88.

RECEIPTS

Balance in treasury December 1, 1913		$1,029.65
Fellowship fees, 1910 (1)	$10.00	
1911 (1)	10.00	
1912 (3)	30.00	
1913 (10)	100.00	
1914 (256)	2,560.00	
1915 (1)	10.00	
1 for 9 years in advance	90.00	
		2,810.00
Initiation fees (12)		120.00
Life commutation (1)		100.00
Interest on investments:		
Iowa Apartment House stock	50.00	
Ontario Apartment House stock	200.00	
Texas and Pacific Railroad Company bonds	100.00	
U. S. Steel Corporation bonds	150.00	
St. Louis, Iron Mountain and Southern Railway Company bond	50.00	
St. Louis and San Francisco Railroad Company equipment bond	50.00	
Fairmont and Clarksburg Traction Company bonds	100.00	

Consolidation Coal Company bonds......	100.00		
Chicago Railways Company bond........	100.00		
Southern Bell Telephone and Telegraph Company bonds......................	50.00		
Interest on deposits, Baltimore Trust Company	70.74		
		1,020.74	
Case Library, accessions 1913........................		150.00	
Collection charge added to checks..................		.50	
Refund for overcharge..............................		9.50	
Received from Secretary:			
Sales of publications..................	$1,288.48		
Authors' separates.....................	22.20		
Collection charges added to checks......	.46		
Paleontological Society's share of printing	10.00		
Binding Bulletin.......................	1.60		
		1,322.74	
			$6,563.13

EXPENDITURES

Secretary's office:			
Administration	$365.96		
Bulletin	118.89		
Allowance	700.00		
		$1,184.85	
Treasurer's office:			
Postage, bond, safe-deposit box..........	$53.75		
Allowance for clerical hire.............	50.00		
		103.75	
Publication of Bulletin:			
Printing[2]	$1,617.70		
Engraving	342.67		
Editor's allowance....................	250.00		
		2,210.37	
Purchase of two Southern Bell Telephone and Telegraph five per cent bonds, with interest..................		2,008.88	
			5,507.85
Balance in Baltimore Trust Company December 1, 1914...........			1,055.28
			$6,563.13

Respectfully submitted,

Wm. Bullock Clark,
Treasurer.

[2] This item includes transportation charges on the regular distribution of the Bulletin $33.42
and the following charges which have been refunded by the authors:
Authors' separates in excess of number given gratis by the Society...... 22.20

Editor's Report

To the Council of the Geological Society of America:

The Editor submits herewith his annual report. The following tables cover statistical data for the twenty-five volumes thus far issued:

Cost.	Average—Vols. 1-20.	Vol. 21.	Vol. 22.	Vol. 23.	Vol. 24.	Vol. 25.
	pp. 610. pls. 55.	pp. 839. pls. 54.	pp. 759. pls. 31.	pp. 774. pls. 43.	pp. 755. pls. 36.	pp. 820. pls. 28.
Letter press..	$1,686.58	$2,049.95	$1,660.45	$1,750.40	$1,647.90	$2,049.19
Illustrations..	390.99	404.27	260.81	274.70	288.80	342.67
	$2,077.57	$2,454.22	$1,921.26	$2,025.10	$1,936.70	$2,391.86
Average per page..	$3.41	$2.93	$2.53	$2.62	$2.56	$2.91

Classification.

Volume.	Areal geology.	Physical geology.	Glacial geology.	Physiographic geology.	Petrographic geology.	Stratigraphic geology.	Paleontologic geology.	Economic geology.	Official matter.	Memorials.	Unclassified.	Total.
	Number of pages.											
1.......	116	137	92	18	83	44	47	.....	60	4	4	593+xii
2.......	56	110	60	111	52	168	47	9	55	1	7	662+xiv
3.......	56	41	44	41	32	158	104	.....	61	15	1	541+xii
4	25	134	38	74	52	52	14	.....	47	32	2	458+xii
5	138	135	70	54	28	51	107	.....	71	14	9	665+xii
6..	50	111	75	39	71	99	1	.....	63	25	4	538+x
7.......	38	77	105	53	40	21	123	4	66	28	13	558+x
8.......	34	50	98	5	43	67	58	14	79	8	....	446+x
9.......	2	102	138	.....	44	28	64	16	64	12	....	460+x
10.......	35	33	96	37	59	62	68	28	84	27	17	534+xiii
11.......	65	110	21	10	54	31	188	7	71	60	46	651+xii
12.......	199	39	55	53	24	98	5	5	70	2	....	538+xi
13.......	125	17	13	24	28	116	42	4	165	32	29	583+xii
14.......	48	47	48	59	183	118	22	1	80	14	1	609+xi
15	26	124	3	94	36	267	.....	.....	77	17	3	636+x
16.......	64	111	78	30	102	141	19	.....	67	22	15	636+xiii
17.......	49	161	41	84	47	294	27	.....	71	9	2	785+xiv
18	16	164	141	5	29	246	5	.....	68	40	3	717+xii
19.......	106	108	29	66	30	155	32	.....	56	15	20	617+x
20.......	43	54	35	29	37	45	303	8	60	3	132	749+xiv
21......	72	234	75	48	85	70	106	1	111	11	10	823+xvi
22.......	23	54	28	28	23	403	74	.....	63	49	1	747+xii
23.......	75	52	126	108	19	145	134	.....	66	32	1	758+xvi
24.......	18	57	96	57	49	160	106	23	133	53	3	737+xviii
25.	34	211	54	32	156	9	175	.....	108	9	22	802+xviii

Respectfully submitted, JOSEPH STANLEY-BROWN,
Editor.

Respectfully submitted, THE COUNCIL.

December 29, 1914.

On motion, the report was laid on the table as usual until the following day.

ELECTION OF AUDITING COMMITTEE

The Auditing Committee, consisting of H. L. Fairchild, J. M. Clarke, and E. B. Mathews, was then elected, and the Treasurer's report was referred to it for examination.

ELECTION OF OFFICERS

The Secretary declared the vote for officers for 1915 as follows, the ballots having been canvassed and counted by the Council in accordance with the By-Laws:

President:

ARTHUR P. COLEMAN, Toronto, Canada.

First Vice-President:

L. V. PIRSSON, New Haven, Conn.

Second Vice-President:

H. P. CUSHING, Cleveland, Ohio.

Third Vice-President:

E. O. ULRICH, Washington, D. C.

Secretary:

EDMUND OTIS HOVEY, New York City.

Treasurer:

WILLIAM BULLOCK CLARK, Baltimore, Md.

Editor:

JOSEPH STANLEY-BROWN, New York City.

Librarian:

FRANK R. VAN HORN, Cleveland, Ohio.

Councilors:

CHARLES K. LEITH, Madison, Wis.
THOMAS L. WATSON, Charlottesville, Va.

ELECTION OF FELLOWS

The Secretary announced the election in due form of the following Fellows, the ballots having been canvassed and counted by the Council:

JOHN ANDREW ALLEN, B. A., M. Sc., Ph. D., University of Alberta, Strathcona, Canada.

JOSEPH AUSTEN BANCROFT, B. A., M. A., Ph. D., McGill University, Montreal, Canada.

FRANK CATHCART CALKINS, B. S., U. S. Geological Survey, Washington, D. C.

CHARLES CAMSELL, B. A., Geological Survey of Canada, Ottawa, Canada.

CHARLES H. CLAPP, S. B., Ph. D., University of Arizona, Tucson, Arizona.

WILLIAM FRANK EUGENE (REED) GURLEY, University of Chicago, Chicago, Illinois.

RAY VERNON HENNEN, A. B., B. S., C. E., West Virginia Geological Survey, Morgantown, West Virginia.

ROY JAY HOLDEN, B. S., Virginia Polytechnic Institute, Blacksburg, Virginia.

GEORGE DAVID HUBBARD, B. S., M. S., A. M., Ph. D., Oberlin College, Oberlin, Ohio.

WALTER FRED HUNT, A. B., A. M., University of Michigan, Ann Arbor, Michigan.

EDWARD CHARLES JEFFREY, A. B., Ph. D., Harvard University, Cambridge, Mass.

ESPER SIGNIUS LARSEN, JR., B. S., U. S. Geological Survey, Washington, D. C.

JAMES H. LEES, B. A., M. S., Iowa Geological Survey, Des Moines, Iowa.

FRANCOIS EMILE MATTHES, B. S., U. S. Geological Survey, Washington, D. C.

THOMAS POOLE MAYNARD, A. B., Ph. D., Chattanooga, Tenn.

HERBERT E. MERWIN, S. B., Ph. D., Geophysical Laboratory, Washington, D. C.

ALEXANDER HAMILTON PHILLIPS, B. S., D. Sc., Princeton University, Princeton, N. J.

MILLARD KING SHALER, A. B., B. S., United States Embassy, London, England.

STEPHEN TABER, A. B., Ph. D., University of South Carolina, Columbia, S. C.

Announcement was then made by the Secretary that the Society had lost four Fellows by death during the year 1914: Alfred E. Barlow, Albert S. Bickmore, Horace C. Hovey, and Newton H. Winchell, and three Correspondents: H. Rosenbusch, Eduard Suess, and Th. Tschernyschew. Memorials of deceased Fellows were presented as follows:

MEMOIR OF ALFRED ERNEST BARLOW

BY FRANK D. ADAMS

The news of the loss of the *Empress of Ireland*, which brought such widespread sorrow to so many homes, not only in the Dominion of Canada, but also in the United States, came with a sense of personal bereavement to many members of the Geological Society of America when it was learned that Dr. Alfred E. Barlow was among those who had perished. Having attended the closing meeting of the Royal Society of Canada,

Yours very sincerely
Alfred E. Barlow

which was held in Montreal, Doctor Barlow, on the morning of May 28, left with Mrs. Barlow for Quebec, where he took passage for Liverpool, intending to spend some months in England; but that night, when near Father Point, in the Gulf of Saint Lawrence, the *Empress of Ireland* was struck by the collier *Storstadt*, coming from Sydney, Nova Scotia, to Montreal, heavily laden with coal, and in a few minutes sank with most of her passengers and crew. Doctor Barlow, who was very alert, active, and a powerful swimmer, evidently swam away from the sinking vessel supporting his wife, but was struck by a piece of wreckage, rendered unconscious, and both succumbed.

Alfred E. Barlow was born in Montreal on June 17, 1861, and was a younger son of Robert Barlow of the Royal Engineers, who in earlier life was engaged on the Ordnance Survey of England, but subsequently came to Canada, and was appointed by Sir William Logan to the position of Chief Draughtsman on the Geological Survey of Canada, which position he filled for many years, his work leading up finally to the publication of the great Geological Map of the Dominion of Canada, issued by Logan in 1863, which was one of the finest examples of cartography which had appeared up to that time.

Alfred Barlow, having completed his schooling in Montreal, entered the Faculty of Arts of McGill University in 1879, where he studied geology under Sir William Dawson, graduating four years later with first-rank honors in natural science and the Logan gold medal. Shortly after graduating he was appointed to a position on the staff of the Geological Survey of Canada, and for two summers worked under the late Dr. R. W. Ells in the Shickshock Mountains of the Gaspé District and in the Cobequid Mountains of Nova Scotia. In 1885 he became assistant to Dr. A. C. Lawson, and for several seasons worked with him in the Lake of the Woods and Rainy Lake region. This epoch-making investigation awakened in him a keen interest in the problems presented by the ancient crystalline rocks of Canada, to the study of which in their various phases he devoted the remainder of his life.

From 1887 to 1895 he was engaged in a study of the pre-Cambrian rocks of the Sudbury, Nipissing, and Timiskaming districts, in eastern Ontario. The results of this work appear in several reports issued by the Geological Survey of Canada. In these he pointed out the promising character of this region as a field for careful prospecting, which is of interest, since some years later the rich silver veins of the Cobalt Camp were discovered in this area. During this time he also made a detailed report on the geology of the nickel-bearing rocks of the township of Creighton, in the Sudbury District, for the Mond Nickel Company, and the accuracy of certain of his deductions has recently been proved in the discovery of large bodies of very valuable nickel ores in the township of Levack by explorations which were carried out by the company at points indicated by Doctor Barlow. This work on the copper-nickel ores of the Sudbury region was continued for the Geological Survey of Canada, and it is not too much to say that his report on the nickel and copper deposits of Sudbury has now become a classic in the literature of ore deposits. It was Doctor Barlow who first established the claim of these remarkable ore bodies to be considered as of magmatic origin. About this time the writer was requested by Dr. George M. Dawson, then Director of the Geological Survey of Canada, to undertake the mapping and detailed study of a large area of the Grenville Series in the Haliburton and Bancroft districts of eastern Ontario, and as the work developed Doctor Barlow was associated with him. This region was geologically an absolutely virgin field, but it had an area of 4,200 square miles, and it was necessary to make a topographical survey to secure a map on which the geological structures of the region could be shown. Doctor Barlow's ability as an excellent topographer, as well as a keen geologist, and his indefatigable energy contributed largely to the successful completion of this work, the result of which appeared in the Geology of the Haliburton and Bancroft Areas, published by the Geological Survey in 1910. Among the results obtained from the study of this region was the discovery of great bodies of nepheline syenite occurring about the border of the intruding granite batholiths and presenting many remarkable variations in composition, some varieties being rich in corundum, which were subsequently made the basis of an extensive industry for the exploitation of the mineral.

Doctor Barlow served on several important commissions. One of these was that appointment by the Dominion government in 1905 to report on the zinc resources of British Columbia. Another was the commission appointed by the government of the Province of Quebec in 1910 to report on the resources of the Chibougamau District in that province. This is situated in northern Quebec, on the eastern prolongation of the great belt of pre-Cambrian rocks on which farther west the great mining camps of Cobalt, Porcupine, and Sudbury are found. Reports of the mineral richness of this region had been brought in by various explorers and the government was being urged to vote a large sum for the construction of a railroad into this remote region for the purpose of making these supposed mineral deposits accessible. The commission, with Doctor Barlow as chairman, after making a thorough study of the region, reported against the construction of the railroad, thus not only preventing a large and useless expenditure of public money, but also much rash speculation in private funds which would undoubtedly have followed.

In 1907 he severed his connection with the Geological Survey of Canada to engage in private practice as a mining geologist and took up his residence in Montreal.

Doctor Barlow was for many years on the Council of the Canadian Mining Institute, and in 1913 was elected president of the institute, which position he held for two years. He was elected a Fellow of the Geological Society of America in 1906 and a Fellow of the Royal Society of Canada in 1903. He was a member of the Executive Committee of the Twelfth International Geological Congress, which met in Canada in the summer of 1913, and devoted much time to the work of this important gathering. He received the degree of Doctor of Science from McGill University in 1900, and was a lecturer in geology at this university at the time of his demise.

In 1887 he married Frances Elizabeth Toms, of Ottawa, and they leave one son. Doctor Barlow was a man of marked ability, great energy, and abounding enthusiasm—a pleasant companion and a warm friend. His loss will long be felt by the geologists of Canada.

BIBLIOGRAPHY

1882-84. List of fossils collected by A. E. Barlow at Grand Grève and Gaspé. Geol. Surv. of Canada, Report of Progress, 1882-84, p. 24E.

1890-91. Notes on Ontario nickel and copper industries. Geol. Surv. of Canada, Ann. Rept., vol. v, pp. 115-118ss.

On the nickel and copper deposits of Sudbury, Ontario. Geol. Surv. of Canada, Ann. Rept., vol. v, pp. 122-143s.

1891. On the nickel and copper deposits of Sudbury, Ontario. Ottawa Naturalist, vol. v, pp. 51-71.

1892. On the relation of the Laurentian and Huronian on the north side of Lake Huron. Am. Journ. Sci., 3d series, vol. xliv, pp. 236-239.

Summary report on the area including Lake Nipissing and the southern portions of lakes Temagami, Timiscaming, and Keepawa. Geol. Surv. of Canada, Ann. Rept., vol. vi, pp. 34-35A.

1893. Relations of the Laurentian and Huronian rocks to the north of Lake Huron. Bull. Geol. Soc. Am., vol. 4, pp. 313-332.

Summary report on surveys in the Temagami District, Ontario. Geol. Surv. of Canada, Ann. Rept., vol. vi, pp. 30-33AA.

1894. Summary report on surveys in the Temagami District, Ontario. Geol. Surv. of Canada, Ann. Rept., vol. vii, pp. 56-57A.

1895. On some dikes containing "huronite." Ottawa Naturalist, vol. ix, pp. 25-47.

Notes on certain rocks from the Labrador Peninsula. Geol. Surv. of Canada, Ann. Rept., vol. viii, p. 207 and pp. 350-351L.

Summary report on surveys in the Temagami District, Ontario. Geol. Surv. of Canada, Ann. Rept., vol. viii, pp. 61-63A.

The physical features and geology of the route of the proposed Ottawa Canal between the Saint Lawrence River and Lake Huron, by R. W. Ells and A. E. Barlow. Trans. Roy. Soc. Canada, 2d ser., vol. i, sec. iv, pp. 163-190.

1896. Summary report on a geological survey of the Haliburton District, Ontario, by F. D. Adams and A. E. Barlow. Geol. Surv. of Canada, Ann. Rept., vol. ix, pp. 45-53A.

1897. On the occurrence of cancrinite in Canada. Can. Record of Science, vol. vii, p. 22.

On the relations and structure of certain granites and associated arkoses on Lake Timiscaming, Canada, by A. E. Barlow and W. F. Ferrier. Brit. Assoc. Adv. Sci., Rept., pp. 659-660.

On the origin and relations of the Grenville and Hastings Series in the Canadian Laurentian. F. D. Adams and A. E. Barlow [with remarks by R. W. Ells]. Can. Record of Science, vol. vii, pp. 304-316; also in Am. Journ. Sci., 4th series, vol. iii, pp. 173-180.

Summary report on a geological survey of the Haliburton District, Ontario, by F. D. Adams and A. E. Barlow. Geol. Surv. of Canada, Ann. Rept., vol. x, pp. 44-56A.

Notes on the petrography of certain rocks from Lac des Mille Lacs, Ontario. Geol. Surv. of Canada, Ann. Rept., vol. x, pp. 29-31H.

Report on the geology and natural resources of the area included in the Nipissing and Timiscaming map-sheets. Geol. Surv. of Canada, Ann. Rept., vol. x, pt. I, pp. 1-302.

Petrographical notes on a sericite schist from Harold Lake, Ontario. Geol. Surv. of Canada, Ann. Rept., n. s., vol. x, p. 60H.

1898. Summary report on a geological survey of the Haliburton District, Ontario, by F. D. Adams and A. E. Barlow. Geol. Surv. of Canada, Ann. Rept., vol. xi, pp. 106-111A.

Petrographical notes on certain rocks from Fraser River (upper), British Columbia. Geol. Surv. of Canada, Ann. Rept., vol. xi, pp. 34-36D.

Petrographical notes on certain rocks from Winnipeg Lake, Manitoba. Geol. Surv. of Canada, Ann. Rept., vol. xi, pp. 26, 27G.

1899. Summary report on a geological survey of the Haliburton District, Ontario, by F. D. Adams and A. E. Barlow. Geol. Surv. of Canada, Ann. Rept., vol. xii, pp. 122-131A.

On the origin of some Archean conglomerates. Ottawa Naturalist, vol. xii, pp. 205-217, pls. vi-ix.

Petrographical notes on certain rocks from Great Bear and Great Slave Lakes District. Geol. Surv. of Canada, Ann. Rept., vol. xii; app. to pt. C, pp. 29-36.

Petrographical notes on certain rocks from the iron ore deposits of the Kingston and Pembroke Railway District, Ontario. Geol. Surv. of Canada, Ann. Rept., vol. xii, pp. 81-91I.

1900. Summary report on a geological survey of the Haliburton District, Ontario, by F. D. Adams and A. E. Barlow. Geol. Surv. of Canada, Ann. Rept., vol. xiii, pp. 127-129A.

Gravity separations of feldspars in dikes of Shefford Mount., Quebec. Geol. Surv. of Canada, Ann. Rept., vol. xiii, p. 29L.

Tests on auriferous sands from sluice-boxes, Atlin, British Columbia. Geol. Surv. of Canada, Ann. Rept., vol. xiii, pp. 11-13A.

1901. Summary report on a geological survey of the Sudbury District, Ontario. Geol. Surv. of Canada, Ann. Rept., vol. xiv, pp. 113-117A.

Notes on ore from bore-hole, Hepworth, Ontario. Geol. Surv. of Canada, Ann. Rept., vol. xiv, p. 261A.

Report on the origin, geological relations, and composition of the nickel and copper deposits of the Sudbury Mining District, Ontario, Canada. Geol. Surv. of Canada, Ann. Rept., vol. xiv, pt. H, 236 pp.

Petrographical notes on certain rocks from the Klondike District, Yukon. Geol. Surv. of Canada, Ann. Rept., vol. xiv, pp. 10-22B.

1902. Summary report on a geological survey in the Sudbury Mining District, Ontario. Geol. Surv. of Canada, Ann. Rept., vol. xv, pp. 254-269A.

On the nepheline rocks of Ice River, British Columbia. Ottawa Naturalist, vol. 16, pp. 70-76.

Dr. Alfred R. C. Selwyn, Director, Geological Survey of Canada, 1869-1894. Ottawa Naturalist, vol. 16, pp. 171-177.

Petrographical notes on specimens from Bruce Mines District, Ontario. Geol. Surv. of Canada, Ann. Rept., vol. xv, pp. 247A and 104S.

1903. Petrography of rock specimens from British Columbia: (*a*) Texada and Vancouver Island, pp. 254, 255; (*b*) west coast of Vancouver Island, etc., etc., pp. 258-260. Ann. Rept. of Minister of Mines for British Columbia for 1903.

1904. Summary report on geological surveys in the Ontario Corundum districts and Lake Temagami. Geol. Surv. of Canada, Ann. Rept., vol. xvi, pp. 190-194A.

Notes on Craig Mine, Renfrew County, Ontario. Geol. Surv. of Canada, Ann. Rept., vol. xvi, pp. 15, 168.

1905. Petrographical determinations of rock specimens from Texada Island, British Columbia. Trans. Can. Min. Inst., vol. viii, pp. 175-176.

A landslide on the Lièvre River, Quebec. Ottawa Naturalist, vol. 18, pp. 181-190.

1906. On the nickel deposits of Webster, North Carolina. Trans. Can. Min. Inst., vol. ix, pp. 303-316.

Report on some of the undeveloped zinc deposits of British Columbia. Can. Dept. of Int., Mines Br., Rept. of the Commission to investigate the zinc resources of British Columbia, pp. 273-293.

Summary report on the Quebec side of Lake Timiscaming. Summary Rept., Geol. Surv. of Canada, 1906, pp. 113-118.

On the origin and relations of the nickel and copper deposits of Sudbury, Ontario, Canada. Econ. Geol., vol. i, no. 5, pp. 454-466; no. 6, pp. 545-553.

1907. Report of a special committee on the correlation of the pre-Cambrian rocks of the Adirondack Mountains, the "original Laurentian area" of Canada and East Ontario, by F. D. Adams and others. Journ. of Geol., vol. 15, no. 3, pp. 191-217.

1908. The origin of the silver of James township, Montreal River District, Ontario. Trans. Can. Min. Inst., vol. xi, pp. 256-273.

The silver veins of the Montreal River District, Canada. Min. and Sci. Press, vol. 97, Oct. 3, pp. 462-465.

The nepheline and associated alkaline syenites of Eastern Ontario, by F. D. Adams and A. E. Barlow. Trans. Roy. Soc. Can., 3d ser., vol. 2, sec. 4, pp. 3-76.

1909. Report on mining claims in the Montreal River Division. The German Development Co., Ld., Rept. for 1909, pp. 5-21; also Can. Min. Journ., vol. 30, pp. 51-54.

Report on the mining locations belonging to "Miller Lake and Everett Mines, Ld." The German Development Co., Ld., Rept. for 1909, pp. 22-26; also Can. Min. Journ., vol. 30, pp. 57-58.

1910. Geology of the Haliburton and Bancroft areas, Ontario, by F. D. Adams and A. E. Barlow. Geol. Surv. of Canada, memoir no. 6. No. 1082. [French translation, no. 1187.]

Origin of asbestus. Trans. Can. Min. Inst., vol. xiii, pp. 438-443.

1911. Preliminary report on the geology and mineral resources of the Chibougamau region, Quebec, by the Chibougamau Mining Commission. A. E. Barlow, J. C. Gwillim, E. R. Faribault. Quebec Dept. of Colonization, Mines, and Fisheries, 24 pp.

Report on the geology and mineral resources of the Chibougamau region, Quebec, by the Chibougamau Mining Commission. A. E. Barlow, J. C. Gwillim, and E. R. Faribault. Quebec Dept. of Colonization, Mines, and Fisheries, 224 pp.

1911. Memoir of David Pearce Penhallow. Bull. Geol. Soc. Am., vol. 22, pp. 15-19.

1913. Presidential address. Trans. Can. Min. Inst., vol. 16, pp. 4-14.

Excursion A2: The Haliburton-Bancroft area of central Ontario, by F. D. Adams and A. E. Barlow. (Guide Book No. 2, XII Session, Congrès Geol. Internat., pp. 5-98.)

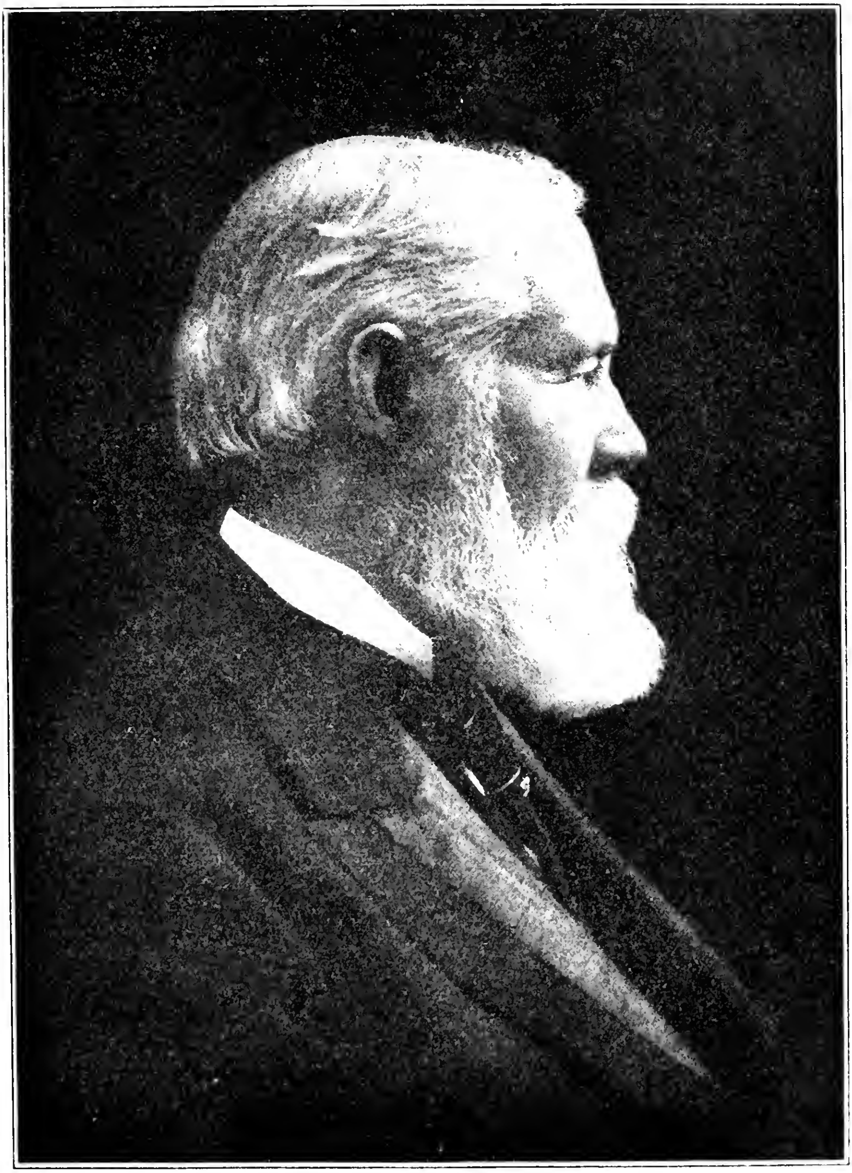
Account of Excursion A2, Haliburton-Bancroft, Ontario. Congrès Geol. Internat., Compte-Rendu, XII Session, Canada, 1913, pp. 960-963.

1914. Corundum, its occurrence, distribution, exploitation, and uses. Geol. Surv. of Canada, No. 1022, Memoir No. 57 (now in press).

ALBERT SMITH BICKMORE

BY GEORGE FREDERICK KUNZ

Albert Smith Bickmore was born in the coast village of Tenants Harbor, in the town of Saint George, Maine, March 1, 1839. As in the cases of most of those who in after life have made their mark in the natural sciences, he already gave evidence as a child of his interest in natural objects. This is testified to by some of his surviving relatives, who recall that he was called a "queer child" because he was constantly hunting after butterflies, shells, and birds. A voyage to Bordeaux, France, when a child, made on a ship of which his father was captain, must have left a strong impression on a mind so sensitively alive to the aspects of nature, and this early experience probably planted the seeds



Albert S. Bickmore

of his love for travel and exploration.[1] After preparation in the district school and in several academies, he entered Dartmouth College, graduating in 1860. His college expenses were partly paid by money earned for teaching during the vacations. Four years' study under the great naturalist and geologist, Louis Agassiz, in the Lawrence Scientific School of Harvard University, prepared him for his later researches.

His extensive researches during his Oriental voyage were not only in the field of natural science, in the narrowest sense, but included the domain of ethnography, and his discovery of the curious Ainu people, the aborigines of Japan, was an important contribution to this science. However, his long, arduous, and faithful service in the American Museum of Natural History was the crowning glory of his career. He had charge of the Department of Public Instruction from 1882 to 1904. His brief professorship of natural his.ory at Madison (now Colgate) University, Hamilton, New York, was partly coincident with the undertaking of his life task in building up our wonderful Museum.

Professor Bickmore was the recipient of the following titles and degrees:

A. B., Dartmouth, 1860, A. M., 1863; B. S., Harvard, 1864; Ph. D., Hamilton, 1869, Dartmouth College, 1889; LL. D., Colgate, 1905; Life Fellow, Royal Geographical Society, London; Fellow American Geographical Society, New York Academy of Sciences, A. A. A. S.; Trustee American Museum of Natural History, Colgate, U., Vassar College.

While studying under Prof. Louis Agassiz, whose only remaining pupil is Dr. David Starr Jordan, of Leland Stanford University, he became his assistant, and went to Bermuda, collecting for Cambridge Museum. He also traveled in the East Indian Archipelago, China and Japan, Siberia, Moscow, Saint Petersburg, Berlin, and London during the years from 1865 to 1868; became professor of natural history in Madison (now Colgate) University, 1869; superintendent of the American Museum of Natural History, 1869-1884, and in the same institution professor in charge of the Department of Public Instruction since 1882. He again traveled, in 1895 to 1904, gathering data and illustrations for lectures on natural history, geography, and history, and he afterward published travels in the East Indian Archipelago in New York, London, and Jena. Professor Bickmore did his part in the Civil War as well, serving for nine months in the 44th Massachusetts Volunteers in 1862 and 1863.

Professor Bickmore, in 1875, was one of the handsomest and most kindly men I had ever met. He told me of his inception of the Museum

[1] See biographical sketch of Professor Bickmore, by J. M. B., in the Watchman Examiner, New York and Boston, August 23, 1914, p. 1159

after returning from his "trip through China and northern Siberia." He asked himself: "Could a great city like New York afford to be without a museum of natural history?" With his ripe experience of travel, his wide knowledge of natural history, and his love of it, fostered by that pioneer naturalist, Louis Agassiz, his dream became a reality, and the Museum is today greater than any of us had dared to hope. People have often spoken of the thirteen buildings that would form the group comprising the Museum of Natural History. They thought of it as a curious architectural plan for a gridiron building, but never realized that it would become a fact. Today we have no less than six buildings.

All who knew him will agree with the statement that while no one has better succeeded in such effort than did the late Professor Bickmore in obtaining gifts and favors for his cherished institution, he was never uncomfortably insistent in his requests, but almost invariably found it possible to persuade the prospective donor that no better place could be found for his specimens than the great museum, where not only the former owner himself could see them under the very best conditions, but they would afford pleasure and instruction to thousands of visitors.

I never knew Professor Bickmore to be in anything but a happy mood. He was frank, fearless, generous, kind, energetic. His whole ambition was embodied in the success of the American Museum of Natural History. Those were the days when the Museum had very little or no money, although it was sustained by loyal and ambitious friends.

Of all those associated with the institution and its inception, only three are now living: Hon. Joseph H. Choate, who has been a trustee throughout the entire period of its existence, and the renowned naturalist, Dr. Daniel Giraud Elliott, who, with the late Doctor Holder, the latter's son, now Dr. Charles Frederick Holder, and Mr. Bargen, an accountant and bookkeeper, formed the entire staff of the Museum when the doors of the Arsenal were opened to admit the public to view the relatively small but interesting and well chosen collection of that early day in the institution's history.

A memorial meeting for Professor Bickmore was held January 29, 1912, at the American Museum of Natural History, short addresses being made, among others, by Prof. Henry Fairfield Osborn, President of the Museum; Cleveland H. Dodge, Joseph H. Choate, Dr. John M. Clarke, and L. P. Gratacap, a curator of the Museum. No one was better qualified to speak of the great work accomplished by Professor Bickmore in connection with the founding and building of the Museum than Mr. Choate, who drafted the charter and by-laws of the new institution and who was one of the few survivors of those who actively supported the

Horace C. Hovey.

project from the outset. Of the "Father of the Museum," as Professor Bickmore has been called, this speaker said that the great change in public opinion as to the value and importance of natural history studies was due in a greater degree to his influence than to any other single cause.

The strong personal influence exercised by Louis Agassiz, among whose many pupils, from 1861 to 1865, was Albert S. Bickmore, is believed to have contributed in large measure to the latter's enthusiastic devotion to the idea of establishing a great museum of natural history. A similar museum had already been projected by Agassiz for Harvard College.[2] When Bickmore came to New York, in 1865, he was introduced to Mr. William Earle Dodge and proposed the matter to him. This was just before Bickmore's departure for the Far East. Just before his return to the country he stopped for a while in London, where he met Sir Richard Owen, Director of the Museum of Natural History, and submitted to him the plans for a New York museum which he had been slowly elaborating during his protracted journey. The hearty approval which the English scientist bestowed upon these plans served to deepen Bickmore's conviction of their value and practicability, and on his return to New York he took up the matter with renewed ardor. One of the most earnest workers in this cause was Theodore Roosevelt, Sr., to whom Bickmore was referred by Mr. Dodge, and soon by his efforts and those of William Haines, Benjamin H. Field, and Robert Colgate a number of representative citizens became interested in the project, several of them becoming members of the original board of trustees, composed of New York's leading citizens.

MEMOIR OF HORACE CARTER HOVEY

BY JOHN M. CLARKE

The science of the earth seems to hold an especial attraction for the servants of its ancient enemy, the Church. As the contentious attitude once assumed by the Church toward this science dissolved away into a better balance and steadier growth, it is little wonder that some part of the clergy have shown a sincere purpose to better acquaint themselves, by personal touch, with the data of geology. The development of the English facts and ideals in our science has put upon the rolls names of distinguished clerics, men who have put aside all bias and have rendered

---

[2] The American Museum of Natural History, its origin, its history, and growth of the departments to December 31, 1909, by Henry Fairfield Osborn, President. 2d ed. New York, 1911.

a service unqualified by tradition or prejudice. American geology, too, also acknowledges its obligations to, and this Society has admitted among its ranks, many an ordained Christian minister.

Of these—indeed, among all of us—the subject of this testimonial has held a singular, if not unique, position, and in this necessarily brief notice of his achievements in this science it is well that we remind ourselves of his devoted service in other fields which lie beyond the scope of our present attention.

The Rev. Horace Carter Hovey, Doctor of Divinity, was born near Rob Roy, Fountain County, Indiana, January 28, 1833, and died at his home in Newburyport, Massachusetts, the place of his last pastorate, July 27, 1914, thus in his 82d year. The blood in his veins, drawn from both sides of his parentage, was of the good vintage of the English yeomanry who established this nation. His parents had followed one of the remoter paths of Puritan dispersion about New England, taking their way from Ipswich, through Brookfield, Malden, and Manchester; thence into Hanover, New Hampshire, and to Thetford, Vermont. From Vermont, in the winter of 1831-1832, they went as home missionaries, with the express object of establishing a Presbyterian institution of higher education in the Wabash Valley. There, at Crawfordsville, the Rev. Edmund Otis Hovey, the father, with his associates, founded Wabash College, and there for more than forty years he served that institution, holding all administrative offices from the lowest to the highest, except the presidency, which he persistently declined. In this somewhat varied scholastic career it was the sciences that invited and held his most continuous service, and through his special concern with geology Doctor Hovey, senior, is fairly entitled to be counted among the pioneer geologists of the Middle West; for even though he himself did not venture into the field of authorship, he kept in personal touch with the leaders in American geology—Dana, Hall, and Newberry. The scientific museum of Wabash College today bears his name—the Hovey Museum—and this important educational factor has been assembled about the nucleus of a little lot of crystals and ores brought by his wife all the long way from Vermont.

The inspiration and influence of such parentage, predisposed on both sides to the love of science, could hardly fail to turn the heart of the son toward the laboratory of nature. He was taught to observe: his eyes and his mind were opened to things of woodland and valley, of rocks and sky. The wondrous beds of crinoids in Coreys Bluff, of which all the world now knows and specimens from which are to be found in most geological museums, were discovered by him when a boy of nine years.

The well directed eyes of this little shaver in science had already in this single act done a thing which in real service the lifetime of another might hardly equal. But love and comprehension of science was not a thing that in those days, in such an atmosphere, could be safely pursued save as an avocation from what was, to that generation, a more serious calling: and so the growing youth, having passed through the course at Wabash College, graduated in 1853, and as students of that institution were definitely designed for the Church, Mr. Hovey completed the purpose of his training by a course in the Lane Theological Seminary at Cincinnati.

Doctor Hovey was an active clergyman all his life and he was one of the original Fellows of the Geological Society. He never pretended, however, to be a professional geologist, even though he became expert and, among us, final in experience and judgment in that phase of the science now designated by the unlovely term *speleology*.

His study of caverns was begun in 1854 and was maintained with ever-growing interest for sixty years. His zeal was fearless. The subterranean world, with its unknown mysteries of darkness and labyrinthine mazes, held no fears for him, and he pursued, even at the age of seventy-five, their bewildering ways in newly discovered parts of the Mammoth Cave, through which the routes were dangerous and difficult enough to have taxed the nerve, the strength, and the agility of a young man.

His first published account of his explorations was in 1855 and related to the Wyandotte Cave of Indiana. His last contribution to the literature of caves was an exhaustive bibliography of the Mammoth Cave (with Dr. R. Ellsworth Call), which was published in 1914, and came to his hands only a few hours before his death.

When Doctor Hovey began his labors, cave-hunting was little else than a bizarre and venturesome underground diversion, seemingly impelled by curiosity only, with a distant intangible hope of solving some hidden problem. Today cave exploration is so far an orderly procedure, with definite modes and objectives, as to have won a distinctive name, a distinctive organization, La Société de Speleologie, and a distinctive organ, *Spelunca*. In the charm of that far-reaching interest which bears on the primitive history of the human race and its contemporaries, the American caverns seem not yet to have a share, but in their physical characters their bearing on broad problems of drainage, on the chemistry of solution, and on the tectonics of limestone plateaus (the caves to which Doctor Hovey gave his especial attention) they are, in magnitude of area and diversity of effects, hardly to be equaled. To these must be added their wondrous and impressive beauty in domes and spires, in crystal mounds and opalescent pools, in glistering spectral icicles and resonant carillons, all the weird and fascinating devices of a buried world, emerging from the slime and dirt, the grime and damp, of the lower regions—in these majestic demonstrations of physical change and the vastitude of results from persistent minor forces the American caves have perhaps few peers.

Doctor Hovey's work may be estimated as having opened to the world a field of great interest and instruction in our country. To it we owe our present extensive knowledge of the Mammoth Cave, much of what is known of the Luray caverns, and so on along the line of American caverns of note. His "Celebrated American Caverns" is a standard work; his "Guide Book to the Mammoth Cave" has passed through fifteen editions; his contributions to the Encyclopedia Britannica are the summaries of an authority, and in his bibliography will be found more than 100 titles which testify to his unflagging and plenteous activities in popularizing and disseminating knowledge of underground phenomena.

A few years after Doctor Hovey had written the first of his papers on cave exploration (1858) the famous bone cave at Brixham, Devonshire, was discovered. Its discoverers thought it important that it be scientifically investigated and communicated their conviction to the Director General of the Geological Survey, who decided that such operations did not fall within the scope of that Survey. Yet this discovery, the exploration of the contents of the cavern by Pengelly and Falconer, led to the unfolding of the whole panorama of the ancient caves and cave life of Britain. Since those years the caves of Europe have proven to be the treasure chests of our human records, and while here in America we must abide with a slenderer hope of such light; yet the life stories of the American caverns, which have been illuminated by the discoveries of Doctor Hovey and his associate, Doctor Call, are of great interest.

In their organic or inorganic phases these problems of the caves pertain to our science of geology, and it is our gratification that he who labored on them so successfully was one of us.

Doctor Hovey was a cautious observer, a clear and forcible writer, and brought to his scientific publications qualities which graced his chiefer profession. He taught his science as he could find opportunity. He traveled much, and in these travels, on one occasion, had opportunity to visit the caverns of central France under the guidance of Martel.

Upon Doctor Hovey's other service to his generation we can not dwell. Labors for the Christian Commission during the last years of the Civil War, in which he went through the battles of the Wilderness, North Anna, and Cold Harbor; his civic activities in the various communities of his pastorate—these have been recorded in other memorials. In later years his appearance at our meetings was only occasional, but we do not forget his fine presence, his handsome face, his courteous, winning, and impressive personality.

BIBLIOGRAPHY

Brachiospongia. Trans. Kansas Acad. Sci., vol. iii, pp. 10-11. 1871.
Discoveries in western caves. Am. Jour. Sci., 3d ser., vol. xvi, pp. 465-471. December, 1878.
One hundred miles in Mammoth Cave. Scribner's Monthly Magazine, vol. xx, pp. 914-924. October, 1880.
Eighty miles in Indiana caverns. Scribner's Monthly, vol. xix, pp. 875-887. 1880.
Recent discoveries, measurements, and temperature observations in Mammoth Cave. Naturalist's Leisure Hour and Monthly Bulletin, No. 8, pp. 8-9. August, 1881.
The temperature of the Mammoth Cave. Scientific American. October 8, 1881.
The new Scylla and Charybdis. Scientific American. October, 1881.
The Mammoth Cave visited by the American Association for the Advancement of Science. Bull. Harvard Univ., No. 20. October, 1881.
Observations on the temperature of the Mammoth Cave, Kentucky. Proc. Conn. Acad. Arts and Sciences. November, 1881.
Hovey's explorations in the Mammoth Cave. Popular Science Monthly, vol. xvii. November, 1880, and January, 1881.
Coal dust as an element of danger in mining. Am. Jour. Sci., 3d ser., vol. xxii, pp. 18-20. 1881.
Coal dust as an element of danger in mining shown by the explosion in the Albion mines, November 12, 1880. Proc. Am. Assoc. Adv. Sci., vol. xxx, pp. 68-69. 1882.
Guide book to the Mammoth Cave of Kentucky. Robert Clarke & Company, Cincinnati. 1882.
A remarkable case of retention of heat by the earth (abstract). Proc. Am. Assoc. Adv. Sci., vol. xxx, pp. 39-40. 1882.
Celebrated American caverns, especially Mammoth, Wyandotte, and Luray. Robert Clarke & Company, Cincinnati. 1882. Second edition, 1896.
Mammoth Cave. Encyclopedia Britannica, 9th and 10th editions, vol. xv, pp. 448-450. 1883.
Subterranean map-making. Proc. Am. Assoc. Adv. Sci., vol. xxxi, pt. ii, pp. 345-346. 1883.
Guide book to the Mammoth Cave. 70 pages. Robert Clarke & Company, Cincinnati. 1884.
Niagara River, Gorge, and Falls. Scientific American Suppl., vol. 22, No. 558, p. 8917. 1886.
The pits and domes of Mammoth Cave. Proc. Am. Assoc. Adv. Sci., vol. xxxviii, pp. 253-255. 1889.
Idem. Scientific American. October, 1889.
American saltpeter caves. Scientific American, vol. 65, p. 3. 1891.
Some measurements in the Mammoth Cave of Indiana. Scientific American, vol. 65, p. 52. 1891.
Diamonds in meteors. Scientific American, vol. 65, p. 129. 1891.

The latest facts about the Megalonyx. Scientific American, vol. 65, p. 161. 1891.

Mammoth Cave, Kentucky. Bull. Am. Geog. Soc., vol. xxiii, pp. 47-79. 1891.

Appendixes to Mammoth Cave guide book, 13th edition. Appendix A, on subterranean fauna and flora. Appendix B, on Ganter Avenue. 1891.

A visit to Chalcedony Park, Arizona. Scientific American, vol. 67, p. 55. 1892.

On the rim and in the depths of the Grand Canyon. Scientific American, vol. 67, pp. 87-89. 1892.

Kansas salt. Scientific American, vol. 66, p. 289. 1892.

The Grand Canyon of the Colorado. Scientific American, vol. 66, pp. 392-393. 1892.

A remarkable instance of recent erosion. Scientific American, vol. 68, p. 152. 1893.

The Isles of Shoals (New Hampshire). Scientific American Suppl., No. 1035, pp. 16547-16548. 1895.

The making of Mammoth Cave. Scientific American, vol. 75, p. 151. 1896.

The colossal cavern of Kentucky. Scientific American, vol. 75, p. 183. 1896.

Geological notes on the Isles of Shoals (abstract). Proc. Am. Assoc. Adv. Sci., vol. xliv, pp. 136-137. 1896.

Mammoth Cave, its environs and contents. Jour. School of Geography, vol. i, pp. 133-139. May, 1897.

Our saltpeter caves in time of war. Scientific American, vol. lxxvi, p. 291. 1897.

Mammoth Cave of Kentucky. (H. C. Hovey and R. Ellsworth Call.) John P. Morton & Company, Louisville, Kentucky. 112 pages. 1897.

The Aven Armand, Lozere, France. Scientific American, vol. 78, pp. 228-229. 1898.

The life and work of James Hall, LL.D. Am. Geol., vol. xxiii, pp. 137-168. 1899.

Mapping the Mammoth Cave. Scientific American Suppl., No. 1229. June 22, 1899.

Facts about Megalonyx. Scientific American Suppl., No. 1300, p. 20839. 1900.

The lead and silver mines of Newbury. Scientific American Suppl., No. 1328, p. 21284. 1901.

Balloon measurements of Mammoth Cave's height. Scientific American, vol. 89, p. 147. 1903.

The colossal cavern of Kentucky. Scientific American Suppl., No. 1455. November 21, 1903.

Colossal cavern. Spelunca, t. v, pp. 57-61. 1904.

Strange mazes and chasms in Mammoth Cave, with diagram of the Mælstrom and photograph of John M. Nelson, the guide. Scientific American Suppl., No. 1540, p. 24680. 1905.

A Mammoth Cave cathedral; some new discoveries of interest. Scientific American Suppl., No. 1651, p. 125. 1907.

Recent explorations in Mammoth Cave, with a revised map of the cave (abstract). Science, n. s., vol. xxviii, p. 381. September 18, 1908.

Hovey's hand-book of the Mammoth Cave. John P. Morton & Company, Louisville, Kentucky. 64 pages. 1909.

Mammoth Cave. Baedeker's United States, p. 584. 1909.

III—Bull. Geol. Soc. Am., Vol. 26, 1914

N. H. Winchell

Kaemper's discoveries in the Mammoth Cave. Scientific American, vol. 100, p. 388. 1909.

Mammoth Cave. Encyclopedia Britannica, 11th edition, vol. xvii, pp. 531-533. 1911.

Mammoth Cave, Kentucky, with an account of Colossal Cavern. (H. C. Hovey and R. Ellsworth Call.) John P. Morton & Company, Louisville, Kentucky. 131 pages. 1912.

Bibliography of Mammoth Cave, Kentucky. (H. C. Hovey and R. Ellsworth Call.) Spelunca, t. ix, No. 73. September, 1913.

MEMOIR OF NEWTON HORACE WINCHELL

BY WARREN UPHAM

In the seventh generation of descent from Robert Winchell, the British immigrant who founded this family in America, living in Windsor, Connecticut, from 1635 until his death, in 1669, Newton Horace Winchell was born in Northeast, Dutchess County, New York, December 17, 1839, and died in Minneapolis, Minnesota, May 2, 1914. His father, Horace Winchell, and his mother, Caroline McAllister Winchell, were highly esteemed school teachers, and both were excellent singers. The father, residing on the ancestral farm, was greatly interested in religious denominational reforms, peaceable arbitration of national disputes, and abolition of slavery, and to advance these reforms he published many pamphlets.

Newton Horace Winchell in boyhood attended the public school and academy at Salisbury, Connecticut, and at the age of sixteen years he began teaching in a district school of his native town. Two years later, in 1858, he entered the University of Michigan, where his eldest brother, Alexander, was the professor of geology. The next eight years were spent in studies at the university and in school teaching, alternately, the schools taught being in Ann Arbor, Grass Lake, Flint, Kalamazoo, Colon, and Port Huron, Michigan. Previous to his graduation at the university, in 1866, he had been two years the superintendent of the public schools in Saint Clair, Michigan; and next, after graduation, he was again superintendent of schools at Adrian, in that State, for two years, 1867-1869. He received from his Alma Mater the degree of Master of Arts in 1867.

Like his brother, Prof. Alexander Winchell, with whose family he had his home during the early part of his university studies, at Ann Arbor, Michigan, Newton Horace devoted himself mainly to the science of geology, with allied interest in all branches of natural history. In Michigan he did much early work for botany, and in his latest years, after his geological survey of Minnesota was completed, he performed very valuable services for the Minnesota Historical Society on the archeology and ethnology of this State and the Northwest.

During a year, in 1869-1870, he was an assistant to Prof. Alexander Winchell on the Geological Survey of Michigan, and later in 1870 he visited and reported on the copper and silver deposits of New Mexico. In 1871 he assisted Prof. J. S. Newberry, the State geologist of Ohio, surveying and reporting on twenty counties in the northwestern part of that State.

In July, 1872, N. H. Winchell was invited by President William W. Folwell, of the University of Minnesota, to take up the work then recently ordered by the legislature for a survey of the geology and natural history of this State, to be done under the direction of the Board of Regents of the University. In this work he continued twenty-eight years, until 1900; and during the first seven years, until 1879, he performed also the full duties of the university professorship of geology. Later he relinquished teaching, aside from occasional lectures, and gave all his time to the diversified duties of the State survey and the curatorship of the university museum.

In the summer of 1874 Professor Winchell accompanied General Custer's expedition to the Black Hills, brought back many valuable additions for the museum, and prepared a report which contains the first geological map of the interior of the Black Hills.

In 1873 he was one of the organizers of the Minnesota Academy of Natural Sciences, which he served during three terms as president, and he continued as one of its most active members throughout his life.

He was a Fellow of the American Association for the Advancement of Science and presided over its geological section at the Philadelphia meeting in 1884. He was one of the chief founders of this Geological Society of America, in 1889, and was its president in 1902. He was a member of national societies of mineralogy and geology in France and Belgium. In the International Congress of Geologists he became a member in 1888, being reporter for the American Committee on the nomenclature of the Paleozoic series; contributed papers in French to its subsequent meetings at Boulogne and Zurich, and attended its triennial meeting of August, 1913, in Toronto.

Under appointment by President Cleveland in 1887, Professor Winchell was a member of the United States Assay Commission. His geological reports received a diploma and medal at the Paris Exposition of 1889 and a medal at the World's Fair in Chicago in 1893.

He was the chief founder of the American Geologist, a monthly magazine, which was published in Minneapolis, under his editorship, during eighteen years, 1888-1905, in two volumes yearly, forming a series of thirty-six volumes. This work, in which he was much assisted by Mrs. Winchell, greatly promoted the science of geology, affording means of publication to many specialists and amateurs throughout this country. It also brought out many biographic sketches, with portraits, of the principal early American workers in this wide field of knowledge.

In one of the bulletins of the Minnesota Geological Survey, entitled "The Iron Ores of Minnesota," 430 pages, with maps, published in 1891, Prof. N. H. Winchell had the aid of his son, Horace Vaughn Winchell; and in a text-book, "Elements of Optical Mineralogy," 502 pages, 1909, he was associated in authorship with his younger son, Prof. Alexander Newton Winchell, of the University of Wisconsin. During parts of the later years of the Minnesota survey he was aided by his son-in-law, Dr. Ulysses S. Grant, professor of geology in the Northwestern University, Evanston, Illinois.

In 1895-1896 Professor and Mrs. N. H. Winchell spent about a year in Paris, France, and again he was there during six months in 1908, his attention being given mainly during each of these long visits abroad to special studies and investigations in petrology.

For the Geological and Natural History Survey of Minnesota, Professor Winchell published twenty-four Annual Reports, being one each year for the years from 1872 to 1894, inclusive, and the last in this series being for the years 1895-1898, published in 1899. These reports of progress of the survey range in size from 42 pages to 504 pages, comprising many very important papers on the observations of the geology of all parts of the State; also on its ornithology, entomology, botany, paleontology, etc., by Professor Winchell and his assistants. In the last of these annual reports a general index of all the series fills 106 pages.

Ten bulletins of this Survey were published in the years 1887 to 1894, inclusive, ranging from 37 to 430 pages, the largest being on "The Iron Ores of Minnesota," before mentioned, and the last, by J. Edward Spurr, "The Iron-bearing Rocks of the Mesabi Range in Minnesota," 268 pages.

The final reports of the Geology of Minnesota form six quarto volumes, and the third of these volumes, on Paleontology, is bound in two parts. Volume I, published in 1884, comprises the reports of the counties in the southern third of the State; Volume II, published in 1888, treats of the counties in the next third part of the State, proceeding northward, and Volume IV, published in 1899, contains reports on the more northern counties, including the great belts of iron-ore deposits called the Vermilion and Mesabi ranges. Volume V, 1900, by N. H. Winchell and U. S. Grant, deals with the structural and petrographic geology of the Taconic and Archean rocks. A geological atlas forms Volume VI, published in 1901, in which are reprinted all the map plates, eighty-eight in number, of the preceding volumes, with brief descriptions for each, written by Professor Winchell; and a general map is also presented, showing the approximate areas of the geologic systems below the drift.

My association with Prof. N. H. Winchell began in June, 1879. Coming from the Geological Survey of New Hampshire, in which I had been for several years an assistant, I was thenceforward one of the assistants of the Minnesota Survey six years, until 1885, and again in 1893 and 1894. In the meantime and later, while I was an assistant geologist of the surveys of the United States and Canada, on the exploration, mapping, and publication of the Glacial Lake Agassiz, which occupied the basin of the Red River and of lakes Winnipeg and Manitoba, my frequent association with Professor Winchell kept me constantly well acquainted with the progress of his Minnesota work. Since the spring of 1906 he had been in the service of the Minnesota Historical Society, having charge of its Department of Archeology. During all these thirty-five years I had intimately known him and had increasingly revered and loved him. Besides being a skilled geologist, Newton Horace Winchell was a good citizen, a Christian in faith and practice, beloved by all who knew him.

Among the many special investigations which Prof. N. H. Winchell published during the forty-five years of his active work as a scientist, author, and editor, none probably has been more widely influential on geologic thought and progress than his studies and estimates of the rate of recession of the Falls of Saint Anthony, cutting the Mississippi River gorge from Fort Snelling to the present site of the falls in Minneapolis. This investigation, first published in 1876, gave about 8,000 years as the time occupied by the gorge erosion, which is likewise the approximate measure of the time that has passed since the closing stage of the Ice Age, or Glacial period, when the border of the waning ice-sheet was melted away on the area of Minnesota.

Artificially chipped quartz fragments and rude aboriginal implements found in the Mississippi Valley drift at Little Falls, in central Minnesota, belonging to the time of final melting of the ice-sheet there, and other traces of man's presence at nearly the same time, or even much earlier, in numerous other localities of the southern part of our great North American glaciated area, have led Professor Winchell and others, as the late Hon. J. V. Brower, Professors G. F. Wright and F. W. Putnam, and myself, to a confident belief that mankind occupied this continent during the later part of the Ice Age, or even quite probably much earlier in that period, and possibly even before our continental glaciation began. This very interesting line of investigation was the theme of the last paper written by Professor Winchell, entitled "The Antiquity of Man in America Compared with Europe," which he presented as a lecture before the Iowa Academy of Sciences in Cedar Falls, Iowa, on Friday evening, April 24, only a week before he died.

The work on which he was engaged for the Minnesota Historical Society during his last eight years, based on very extensive collections, by Hon. J. V. Brower, of aboriginal implements from Minnesota and other States west to the Rocky Mountains and south to Kansas, enabled Professor Winchell to take up very fully the questions of man's antiquity and of his relation to the Ice Age. From that later work resulted a quarto volume, published in 1911, entitled "The Aborigines of Minnesota," 761 pages, with many illustrations and about 500 maps of groups of Indian mounds.

This last volume of his publications and the twenty-four Annual Reports and six quarto volumes of Final Reports of the Geological and Natural History Survey of Minnesota are monuments more enduring than bronze, which will be consulted and studied during all the coming centuries by investigators of the origin and history of the races of mankind and by all interested in geology or earth lore, not only in the schools and universities of Minnesota, but of all the world.

Newton Horace Winchell was married to Miss Charlotte Sophia Imus, of Galesburg, Michigan, August 24, 1864. She survives him, as also do all their five children, namely, Horace Vaughn Winchell, geologist and mining assayer, Minneapolis; Ima Caroline, Mrs. Frank N. Stacy, Minneapolis; Avis, Mrs. Ulysses Sherman Grant, Evanston, Illinois; Prof. Alexander Newton Winchell, Madison, Wisconsin, and Louise, Mrs. D. Draper Dayton, Minneapolis.

Professor Winchell had enjoyed somewhat good health until the last week, although suffering in some degree with a chronic trouble of many years, and his death resulted from a needed surgical operation done on the preceding day.

He was my friend and it is hard to say Farewell!

BIBLIOGRAPHY

1861. Catalogue of plants in the lower peninsula of Michigan. First biennial report of the Geol. Surv. Mich., 1861, pp. 245-317.

1869. Does the earth move on its axis? Michigan Teacher. May and June, 1869.

The Cheboygan region. Michigan Farmer. Dec., 1869.

The Au Sable. Detroit Tribune (two papers). Dec., 1869.

1870. The Thunder Bay region. Detroit Free Press. April 11, 1870.

A sunken lake and its outlet. Detroit Tribune. 1870.

Phenomena of the post-Tertiary. University Chronicle, Ann Arbor. August, 1870.

Geological notes in the Thunder Bay region. Alpena Pioneer (six papers). Oct.-Dec., 1870.

1871. The building stones of Michigan. American Builder (three papers). June, 1871.

The geology of Putnam County, Ohio. Putnam County Sentinel. Oct., 1871.

Sketch of Crawford County, Ohio. 1871.

The glacial features of Green Bay of Lake Michigan, with some observations on a probable former outlet of Lake Superior. Am. Jour. Sci., 3d ser, vol. ii, pp. 15-19. July, 1871.

1872. Sketch of Delaware County, Ohio. Delaware Gazette. July 8, 1872.

The surface geology of northwestern Ohio. Proc. Am. Assoc. Adv. Sci., vol. xxi, pp. 152-186. 1872. Abstract in Am. Jour. Sci., vol. iv, pp. 321-322. 1872.

1873. The first annual report of the Geological and Natural History Survey of Minnesota, 1872. First and second editions identical, 112 pp. 8vo. This report contains:

General sketch of the geology of Minnesota. pp. 40-48, 60-118.

Preliminary geologic map of Minnesota.

Chart of geologic nomenclature, intended to express the relation of Minnesota to the great geological series of the earth.

The drift-deposits of the Northwest. Popular Science Monthly. June and July, 1873, vol. iii. pp. 202-210, 286-297.

Notes on the drift-soils of Minnesota. Fourth annual report of the commissioner of statistics of Minnesota, 1873.

The Devonian limestones in Ohio. Proc. Am. Assoc. Adv. Sci., vol. xxii, pp. 100-104. 1873.

The geology of Sandusky, Seneca, Wyandot, and Marion counties, Ohio. Rept. Geol. Surv. Ohio, vol. i, pp. 591-645; 4 maps. Columbus, 1873.

1874. The geology of Ottawa, Crawford, Morrow, Delaware, Van Wert, Union, Paulding, Hardin, Hancock, Wood, Putnam, Allen, Auglaize, Mercer, Henry, and Defiance counties, Ohio. Rept. Geol. Surv. Ohio, vol. ii, pp. 227-438. Columbus, 1874.

The second annual report of the Geological and Natural History Survey of Minnesota, 1873. 219 pp. 8vo. St. Paul, 1874. This report contains:

The Belle Plaine salt well, pp. 79-87.

Peat, pp. 88-127.

The geology of the Minnesota Valley, pp. 127-212.

On the Hamilton in Ohio. Am. Jour. Sci., 3d ser., vol. vii, pp. 395-398. 1874.

Report concerning the salt spring lands due the State of Minnesota, 1874. 26 pp. 8vo.

Geological notes from early explorers in the Minnesota Valley. Bull. Minn. Acad. Sci., vol. i, pp. 89-101, 153-156. 1874.

Report on the copper and silver districts of southwestern New Mexico. Mines and Mining west of the Rocky Mountains, pp. 335-343. Washington, 1874.

1875. Report of the curator of the Museum. Dec. 14, 1874. Univ. Minn. Report for 1874.

Notes on the Big Woods. Read before the Minnesota Hort. Soc., 1875. Trans. Hort. Soc.

The economical geology of the region of Cheboygan and old Mackinac in the counties of Presque Isle, Cheboygan, and Emmet, State of Michigan. Report of the Michigan Board of Agriculture for 1873, pp. 103-107. 1875.

The third annual report of the Geological and Natural History Survey of Minnesota, 1874. 44 pp. 8vo. St. Paul, 1875. This report contains:

Report on the geology of Freeborn County, pp. 5-19, with a colored map.

Report on the geology of Mower County, pp. 20-36, with a colored map.

Report of a reconnaissance of the Black Hills of Dakota, made in the summer of 1874 by Capt. William Ludlow. Geological report by N. H. Winchell, pp. 21-65, 4to; contains the first geological map of the interior of the Black Hills. Also in U. S. A. Rept. Chief Engineers, 1874; Appendix PP. pp. 1131-1172. Washington, 1875.

Charcoal table: Used in the mineralogical laboratory of the University of Minnesota. 1875.

Note on lignite in the Cretaceous of Minnesota. Am. Jour. Sci., 3d ser., vol. x, p. 307. 1875.

1876. Vegetable remains in the drift-deposits of the Northwest. Proc. Am. Assoc. Adv. Sci., vol. xxiv, pp. 43-56. 1876.

On the parallelism of Devonian outcrops in Michigan and Ohio. Proc. Am. Assoc. Adv. Sci., vol. xxiv, pp. 57-59. 1876.

Notes on a deep well drilled at East Minneapolis in 1874-1875. Bull. Minn. Acad. Sci., vol. i, pp. 187-189. 1876. Reprinted in the fifth report on the Minnesota Survey.

The fourth annual report on the Geological and Natural History Survey of Minnesota for 1875. 120 pp. 8vo. St. Paul, 1876. This report contains:

Report on the geology of Fillmore County, pp. 251-303, with a map. Republished in the "History of Fillmore County," in 1882.

1877. The fifth annual report of the Geological and Natural History Survey of Minnesota for 1876. 248 pp. 8vo. St. Paul, 1877. This report contains:

The geology of Houston County, pp. 9-50, with a map.

The geology of Hennepin County, pp. 131-201, with a map. This report includes a discussion of the recession of the Falls of St. Anthony.

The Cretaceous in Minnesota. Bull. Minn. Acad. Sci., vol. i, pp. 347-349. 1877.

1878. The sixth annual report of the Geological and Natural History Survey of Minnesota for 1877. 226 pp. 8vo. Minneapolis, 1878. This report contains:

The water supply of the Red River Valley, pp. 9-42.

Reconnaissances (in Wright, Goodhue, and Rice counties and along Northern Pacific Railroad), pp. 43-49.

The geology of Morrison County, pp. 50-53.

The geology of Ramsey County, pp. 66-92, with a map.

The geology of Rock and Pipestone counties, pp. 93-111, with a map.

The recession of the Falls of St. Anthony. Quart. Jour. Geol. Soc. London, vol. xxxiv, pp. 886-901. Nov., 1878.

1879. The seventh annual report of the Geological and Natural History Survey of Minnesota for 1878. 123 pp. 8vo. Minneapolis, 1879. This report contains:

Sketch of the work of the season of 1878 (a preliminary report on the stratigraphy and mineral resources of the northern part of the State), pp. 9-25.

Section of a deep well at Emmetsburg, Iowa. Bull. Minn. Acad. Sci., vol. i, pp. 387-388. 1879.

Minnesota (geological formations). Macfarlane's Am. Geol. R. R. Guide, pp. 145-147. 1879.

1880. The eighth annual report of the Geological and Natural History Survey of Minnesota for 1879. 183 pp. 8vo. St. Paul, 1880. This report contains:

Lithology (microscopic examination of rocks), pp. 10-22.

The Cupriferous series at Duluth, pp. 22-26.

Paleontology (Lingula, Crania, Orthis), pp. 60-69.

Castoroides ohioensis, pp. 181-183.

Annual address of the President of the Minnesota Academy of Science. Bull. Minn. Acad. Sci., vol. i, pp. 389-401. 1880.

The Cupriferous series in Minnesota. Proc. Am. Assoc. Adv. Sci., vol. xxix, pp. 422-425. 1880.

Preliminary report on the building stones, clays, limes, cements, roofing, flagging, and paving stones of Minnesota. Geol. and Nat. Hist. Surv. Minn. 37 pp. 8vo. 1880.

The ancient copper mines of Isle Royale (abstract). Bull. Minn. Acad. Sci., vol. i, p. 29. 1880. Printed in full in Popular Science Monthly, vol. xix, pp. 601-620. 1881.

1881. The ninth annual report of the Geological and Natural History Survey of Minnesota for 1880. 403 pp. 8vo. St. Paul, 1881. This report contains:

Preliminary list of rocks (field descriptions and notes on 442 crystalline rocks from northern Minnesota), pp. 10-114.

Paleontology (Orthis and Strophomena), pp. 115-122.

The water supply of the Red River Valley, pp. 156-174.

The Cupriferous series in Minnesota, pp. 385-387.

Dall's observations on arctic ice, and the bearing of the facts on the glacial phenomena of Minnesota. Am. Jour. Sci., 3d ser., vol. xxi, pp. 358-360. 1881.

Circular letter to the geologists of America (as chairman of a committee for the organization of what became the Geological Society of America). 1881. Reprinted in Am. Geol., vol. vi, pp. 184-185. 1890.

The State and higher education. Bull. Minn. Acad. Sci., vol. ii, pp. 1-18. 1881.

Typical thin sections of the Cupriferous series in Minnesota. Proc. Am. Assoc. Adv. Sci., vol. xxx, pp. 160-166. 1881.

1882. The tenth annual report of the Geological and Natural History Survey of Minnesota for 1881. 254 pp. 8vo. St. Paul, 1882. This report contains:

- Preliminary list of rocks (field descriptions and notes on 393 rock samples from northern Minnesota), pp. 9-122.
- The Potsdam sandstone, pp. 123-136.
- Typical thin sections of the rocks of the Cupriferous series in Minnesota, pp. 137-143.
- Geological notes on Minnesota (translation of "Geologische Notizen aus Minnesota," by J. H. Kloos. Zt. d. d. geol. Gesell., vol. xxiii, pp. 417-448; 648-652, with map, 1871), pp. 175-200.
- The geology of the deep well drilled by G. C. Whelpley at Minneapolis, at the "C" Washburn mill, pp. 211-217.

Résumé d'une communication sur la nomenclature géologique dans l'échelle stratigraphique. Congrès géol. internat. C. R., 2d session, pp. 642-646. 1882.

Report of the section of mineralogy. Bull. Minn. Acad. Sci., vol. ii, pp. 390-416. 1882.

Geology of the Minnesota Valley. History of the Minnesota Valley, pp. 169-176 (700-707). 1882.

1883. The eleventh annual report of the Geological and Natural History Survey of Minnesota for 1882. 220 pp. 8vo. Minneapolis, 1883. This report contains:

- The mineralogy of Minnesota, pp. 5-29.
- The crystalline rocks of Minnesota (translation of "Ueber die krystallinischen Gesteine von Minnesota in Nord-Amerika," by A. Streng and J. H. Kloos. Neues Jahrb., 1877, pp. 31-56, 113-138, 225-242), pp. 30-85.
- Note on the age of the rocks of the Mesabi and Vermilion iron districts, pp. 168-170.

Resolutions on the death of Darwin. Bull. Minn. Acad. Sci., vol. ii, pp. 386-387. 1883.

The Lake Superior rocks. Science, vol. i, p. 334. 1883.

Clay pebbles from Princeton, Minn. Proc. Am. Assoc. Adv. Sci., vol. xxxii, p. 238. 1883.

1884. The twelfth annual report of the Geological and Natural History Survey of Minnesota for 1883. 410 pp. 8vo; 23 plates. Minneapolis, 1884. This report contains:

- The comparative strength of Minnesota and New England granites, pp. 11-18. Also in abstract in Proc. Am. Assoc. Adv. Sci., vol. xxxii, pp. 249-250. 1884.

Minnesota (building stones). 10th Census U. S., Report on building stones for 1880, pp. 244-256. (Vol. X.)

The crystalline rocks of the Northwest. Am. Nat., vol. xviii, pp. 984-1001. 1884. Proc. Am. Assoc. Adv. Sci., vol. xxxiii, pp. 363-379. Abstract, Science, vol. iv, pp. 238-240. 1884. 13th Ann. Rept. Geol. and Nat. Hist. Surv. Minn., pp. 36-38.

The geology of Minnesota; volume I of the final report of the Geological and Natural History Survey of Minnesota. 697 pp. 4to; 43 plates and 52 figures. Minneapolis, 1884. This report contains:

Historical sketch of explorations and surveys in Minnesota, pp. 1-110.

The general physical features of Minnesota, pp. 111-141.

The building stones of Minnesota, pp. 142-203.

The geology of Houston, Winona, Fillmore, Mower, Freeborn, Pipestone, Rock, and Rice counties, pp. 207-324, 347-366, 376-393, 533-561, 648-673.

1885. The thirteenth annual report of the Geological and Natural History Survey of Minnesota for 1884. 196 pp. 8vo; 4 plates. St. Paul, 1885. This report contains:

Notes of a reconnaissance into Pope County, May, 1884, pp. 10-19.

Notes of a trip across the Mesabi range to Vermilion Lake, pp. 20-24.

The Vermilion iron ores, pp. 25-35.

The Humboldt salt well in Kittson County, pp. 41-44.

The deep well at Lakewood cemetery, Minneapolis, pp. 50-54.

Notes on the artesian wells at Mendota, Hastings, Red Wing, Lake City, and Brownsville, and on the deep well at St. Paul, pp. 55-64.

Fossils from the red quartzite at Pipestone, pp. 65-72.

The mineral exhibit of Minnesota at the New Orleans Exposition, 1884. 5th Ann. Rept. Cal. State Mineralogist for 1885, pp. 167-169.

Notes on the sandstone of Taquamenon Bay, Lake Superior. Am. Jour. Sci., 3d ser., vol. xxix, pp. 339-340. 1885.

1886. The fourteenth annual report of the Geological and Natural History Survey of Minnesota for 1885. 353 pp. 8vo; 2 plates. St. Paul, 1886. This report contains:

Notes on some deep wells in Minnesota, pp. 11-16; 348-353.

New species of fossils, pp. 313-318.

A supposed natural alloy of copper and silver from the north shore of Lake Superior, pp. 319-324.

Revision of the stratigraphy of the Cambrian in Minnesota, pp. 325-337.

The Taconic controversy in a nutshell. Science, vol. vii, p. 34. 1886.

1887. The fifteenth annual report of the Geological and Natural History Survey of Minnesota for 1886. 446 pp. 8vo; 2 maps. St. Paul, 1887. This report contains:

Report of N. H. Winchell (on iron ores and areal geology and stratigraphy of northern Minnesota), pp. 211-398.

Notes on classification and nomenclature for the American Committee of the International Geological Congress. March, 1887. Am. Nat., vol. xxi, pp. 693-700. 1887.

The iron-bearing formations of northeastern Minnesota. Bull. Minn. Acad. Sci., vol. iii, pp. 168-169. 1887.

1888. The sixteenth annual report of the Geological and Natural History Survey of Minnesota for 1887. 504 pp. 8vo. St. Paul, 1888. This report contains:

The original Huronian, pp. 13-40.

The Marquette and Gogebic iron regions, pp. 40-60.

Grand Marais, Gunflint Lake, Tower, etc. (areal study of geology of northeastern Minnesota), pp. 60-129.

The Geology of Minnesota: volume II of the final report of the Geological and Natural History Survey of Minnesota. 695 pp. 4to; 42 plates and 32 figures. St. Paul, 1888. This report contains:

The geology of Wabasha, Goodhue, Dakota, Hennepin, Ramsey, and Washington counties, pp. 1-101, 264-398. The chief feature of the volume is the final discussion of the recession of the Falls of St. Anthony, with illustrations showing their position from the time of their discovery by Hennepin to 1857.

The Animikie black slates and quartzites and the Ogishke conglomerate of Minnesota the equivalent of the "Original Huronian." Am. Geol., vol. i, pp. 11-14. 1888.

Irving and Chamberlin on the Lake Superior sandstones. Am. Geol., vol. i, pp. 44-51. 1888.

Some objections to the word *Taconic* considered. Am. Geol., vol. i, pp. 162-172. 1888.

A great primordial quartzite. Am. Geol., vol. i, pp. 173-178. 1888.

The proposed Geological Society (with C. H. Hitchcock). Am. Geol., vol. i, pp. 394-395. 1888.

Report of the subcommittee on the Lower Paleozoic. Presented for the American committee to the International Congress of Geologists, London session, 1888. Am. Geol., vol. ii, pp. 193-224. 1888.

Some thoughts on eruptive rocks, with special reference to those of Minnesota. Proc. Am. Assoc. Adv. Sci., vol. xxxvii, pp. 212-221. 1888.

1889. The seventeenth annual report of the Geological and Natural History Survey of Minnesota for 1888. 273 pp. 8vo. St. Paul, 1889. This report contains:

General report of progress made in the study of the crystalline rocks of Minnesota, pp. 5-74.

The history of geological surveys in Minnesota. Bull. 1, Geol. and Nat. Hist. Surv. Minn. 37 pp. 8vo. St. Paul, 1889.

Natural gas in Minnesota. Bull. 5, Geol. and Nat. Hist. Surv. Minn. 39 pp. 8vo. St. Paul, 1889.

Exhaustion of anthracite coal. Am. Geol., vol. iii, pp. 45-48. 1889.

A new glacial theory. Am. Geol., vol. iii, pp. 138-140. 1889.

Geological Society of America. Am. Geol., vol. iii, pp. 140-146. 1889.

Natural science at the University of Minnesota. Am. Geol., vol. iii, pp. 165-169. 1889.

The origin of prairies. Am. Geol., vol. iii, pp. 182-183. 1889.

The so-called Huronian rocks in the vicinity of Sudbury, Ontario. Bull. Minn. Acad. Sci., vol. iii, pp. 183-185. 1889.

American petrographical microscopes. Am. Geol., vol. iii, pp. 225-230. 1889.

Unconformity at the falls of the Montmorenci. Am. Geol., vol. iii, pp. 333-334. 1889.

Sandy simoon in the Northwest. Am. Geol., vol. iii, pp. 397-399. 1889.

Benjamin Franklin Shumard, a sketch. Am. Geol., vol. iv, pp. 1-6. 1889.

On a possible chemical origin of the iron ores of the Keewatin in Minnesota (with H. V. Winchell). Am. Geol., vol iv, pp. 291-300, 383-386. 1889. Proc. Am. Assoc. Adv. Sci., vol. xxxviii, pp. 235-242. 1889.

Methods of stratigraphy in studying the Huronian. Am. Geol., vol. iv, pp. 342-357. 1889.

Notice of the discovery of Lingula and Paradoxides in the red quartzites of Minnesota. Bull. Minn. Acad. Sci., vol. iii, pp. 103-105. 1889.

Professor Irving and the Keewatin series and the origin and horizon of the iron ores of the Vermilion Lake series (with H. V. Winchell). Am. Geol., vol. iv, pp. 383-386. 1889.

1890. The eighteenth annual report of the Geological and Natural History Survey of Minnesota for 1889. 234 pp. 8vo. St. Paul, 1890. This report contains:

Record of field observations in 1888 and 1889 (studies of crystalline rocks of northeastern Minnesota), pp. 7-63.

The Brenham, Kiowa County, Kansas, meteorites (with J. A. Dodge). Am. Geol., vol. v, pp. 309-312; vol. vi, pp. 370-377. 1890.

A sketch of Richard Owen. Am. Geol., vol. vi, pp. 135-145. 1890.

The pre-natal history of the Geological Society of America. Am. Geol., vol. vi, pp. 181-194. 1890.

The Taconic iron ores of Minnesota and western New England (with H. V. Winchell). Am. Geol., vol. vi, pp. 263-274. 1890.

Quebec not in conflict with Taconic. Am. Geol., vol. vi, pp. 310-311. 1890.

What constitutes the Taconic Mountains? Proc. Am. Assoc. Adv. Sci., vol. xxxix, pp. 246-247. 1890. Also Am. Geol., vol. vi, p. 247. 1890.

The eastern equivalents of the Minnesota iron ores. Read before Minn. Acad. Sci., Oct. 7, 1890. Published in Iron Ores of Minnesota, pp. 411-419.

Northern Pacific Railroad. Macfarlane's Geol. Railway Guide, 2d ed., pp. 258-259. 1890.

1891. The iron ores of Minnesota: their discovery, development, geology, origin, and comparison with those of other mining districts (with H. V. Winchell). 430 pp. 8vo; 41 plates and three maps. Bull. 6, Geol. Nat. Hist. Surv. Minn. Minneapolis, 1891.

Museums and their purposes. A lecture, May, 1891; published in No. 1 of St. Paul Academy of Science. 1891.

A letter to the Minnesota Horticultural Society, describing certain maps of the State of Minnesota. Rept. Minn. Hort. Soc., 1891, pp. 296-299.

Mining (in Minnesota). Minn. Blue Book, pp. 306-308. 1891.

Alexander Winchell. Am. Geol., vol. vii, p. 195. 1891.

The crenitic hypothesis. Am. Geol., vol. viii, pp. 110-111. 1891.

The International Congress of Geologists. Washington meeting. Am. Geol., vol. viii, pp. 243-258. 1891.

Jean N. Nicollet. A sketch of his life. Am. Geol., vol. viii, pp. 343-352. 1891.

Recent studies in spherulitic crystallization. Am. Geol., vol. viii, pp. 387-392. 1891.

1892. The nineteenth annual report of the Geological and Natural History Survey of Minnesota for 1890. 255 pp. 8vo; 41 figures and 2 plates. Minneapolis, 1892. This report contains:

Geognostic and geographic observations in the State of Minnesota (a partial translation of "Geognostische und geographische Beobachtungen in Staate Minnesota." Zeit. Gesell. für Erdkunde, Berlin, vol. xii, pp. 266-320, 1877), pp. 81-121.

The geoogy of the iron ores of Minnesota. Trans. Geol. Soc. Australia, vol. i, part 14, pp. 171-180. 1892.

Memorial sketch of Alexander Winchell. Bull. Geol. Soc. Am., vol. 3, pp. 1-13. 1892.

Archean eruptive rocks of Finland. Am. Geol., vol. ix, pp. 49-52. 1892.

Alexander Winchell: an editorial tribute (with E. W. Claypole). Am. Geol., vol. ix, pp. 71-148. 1892.

The so-called Laurentian limestones at St. John, New Brunswick. Am. Geol., vol. ix, pp. 198-200. 1892.

New species of Brachiopoda from the Trenton and Hudson River groups of Minnesota (with Charles Schuchert). Am. Geol., vol. ix, pp. 284-294. 1892.

The Kawishiwin agglomerate. Am. Geol., vol. ix, pp. 359-368. 1892.

An approximate interglacial chronometer (three plates). Am. Geol., vol. x, pp. 69-80. 1892.

Some problems of the Mesabi iron ore. Am. Geol., vol. x, pp. 169-179. 1892.

The United States Geological Survey. Am. Geol., vol. x, pp. 179-181. 1892.

The topographical map of the United States. Am. Geol., vol. x, pp. 304-310. 1892.

The iron-bearing rocks of Minnesota. Abstract. Bull. Minn. Acad. Sci., vol. iii, pp. 277-280. 1892.

1893. The twentieth annual report of the Geological and Natural History Survey of Minnesota for 1891. 344 pp. 8vo; 12 plates. Minneapolis, 1893. This report contains:

The crystalline rocks; some preliminary considerations as to their structures and origin, pp. 1-28.

Field notes, pp. 29-34.

Oxide of manganese, pp. 321-322.

The Norian of the Northwest. Prefatory note to Bull. 8, Geol. Nat. Hist. Surv. Minn., pp. i-xxxiv. 1893.

The geology of Hennepin County. Atwater's History of Minneapolis, chapter vi. 1893.

Frondescent hematite. Am. Geol., vol. xi, pp. 20-21. 1893.

The unit of geological mapping for State surveys. Am. Geol., vol. xi, pp. 44-47. 1893.

The topographical work of the United States Geological Survey. Am. Geol., vol. xi, pp. 47-55. 1893.

The Illinois State Museum. Am. Geol., vol. xi, pp. 109-110. 1893.

Professor Wright's book a service to science. Am. Geol., vol. xi, p. 194. 1893.

Prehistoric America, by Stephen D. Peet. (A review.) Am. Geol., vol. xi, pp. 349-352. 1893.

Northwestern Columbian Museum (late the Minneapolis Exposition). A circular prepared and printed at Chicago, Nov., 1893.

The twenty-first annual report of the Geological and Natural History Survey of Minnesota for 1892. 171 pp. 8vo; 2 plates, 10 figures. Minneapolis, 1893. This report contains:

Summary statement and comparative nomenclature, pp. 1-4.

Field observations of N. H. Winchell in 1892, pp. 79-160.

Sponges, graptolites, and corals from the Lower Silurian in Minnesota (with Charles Schuchert). Advance pages from "The Geology of Minnesota," volume iii, of the final report of the Geological and Natural History Survey of Minnesota, pp. 55-59. Minneapolis, 1893.

The Lower Silurian brachiopoda of Minnesota (with Charles Schuchert). Advance pages from "The Geology of Minnesota," volume iii, of the final report of the Geological and Natural History Survey of Minnesota, pp. 333-474. Minneapolis, 1893.

Report of the State Board of Geological Survey (Michigan) for the years 1891 and 1892. 192 pp. 8vo. Lansing, 1892. (A review.) Am. Geol., vol. xi, pp. 344-349. 1893.

1894. The twenty-second annual report of the Geological and Natural History Survey of Minnesota for 1893. 210 pp. 8vo; 7 plates. Minneapolis, 1894. This report contains:

List of rock samples (with geological notes), pp. 5-17.

The exhibit of the Survey at the Columbian Exposition, pp. 201-202.

Increase Allen Lapham. Am. Geol., vol. xiii, pp. 1-38. 1894.

Pebbles of clay in stratified gravel and sand. Glacialists' Magazine, vol. i, pp. 171-174. 1894.

Artesian water supply for Minneapolis; letter to the City Council. Saturday Spectator, Aug. 12, 1894. 5 pp.

L'extension du système Taconique vers l'ouest. Congrès Géologique Intern., 1894, pp. 272-308.

The Columbian Exposition. The crystalline rocks. Am. Geol., vol. xiv, pp. 46-47. 1894.

The mineral industry. Am. Geol., vol. xiv, pp. 185-187. 1894.

The origin of spheroidal basalt. Am. Geol., vol. xiv, pp. 321-326. 1894.

A sketch of geological investigation in Minnesota. Jour. Geol., vol. ii, pp. 692-707. 1894.

Sketch of John Locke. Am. Geol., vol. xiv, pp. 341-356. 1894.

A new meteorite: Minnesota No. 1. Am. Geol., vol. xiv, p. 389. 1894.

1895. The twenty-third annual report of the Geological and Natural History Survey of Minnesota for 1894. 255 pp. 8vo; 3 plates. Minneapolis, 1895. This report contains:

The origin of the Archean greenstones, pp. 4-35.

The progress of mining, pp. 215-217.

List of rock samples, pp. 238-240.

The Geology of Minnesota; final report of the Geological and Natural History Survey of Minnesota, volume iii, part 1. 474 and lxxv pp. 4to; 42 plates and 34 figures. Minneapolis, 1895. This report contains:

Historical sketch of investigation of the Lower Silurian in the Upper Mississippi Valley (with E. O. Ulrich), pp. ix-liii.

Note on other Cretaceous fossils in Minnesota, pp. 53-55.

Sponges, graptolites, and corals from the Lower Silurian in Minnesota (with Charles Schuchert), pp. 55-59.

The Lower Silurian brachiopoda of Minnesota (with Charles Schuchert), pp. 333-374.

The age of the Galena limestone. Am. Geol., vol. xv, pp. 33-39. 1895.

The source of the Mississippi. Am. Geol., vol. xvi, pp. 323-326. 1895. See also Minn. Hist. Soc. Coll., vol. viii, part 2, pp. 226-231. 1896.

The feldspars. Am. Geol., vol. xvi, pp. 51-58. 1895.

Crucial points in the geology of the Lake Superior region. A series of ten articles, as follows:

The stratigraphic base of the Taconic or Lower Cambrian. Am. Geol., vol. xv, pp. 153-162. 1895.

The paleontologic base of the Taconic or Lower Cambrian. Am. Geol., vol. xv, pp. 229-234. 1895.

The eruptive epochs of the Taconic or Lower Cambrian. Am. Geol., vol. xv, pp. 295-304. 1895.

Canadian localities of the Taconic eruptives. Am. Geol., vol. xv, pp. 356-363. 1895.

Steps of progressive research in the geology of the Lake Superior region prior to the late Wisconsin Survey. Am. Geol., vol. xvi, pp. 12-20. 1895.

The Keweenawan according to the Wisconsin geologists. Am. Geol., vol. xvi, pp. 75-86. 1895.

A rational review of the Keweenawan. Am. Geol., vol. xvi, pp. 150-162. 1895.

The synchronism of the Lake Superior region with other portions of the North American continent. Am. Geol., vol. xvi, pp. 205-213. 1895.

The latest eruptives of the Lake Superior region. Am. Geol., vol. xvi, pp. 269-271. 1895.

Comparative taxonomy of the rocks of the Lake Superior region. Am. Geol., vol. xvi, pp. 331-337. 1895.

1896. Sur la météorite tombée le 9 Aout, 1894, près de Fisher, Minnesota. C. R., Acad. Sci., vol. cxxii, pp. 681-682. 1896.

Sur un cristal de labrador du gabbro de Minnesota. Bull. Soc. Min. France, vol. xix, pp. 90-92. 1896.

Lacroix's axial goniometer. Am. Geol., vol. xvii, pp. 79-82. 1896.

Microscopic characters of the Fisher meteorite. Am. Geol., vol. xvii, pp. 173-176; 234-238. 1896.

Discovery and development of the iron ores of Minnesota. Minn. Hist. Soc. Coll., vol. viii, pp. 25-40. 1896.

Volcanic ash from the north shore of Lake Superior (with U. S. Grant). Am. Geol., vol. xviii, pp. 211-213. 1896.

The Arlington iron: Minnesota No. 2. Am. Geol., vol. xviii, pp. 267-271. 1896.

The Black River limestone at Lake Nipissing. Am. Geol., vol. xviii, pp. 178-179. 1896.

The missing link. Am. Geol., vol. xviii, pp. 179-181. 1896.

1897. The Geology of Minnesota: final report of the Geological and Natural History Survey of Minnesota, volume iii, part 2, pp. 475-1081 and lxxvi-cliv, 4to; 48 plates and 133 figures. Minneapolis, 1897. This report contains:

The Lower Silurian deposits of the Upper Mississippi province: a correlation of the strata with those in the Cincinnati, Tennessee, New York, and Canadian provinces, and the stratigraphic and geographic distribution of the fossils (with E. O. Ulrich). pp. lxxxiii-cxxviii.

An important aid to the investigator and general student. Am. Geol., vol. xix, pp. 209-210. 1897.

Some new features in the geology of northeastern Minnesota. Am. Geol., vol. xx, pp. 41-51. 1897.

Light in the East. Am. Geol., vol. xx, pp. 128-129. 1897.

The Missouri Geological Survey. Am. Geol., vol. xx, pp. 181-184; 270-271. 1897.

The Fisher meteorite. Its chemical and mineral composition. Am. Geol., vol. xx, pp. 316-318. 1897.

The geological chronology of Renevier. Am. Geol., vol. xx, pp. 318-321. 1897.

The close of the twentieth volume. Am. Geol., vol. xx, pp. 403-405. 1897.

The Taconic according to Renevier. Am. Geol., vol. xx, pp. 405-407. 1897.

Minnesota quartzite. Stone, vol. xiv, pp. 122-125. 1897.

1898. A new iron-bearing horizon in the Keewatin in Minnesota. Proc. Lake Sup. Mg. Inst., vol. v, pp. 46-48. 1898.

Relation of geology to topography; discussion of a paper by J. C. Branner. Trans. Am. Soc. Civ. Eng., vol. xxxix, pp. 83-84. 1898.

The determination of the feldspars. Am. Geol., vol. xxi, pp. 12-49. 1898.

Some resemblances between the Archean of Minnesota and of Finland. Am. Geol., vol. xxi, pp. 222-229. 1898.

The significance of the fragmental eruptive debris at Taylor's Falls, Minn. Am. Geol., vol. xxii, pp. 72-78. 1898.

The question of differentiation of magmas. Am. Geol., vol. xxii, pp. 113-123. 1898.

The oldest known rock. Abstract. Proc. Am. Assoc. Adv. Sci., vol. xlvii, pp. 302-303: Science, vol. viii, p. 504. Am. Geol., vol. xxii, pp. 262-263. 1898.

Note on the characters of mesolite from Minnesota. Am. Geol., vol. xxii, pp. 228-230. 1898.

The origin of the Archean igneous rocks. Am. Geol., vol. xxii, pp. 299-310. 1898.

Thomsonite and lintonite from the north shore of Lake Superior. Am. Geol., vol. xxii, pp. 347-349. 1898.

1899. The twenty-fourth annual report of the Geological and Natural History Survey of Minnesota for 1895-1898. 284 + xxviii pp. 8vo. Minneapolis, 1898. This report contains:

- Summary statement (of work, museum, library, cost, and results of the Survey), pp. vii-xxviii.
- Rock samples collected in 1896-1898 (with geological notes), pp. 1-84.
- General index of the annual reports of the Minnesota Survey [reports i-xxiv], pp. 179-284.

The Geology of Minnesota; final report of the Geological and Natural History Survey of Minnesota, volume iv, 630 pp. 4to; 79 plates and 111 figures. St. Paul, 1899. This report contains:

- Preface (discussion of classification of Archean), pp. xiii-xx.
- Geology of Carlton County, pp. 1-24.
- Geology of St. Louis County, pp. 212-265.
- Geology of Lake County, pp. 266-312.
- Geology of (parts of) the Mesabi iron range, pp. 358-398.
- Geology of the Pigeon Point plate, pp. 502-521.
- Geology of the Vermilion Lake plate, pp. 522-549.
- Geology of the Carlton plate, pp. 550-565.
- Geology of the Duluth plate, pp. 566-580.

Thalite and bowlingite from the north shore of Lake Superior. Am. Geol., vol. xxiii, pp. 41-44. 1899.

Chlorastrolite and zonochlorite from Isle Royale. Am. Geol., vol. xxiii, pp. 116-118. 1899.

Common zeolites from the Minnesota shore of Lake Superior. Am. Geol., vol. xxiii, pp. 176-177. 1899.

The optical characters of jacksonite. Am. Geol., vol. xxiii, pp. 250-251. 1899.

Adularia and other secondary minerals from the copper-bearing rocks. Am. Geol., vol. xxiii, pp. 317-318. 1899.

Loewinson-Lessing's classification of rocks and differentiation of magmas. Am. Geol., vol. xxiii, pp. 346-369. 1899.

1900. The Geology of Minnesota; final report of the Geological and Natural History Survey of Minnesota, volume v, 1027 and xxvii pp. 4to; 6 plates and 55 figures. St. Paul, 1900. This report contains:

- Preface (classification of Taconic and Archean), pp. xxiii-xxvii.
- Structural geology, pp. 1-74.
- Petrographic geology of the crystalline rocks of Minnesota (with U. S. Grant), pp. 75-936.
- Mineralogy and petrology of Minnesota, pp. 957-999.

Geological Survey of Michigan, volume vi, parts i and ii (a review). Am. Geol., vol. xxv, pp. 122-126. 1900.

1901. The Geology of Minnesota; final report of the Geological and Natural History Survey of Minnesota, volume vi, atlas of 90 plates, 4to. St. Paul, 1901. Twenty-eight plates and all the synoptical descriptions are by N. H. Winchell.

Retreat of the ice-margin across Minnesota (abstract). Science, vol. xiii, pp. 509-510. 1901.

Croll's theory redivivus. Am. Geol., vol. xxvii, pp. 174-178. 1901.

Glacial lakes of Minnesota. Bull. Geol. Soc. Am., vol. xii, pp. 109-128. 1901.

The Archean of the Alps. Am. Geol., vol. xxviii, pp. 189-200. 1901.

Edward Waller Claypole. Am. Geol., vol. xxviii, pp. 247-248. 1901.

The origin of Australian iron ores. Am. Geol., vol. xxviii, pp. 248-250. 1901.

Fundamental changes in the Archean and Algonkian as understood by Professor Van Hise, of the United States Geological Survey. Am. Geol., vol. xxviii, pp. 385-388. 1901.

1902. Sketch of the iron ores of Minnesota. Am. Geol., vol. xxix, pp. 154-162. 1902. Also published in Proc. Int. Mg. Cong., 4th session, pp. 136-140. 1902.

Some geologic evidence of the deluge. Chicago Record Herald, May 11, 1902.

The Sutton Mountain. Am. Geol., vol. xxx, pp. 118-120. 1902.

The Lansing (Kansas) skeleton. Am. Geol., vol. xxx, pp. 189-194. 1902.

The geology of the Mississippi Valley at Little Falls, Minnesota. Memoirs of Exploration in the Basin of the Mississippi, vol. v, Kakabikansing, pp. 89-104. 1902.

The American Monthly Journal of Geology and Natural Science. Am. Geol., vol. xxx, pp. 62-64. 1902.

Regeneration of clastic feldspars. Abstract. Science, vol. xv, p. 85. 1902. Printed in full in Bull. Geol. Soc. Am., vol. 13, pp. 522-525. 1903.

1903. Some results of the late Minnesota Geological Survey. Am. Geol., vol. xxxi, pp. 246-253. 1903.

Was man in America in the Glacial period? Presidential address, Geol. Soc. Am., Dec. 30, 1902. Bull. Geol. Soc. Am., vol. 14, pp. 133-152. 1903.

The Pleistocene geology of the Concannon farm, near Lansing, Kansas. Am. Geol., vol. xxxi, pp. 263-308. 1903.

Geological and archeological excursion to Nehawka, Nebraska, August 14, 1902. Nebraska Board of Agriculture, report for 1902, pp. 314-317.

Metamorphism of Laurentian limestones of Canada. Am. Geol., vol. xxxii, pp. 385-392. 1903.

Granite. Address at unveiling of the Coronado obelisk at Logan Grove, Kansas, August 12, 1902. Memoirs of Exploration in the Basin of the Mississippi, vol. vii, Kansas, pp. 87-91. 1903.

1904. The evolution of climates. Am. Geol., vol. xxxiii, pp. 116-122. 1904.

Where did life begin? Am. Geol., vol. xxxiii, pp. 185-189. 1904.

Peleliths. Am. Geol., vol. xxxiii, pp. 319-325. 1904.

The colossal bridges of Utah. Am. Geol., vol. xxxiv, pp. 189-192. 1904.
The Baraboo iron ore. Am. Geol., vol. xxxiv, pp. 242-253. 1904.
The stone reefs of Brazil. Am. Geol., vol. xxxiv, pp. 319-324. 1904.
Professor Winchell's notes on a very brilliant meteorite. Popular Astronomy, vol. xii. pp. 553-555 (misnumbered 252-255). 1904.
Notes on the geology of the Hellgate and Big Blackfoot valleys. Montana. Abstract. Bull. Geol. Soc. Am., vol. 15, pp. 576-578. 1904.
Notes on the geology of the Hellgate Valley between Missoula and Elliston, and northward to Placid Lake, in Montana. Abstract. Science, vol. xix, pp. 524-525. 1904.

1905. Deep wells as a source of water supply for Minneapolis. 29 pp., 4 pls. Published by citizens, Minneapolis, 1905. Also in Am. Geol., vol. xxxv, pp. 266-291. 1905.
Another meteorite in the Supreme Court. Am. Geol., vol. xxxvi, pp. 47-49. 1905.
The Willamette meteorite. Am. Geol., vol. xxxvi, pp. 250-257. 1905.

1906. The Keweenawan at Lake of the Woods in Minnesota. Abstract. Science, vol. xxiii, p. 289. 1906.
Glacial lakes of St. Louis and Nemadji. Abstract. Bull. Min. Acad. Sci., vol. iv, No. 2, p. 208. 1906.

1907. Origin of the word Canada. Nat. Geog. Mag., vol. xviii, p. 215. 1907.
Pre-Indian inhabitants of North America. Records of the Past, vol. vi, pp. 145-157; 163-181; 17 figs. 1907.
Pre-Columbian elephant medals found in Minnesota. Am. Anthrop., vol. ix, pp. 358-361. 1907.
A white man's stone cairn. Am. Anthrop., vol. ix, pp. 654-655. 1907.
The Cuyuna iron range. Econ. Geol., vol. ii, pp. 565-571. 1907.
The massacre of the Verendrye party at Lake of the Woods. Magazine of History, vol. vi, pp. 225-235. 1907.

1908. Migration of the early Babylonian civilization. Records of the Past, vol. vii, p. 176. 1908.
The prehistoric aborigines of Minnesota and their migrations. Pop-Sci. Monthly, vol. lxxiii, pp. 207-225. 1908.
Sees no danger in artesian water. Minneapolis Tribune, Sept. 13, 1908.
Mining and quarrying. Minnesota in Three Centuries, vol. iv, pp. 375-388. 1908.
Structures of the Mesabi iron ore. Proc. L. Sup. Mg. Inst., vol. xiii, pp. 189-204, 8 figs. 1908.

1909. Elements of Optical Mineralogy: an introduction to microscopic petrography, with description of all minerals whose optical elements are known, and tables arranged for their determination microscopically (with Alexander N. Winchell). pp. viii, 502, 8vo; 350 figures and 4 plates. New York, 1909.
Habitations of the Sioux in Minnesota. Wisconsin Archeologist, vol. vii, pp. 155-164. 1909.
A diamond drill core section of the Mesabi rocks. I. Megascopic characters. Proc. L. Sup. Mg. Inst., vol. xiv, pp. 156-178. 1909.
The Kensington rune stone, and report for the Museum committee. Norwegian-American, Northfield, Minn. 1909.

Possible pre-Glacial human remains in the region of Washington, D. C. Records of the Past. vol. viii, pp. 249-252. 1909.

1910. A diamond drill core section of the Mesabi rocks. II. Microscopic characters. III. Remarks on the foregoing section. Proc. L. Sup. Mg. Inst., vol. xv, pp. 100-141. 1910.

Hennepin at the Falls of St. Anthony. Bull. Minn. Acad. Sci., vol. iv, pp. 380-384. 1910.

Prehistoric aborigines of Minnesota and their migrations. Abstract. Bull. Minn. Acad. Sci., vol. iv, pp. 378-379. 1910.

Extinct Pleistocene mammals of Minnesota. Bull. Minn. Acad. Sci., vol. iv, pp. 412-422; 2 pl. 1910.

The Kensington rune stone. A preliminary report by the Museum Committee of the Minnesota Historical Society. (With bibliography by Mr. Holand.) 66 pp. 8vo; 5 pl. St. Paul. 1910. Also in Minn. Historical Society Collections, vol. xv, pp. 221-286. 1915.

1911. Map of Minnesota, showing the mean annual rainfall and the subsoils.

The iron ore ranges of Minnesota and their differences. Bull. Minn. Acad. Sci., vol. v, pp. 43-68, 24 figs. 1911.

The genesis of certain greensands of Minnesota. Abstract. Science, vol. xxxiii, pp. 462-463. 1911.

A diamond drill core section of the Mesabi rocks. IV. Geological bearing of the foregoing described facts. Proc. L. Sup. Mg. Inst., vol. xvi, pp. 61-69. 1911.

The Aborigines of Minnesota. A report based on the collections of Jacob V. Brower, and on the field surveys of Alfred J. Hill and T. H. Lewis. pp. xiv, 761, 4to; with 36 pl., 26 inserts, and 642 figs. Minn. Hist. Society, St. Paul, 1911.

Were the Outagami of Iroquois origin? Miss. Valley Hist. Assoc., vol. iv, pp. 181-188. 1911.

1912. Progress of opinion as to the origin of the Lake Superior iron ores. Bull. Geol. Soc. Am., vol. 23, pp. 317-328. 1912.

Saponite, thalite, greenalite, greenstone. Bull. Geol. Soc. Am., vol. 23, pp. 329-332. 1912.

Memoir of Christopher Webber Hall. Bull. Geol. Soc. Am., vol. 23, pp. 28-30. 1912.

Paleolithic artifacts from Kansas. Records of the Past. vol. xi, pp. 174-178. 1912.

1913. The weathering of aboriginal stone artifacts; a consideration of the paleoliths of Kansas. Coll. Minn. Hist. Soc., vol. xvi, pt. 1, pp. xiv, 186; 19 pls., 20 figs. 1913.

The age of the Mesabi iron-bearing rocks of Minnesota. Abstract. Science, vol. xxxvii, p. 457. 1913.

1914. The founders of the Academy. Bull. Minn. Acad. Sci., vol. v, pp. 108-116. 1914.

L'homme primitif dans le Kansas. C. R. Congrès Intern. Anthrop. Archéol. Genève, 1914.

The antiquity of man in America compared with Europe. Lecture delivered before the Iowa Academy of Science, April 24, 1914.

Very truly yours
Joseph LeConte

MEMOIR OF JOSEPH LE CONTE [1]

BY HERMAN L. FAIRCHILD

The story of Le Conte's life has been so well told in his autobiography[2] and in memorials[3] published at the time of his death that only a brief outline will be necessary here.

On his father's side he was Huguenot, his ancestors coming to America about 1690. His mother's family was Puritan. Louis, the father of Joseph, was a native of New York and a graduate of Columbia College. He studied medicine "to better care for the slaves on his father's plantation." His home was Woodmanston plantation, Liberty County, Georgia, in a Puritan colony, orthodox and exclusive. Joseph was the fifth child and youngest son. His mother, Anne Quartermain, a Puritan, died when Joseph was three years old, and "he was brought up by his father with the most tender care. The father was a very remarkable man—a good physician, a skillful chemist and naturalist, a great hunter, fond of all manly sports, and a passionate lover of nature. Young Le Conte owed much to his father's training, but he was partly prepared for college by Alexander Stephens." Joseph was born February 26, 1823, and died in Yosemite Valley July 6, 1901.

At the age of 18, young Le Conte graduated at Athens College, and in 1845, at the age of 22, he graduated in medicine in the College of Physicians and Surgeons in New York and began the practice of medicine in his home district in Georgia. In 1847 he married Caroline E. Nisbit.

He found the life of a country physician unsatisfactory, and, becoming interested in osteology, he went to Cambridge, Massachusetts, in 1850, as a pupil of Agassiz. In 1851 he accompanied Agassiz in the latter's study of the Florida coral reefs.

Turning from medicine to natural science, he became, in 1852, Professor of Science at Oglethorpe University, Midway, Georgia, teaching physics, chemistry, and "natural science." After one year at Oglethorpe and five years at his alma mater, Athens, Georgia, he accepted the professorship of Chemistry and Geology at South Carolina College, Columbia, South Carolina, which position he held until the end of the Civil

[1] Soon after the death of Professor Le Conte the preparation of his memoir was undertaken by Dr. W J McGee. The multiplicity of his duties prevented immediate writing and the matter was long delayed, and his illness caused further delay and final failure. Then the change in the Secretaryship of the Society diverted attention from the matter.

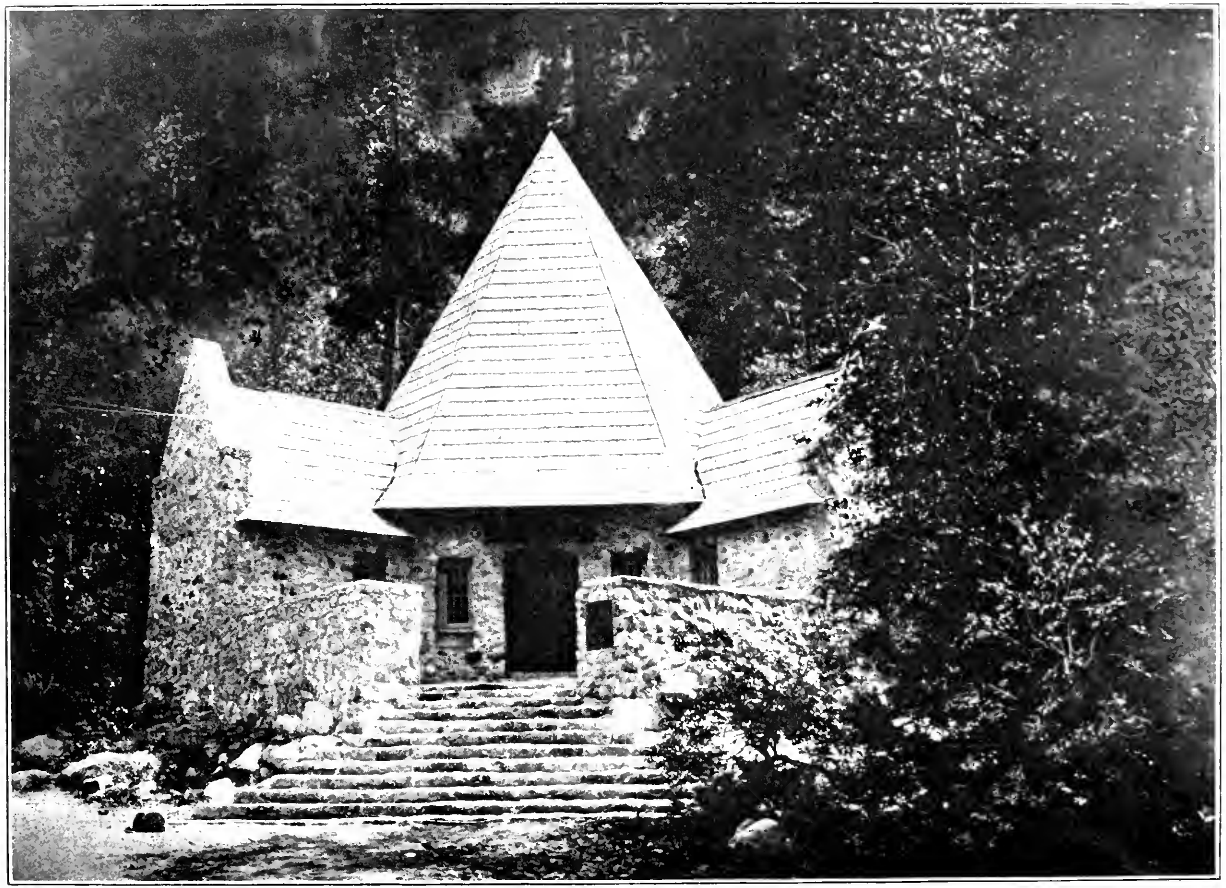
[2] The Autobiography of Joseph Le Conte. D. Appleton & Co. 1903.

[3] The writer is specially indebted to the memoir by S. B. Christy, in the Trans. Am. Inst. Mining Engineers, from which the quoted matter in the present writing is mostly taken.

War. Like many others, he was forced against his judgment and desire to join the forces of secession. He was employed as geologic expert in search for niter deposits and as chemist in the manufacture of medicines and explosives. Probably the most interesting part of his autobiography is that relating to the Civil War, with the story of his experiences during the war and the succeeding period of reconstruction. Becoming discouraged with the conditions in the South, he and his brother John successfully applied for positions in the new University of California, and began work there in 1869, teaching botany, zoology, and geology, without assistance or laboratory appliances.

Le Conte was a fine representative of the older group of eminent geologists who were self-taught and with knowledge in many departments of science. The breadth of his interest is shown by an analysis of his list of writings, which, as given in Christy's memoir, has 211 titles. Excluding repetitions or duplicate publication, the number is about 200. Of these geology includes only 57, philosophy 48, physics (mostly optics) 48, biology and medicine 16, education 10, biography 6, zoology 4, sociology and travel 2 each, and 5 unclassified. A corrected list of his writings in geology is here appended, making 62 titles, not including the revisions of his text-books.

That Le Conte's mind was of the philosophic type rather than the scientific is shown not only by the wide variety and deductive character of his writings, but also by the fact that he is probably better known to the general public through his philosophic essays, chiefly on evolution, than by his geologic work. His Elements of Geology, issued in 1878, was for many years probably the most popular American treatise on the science and gave him his public reputation as a geologist. His favorite theme in geology, origin of the continents and formation of mountains, testifies to the philosophic bent of his mind. One of his first papers, in 1859 (fifth in the appended list), was on continent formation, and his residence after 1869 in California greatly stimulated this line of thought. At least one-third of all the titles in the list falls into geophysics. While he was fond of life in the open and made several trips in the Cordilleras, recording important observations, he was not an enthusiastic field student, and his record of facts of observation is not large. If he had remained during his life in South Carolina, it seems more than possible that his philosophic bent might have kept him from reaching eminence in geology; but, being transplanted to the Cordilleran region, his geologic interest was inevitable. The genesis of the Sierras and diastrophism were attractive subjects for his keen intellect. Concerning his intellectual tastes, he writes in his autobiography (pages 285-286, 287-288):



LE CONTE MEMORIAL LODGE, YOSEMITE VALLEY

"Until I was thirty I could not have said whether my tastes were more in the direction of science or of art or of philosophy. Circumstances turned me mainly in the direction of science, but I could never be a specialist in the narrow sense of the term. My writings and my thoughts, like my education, have been in many directions." . . . "Yet some of my heartiest and most valued friends think that my reputation hereafter will be more philosophic than scientific. It may be so, for even my science is not special in the narrow sense, but is rather a sort of philosophic science, dealing mainly with larger questions. The domains of science and philosophy are not separated by hard and fast lines; they largely overlap; and it is in this border land that I love to dwell."

Any one who may be interested in Le Conte's views on geophysical problems will find them crystallized in the Elements of Geology, and with fuller presentation in three papers: his presidential address before the American Association for the Advancement of Science, at the Madison meeting, 1893;[4] his address as retiring President of this Society, at its eighth summer meeting, at Buffalo, 1896,[5] and in his memoir of Dana.[6]

Like all students of earth science of his and previous time, his geophysical philosophy was founded on the conception of a globe cooling from incandescence. If we abandon the hypothesis of an originally liquid globe, as quite certainly we must, much of the writings of Le Conte and Dana will have only an historic and academic interest; but a brief statement of their views, based on the Laplacian hypothesis, may be of some interest if placed alongside those of Chamberlin, based on the planetesimal hypothesis.

In his presidential address Le Conte recognized four classes of earth-crust movements, in the following order of greatness:

"(1) Those greatest, most extensive, and probably primitive movements by which ocean basins and continental masses were first differentiated and afterward developed to their present condition; (2) Those movements by lateral thrust by which mountain ranges were formed and continued to grow until balanced by exterior erosive forces; (3) Certain movements over large areas, but not continuous in one direction, and therefore not indefinitely cumulative like the two preceding, but oscillatory, first in one direction, then in another, now upward and then downward; (4) Movements by gravitative readjustment, determined by transfer of load from one place to another. . . .

"Of these four kinds and grades of movement the first two are primary and continuous in the same direction, and therefore cumulative, until balanced by leveling agencies. The other two, on the contrary, are not necessarily continuous in the same direction, but oscillatory. They are, moreover, secondary.

[4] Proc. Am. Assoc. Adv. Sci., vol. 42, 1893, pp. 1-27; Jour. Geol., vol. 1, 1893, pp. 542-573.

[5] Bull. Geol. Soc. Am., vol. 8, 1897, pp. 113-126.

[6] Bull. Geol. Soc. Am., vol. 7, 1895, pp. 461-474.

and are imposed on the other two or primary movements as modifying, obscuring, and often completely masking their effects."

According to Dana's conception, the solidification of the globe was first at the center. The investing liquid arranged itself in layers of increasing density downward from the surface to the solid nucleus. Certain areas of the surface became crusted earlier than the general surface. Becoming heavier by solidification than surrounding mass, the solid crust sank, and was replaced by inflow of the lighter superficial fluid, which in turn solidified and sank. The result was to build up from the solid nucleus below a lighter, solid mass that constituted the primitive continent. The less rapidly crusting areas, of denser materials, formed the oceanic areas. (Le Conte's Geological Society address, page 118.) Le Conte's theory did not emphasize the conditions and effects of the superficial crusting as did Dana's, but assumed areal differences in density and conductivity.

"If, then, over some large areas the matter of the earth were denser and more conductive than over other large areas, the former areas, by reason of their greater density alone, would sink below the mean level and form hollows; for even in a solid—much more in a semi-liquid, as the earth was at that time—there must have been static equilibrium (isostasy) between such large areas. This would be the beginning of oceanic basins; but the inequalities from this cause alone would probably be very small but for the concurrence of another and much greater cause, viz., the greater conductivity of the same areas. Conductivity is not, indeed, strictly proportional to density; but in a general way it is so. It is certain, therefore, that the denser areas would be also the more conductive, and therefore the more rapidly cooling and contracting areas. This would increase, and in this case progressively increase the depression of these areas.

"The two causes—density and conductivity, isostasy and contraction—would concur, but the latter would be far the greater, because indefinitely cumulative. The originally evenly spheroidal lithosphere would thus be deformed or distorted, and the distortion, fixed by solidification, would be continually increased until now." (Address, page 116.)

This idea of Dana, that the continental areas were the first to solidify and the oceanic areas subsequently, was accepted by Le Conte and applied in harmony with his own thought as follows:

". . . But a little reflection will show that these two facts, namely, the earlier crusting of the land areas and the more rapid cooling and contraction of the ocean areas, are not inconsistent with one another; for the more conductive and rapidly cooling areas would really be the last to crust, because surface solidification would be delayed by the easy transference of heat from below, while the less conductive land areas would certainly be the first to crust, because the non-conductivity of those areas would prevent the access of heat from below."

The hypothesis assumes sufficient heterogeneity of composition of the globe and unequal density as the causes initiating the greater subsidence of the oceanic areas, and unequal heat conductivity and static equilibrium as the conditions necessary to progressively increase the surface relief. As a corollary to this, it follows that the continental masses and the oceanic depressions are permanent features, as taught by Dana.

The original heterogeneity, in efficient degree, would seem improbable in a rotating globe built from superheated gaseous material commingling and diffusing through long eons of time. This objection Le Conte met by claiming that the efficient differences in density and conductivity were very small and the resultant surface relief of the globe comparatively insignificant. It is impossible to confidently contradict the assumption, but it would seem as if the heterogeneity in a sphere of superheated matter would not be represented by such large unit areas as the present continents and oceans.

According to the planetesimal hypothesis, the planet was slowly built by accretion of cold particles and was always solid and always cold at the surface. Whatever heterogeneity and irregularity of figure was produced by unequal infall of the planetesimals, or by differences in their composition, could not be destroyed by liquid convection and diffusion; but original heterogeneity is not an important factor under this conception. Professor Chamberlin postulates only such slight inequality or small depressions in the surface of the embryo planet as would contain the shallow waters of the primitive ocean. The exposed areas, subjected to weathering processes, became relatively lighter in weight, while the suboceanic areas, by protection from weathering and by concentration, became superior in density. This difference in specific gravity of large areas by epigene processes began when the growing globe was small, probably smaller than the planet Mars, or as soon as it was able to retain its atmosphere and hydrosphere; and the differential density and surface relief has been perpetuated to the present time. Isostatic equilibrium and comparative permanence of the continental masses follows under this hypothesis the same as under the Laplacian.

The contraction of the earth's crust as an effect of interior cooling and shrinkage has been the subject of philosophic discussion since its recognition by Descartes in 1644; but the first description and mapping of extensive folding of strata in actual demonstration of great horizontal compression was by the Rogers brothers, about 1840, in their Appalachian sections in Virginia and Pennsylvania. American geologists, and particularly Dana and Le Conte, were such active supporters of the contractional theory of mountain formation that it has sometimes been called the American theory. As a topic of geologic philosophy, dealing with such vast elements of force, time, and mass, it was naturally attractive to Le Conte, and formed the subject of his important official addresses. While he perhaps did not add any original element to the theory, he gave such clear analysis and attractive presentation of the arguments for genesis of mountains by compression of areas, weakened by thick sedimentation, that he must stand with Dana as a chief expounder.

We now accept as fact the horizontal crushing of thick strata in the production of the great mountains, but the efficient cause of extensive compression is still a subject of study. Under the Laplacian hypothesis the primary cause is the cooling of the superheated interior; but, according to physical laws and mathematical calculations, the radial contraction produced by any possible loss of heat since Cambrian time can account for only a very small part of the superficial shortening. The amount of contraction of the circumference of the globe in 100,000,000 years, due to the greatest cooling thought possible, is about 10 miles, which is less than the amount of compression represented by any one of the great mountain systems. The circumferential shortening on any great circle of the globe since Cambrian time can not be less than 100 miles.

Under the planetesimal hypothesis the shrinkage of the planet is due to increase of density.

> "The heat of the earth is supposed to have been developed chiefly by reduction of volume and by radio-activity, and the heat thus developed is one of the forces which check further decrease of volume. Loss of heat is, of course, a cause of shrinkage, but its effect is thought to be less than that of molecular and sub-molecular rearrangements of the material of the earth, resulting in greater density. The loss indeed may not be greater than the new heat generated in the shrinkage." [7]

It is estimated that to produce the circumferential shortening of 100 miles would require a radial shortening of 16 miles.[8] This seems impossible from mere loss of heat during recorded geologic time, but possible by condensation of a porous globe built up by infall of cold matter. As the hydrosphere and atmosphere are chiefly matter expelled from the earth's interior, they represent reduction of volume, and some reduction during post-Cambrian time may be credited to that cause.

Concerning oscillatory or diastrophic movements, Le Conte, after giving the proofs of such great down-and-up movements in certain areas, like the Colorado plateau, wrote as follows:

> "It must be confessed that the cause of these oscillatory movements is the most inexplicable problem in geology. Not the slightest glimmer of light has

[7] Chamberlin and Salisbury's Introductory Geology, p. 225.
[8] The same, p. 224.

yet been shed on it. I bring forward the problem here, not to solve it, for I confess my inability, but to differentiate it from other problems, and especially to draw attention to these movements as modifying the effects of movements of the first kind, and often so greatly modifying them as to obscure the principle of the permanency of oceanic basins and continental areas, and even to cause many to deny its truth. Nearly all the changes in physical geography in geological times, with their consequent changes in climate and in the character and distribution of organic forms—in fact, nearly all the details of the history of the earth—have been determined by these oscillatory movements; . . ."[9]

This phenomenon still awaits satisfactory analysis and solution, but is better explained under the planetesimal hypothesis, since this admits of much greater contraction of the globe and of consequent crowding and crushing of the small continental segments between the larger oceanic segments, with consequent warping and buckling of large surface areas, specially along the continental margins, under pressures varying in direction and degree.

In his autobiography Le Conte has given his own estimate of his contribution to the world of thought. He seemed to take the most pride in his writings on evolution. His best original work was probably in optics. Concerning geology, we give his own words:

"In geology, I believe some real substantial advance in science was made in my series of papers: (1) on the structure and origin of mountain ranges; (2) on the genesis of metalliferous veins; (3) especially in that on critical periods in the history of the earth; (4) on the demonstration of the Ozarkian, or better, the Sierran epoch, as one of great importance in the history of the earth. I might mention several others that I believe are of prime importance, but I am willing to stand by these."

A suitable close for this memoir is the fine tribute by Professor Chamberlin.[10]

"With the death of Dr. Joseph Le Conte there has passed away perhaps the last distinguished representative of the general geologist as typified during the past century. This passing type of the general geologist was a distinctive outgrowth and representative of a transitional stage of intellectual procedure—a passage from the former mode in which the generalizing and philosophical factors held precedence and the toilsome modes of scientific verification followed as their servitors, to the present or at least the coming method in which scientific determinations are the basal factors to which generalizations and philosophies are but dependent accessories. We owe much of the transition itself to Dana and Le Conte, the two noblest American representatives of the passing type, for while they grew up under the influence of the older intellectual attitude, they grew out of it in spirit while they steadied and guided

[9] Bull. Geol. Soc. Am., vol. 8, p. 122.
[10] Editorial in Journal of Geology, vol. 9, 1901, pp. 139-140.

the transition. They were distinctively students of geology in the special sense in which that term implies the organized *doctrine* of the earth, rather than students of what might be termed *geics*, the immediate study of the earth itself in the field and laboratory. They were preeminently students of the accumulated data and of the literature of the science, with generalization and philosophic inference as their dominant inspiration. Neither Dana nor Le Conte were eminently field students; much less were they specialists in a chosen field of the broad geological domain. Their point of view was that of the organizer and of the philosopher, and the contribution they made in their chosen sphere was indispensable and immeasurably valuable. . . . None the less, the philosophical factors and the philosophical point of view are indispensable if the science is to make its most wholesome progress, and we owe to Le Conte and to those he typifies an immeasurable debt, for they have kept us in fresh touch with the generalizations and the philosophy of the science, and have inspired us with their own contributions to the broader conceptions of geology and of its relation to kindred sciences. The writings of Le Conte are graced by the fruits of wide learning, a lucid style, a genial attitude, and a candor that has called forth universal love and admiration."

On the platform Le Conte was a picturesque figure. His French descent was evident in his vivacious and somewhat emotional manner, with a high-pitched but clear and resonant voice, modulated to every phase of his theme. In both speech and writings he had naïveté, with self-confidence, but without self-conceit. Had he chosen the pulpit or politics or the stage as his profession, he would undoubtedly have become famous in either calling. He was universally admired and loved. To his students he was "Professor Jo." The Le Conte Memorial Lodge (plate 6), built by the Sierra Club at the foot of Glacier Point, near where he died, is a monument to his memory and a testimony of high regard. The story of his active life may be read in his autobiography, ". . . written with all the frankness of the Confessions of Rousseau, it depicts a noble character without a trace of morbid self-consciousness, breathes a high philosophic spirit, and is enlivened with a fine sense of humor."

BIBLIOGRAPHY[1]

1853. Salt lakes. Ga. Univ. Mag. April, 1853.
1857. On the agency of the Gulf Stream in the formation of the peninsula of Florida. Am. Assoc. Adv. Sci., Proc., vol. 10, pt. 2, pp. 103-119; Am. Jour. Sci. (2), vol. 23, pp. 46-60.
Geology in a course of education. Inaugural address at S. C. College.
1858. Three lectures on coal. Smith. Inst. Rept. for 1857, pp. 119-168.
1859. Theory of formation of continents. Canadian Nat., vol. 4, p. 293.
1872. A theory of the formation of the great features of the earth's surface. Am. Jour. Sci. (3), vol. 4, pp. 345-355, 460-472.

[1] This is a list of only his geologic writings.—H. L. F.

1873. On some of the ancient glaciers of the Sierras. Am. Jour. Sci. (3), vol. 5, pp. 325-342; Cal. Acad. Sci., Proc., vol. 4, pp. 259-262.

On the formation of the features of the earth's surface. Reply to criticisms of T. Sterry Hunt. Am. Jour. Sci. (3), vol. 5, pp. 448-453.

1874. On the great lava flood of the west and on the structure and age of the Cascade Mountains. Am. Jour. Sci. (3), vol. 7, pp. 167-180, 259-267; Cal. Acad. Sci., Proc., vol. 5, pp. 214-220.

1875. On some of the ancient glaciers of the Sierras. Am. Jour. Sci. (3), vol. 10, pp. 126-139; Cal. Acad. Sci., Proc., vol. 6, pp. 38-48.

Geology of New Mexico, Remarks on. Phila. Acad. Sci., Proc., vol. 27, pp. 267-268.

1876. On the evidences of horizontal crushing in the formation of the coast range of California. Am. Jour. Sci. (3), vol. 11, pp. 297-304.

1877. On the critical periods in the history of the earth and their relation to evolution: on the Quaternary as such a period. Am. Nat., vol. 11, pp. 540-557; Kansas City Review, vol. 1, pp. 477-483, 522-530; Am. Jour. Sci. (3), vol. 14, pp. 99-114.

Prairie mounds. Nature, vol. 15, pp. 530-531.

1878. Elements of geology. A text-book for colleges and for the general reader. xiii + 588 pp. 8°. New York. Fourth edition. 1896.

Geological climate and geological time. Nature, vol. 18, pp. 668.

On the structure and origin of mountains, with special reference to recent objections to the contractional theory. Am. Jour. Sci. (3), vol. 16, pp. 95-112.

1879. On the extinct volcanoes about Lake Mono and their relation to the glacial drift. Am. Jour. Sci. (3), vol. 18, pp. 35-44.

1880. Coral reefs and islands. Nature, vol. 22, pp. 558-559.

The old river beds of California. Am. Jour. Sci. (3), vol. 19, pp. 176-190.

1881. Geology of California, in Phelps, A. Contemp. Biog., vol. 1, p. 290.

1882. Rate of denudation. Geol. Mag., vol. 9, p. 289.

Origin of jointed structure in undisturbed clay and marl deposits. Am. Jour. Sci. (3), vol. 23, pp. 233-234.

Judd on volcanoes, Notice of. Californian, vol. 5, p. 85.

The phenomena of mineral vein formation now in progress at Sulphur Bank, California, with W. B. Rising. Am. Jour. Sci. (3), vol. 24, pp. 23-33.

1883. Carson foot-prints. Cal. Acad. Sci., Bull. (?). Nature, vol. 28, pp. 101-102.

On the mineral vein formation now in progress at Steamboat Springs compared with the same at Sulphur Bank. Am. Jour. Sci. (3), vol. 25, pp. 424-428.

Genesis of metalliferous veins. Am. Jour. Sci. (3), vol. 26, pp. 1-19.

The reefs, keys, and peninsula of Florida. Science, vol. 2, p. 764.

Continent formation. Geol. Mag., vol. 10 (II), pp. 523-524.

1884. A compend of geology. 399 pp. 12°. New York.

Elevation and subsidence of earth crust. Nature, vol. 29, pp. 212-213.

The U. S. Geological Survey: review of the second and third reports. Science, vol. 4, pp. 62-71.

1885. Earthquake shocks more violent on the surface than in mines. Science, vol. 6, pp. 540.

Review of "Paradise Found." Science, vol. 5, pp. 406-407.

1886. On the permanence of continents and ocean basins, with special reference to the formation and development of the North American continent. Geol. Mag., vol. 3 (3), pp. 97-101.

Post-Tertiary elevation of the Sierra Nevada, shown by the river beds. Am. Jour. Sci. (3), vol. 32, pp. 167-181.

The development of the North American continent. Geol. Mag., vol. 3 (3), pp. 287-288.

1887. Determination of the depth of earthquakes. Science, vol. 10, pp. 22-24.

The flora of the coast islands of California in relation to recent changes of physical geography. Am. Jour. Sci. (3), vol. 34, pp. 457-460; Cal. Acad. Sci., Bull., vol. 2, pp. 515-520; Am. Geol., vol. 1, pp. 76-81.

1888. Mountain formation. Letter to the Philos. Mag., vol. 25, pp. 450-451.

Glacial motion. Letter to the Philos. Mag., vol. 25, p. 452.

Nomenclature, etc., of eruptives, . . . life of the Archean, and on the nomenclature of the Lower Paleozoic. Inter. Geol. Cong., Am. Committee Reports, 1888, A, pp. 55-57.

On nomenclature of Cenozoic formations. Inter. Geol. Cong., Am. Committee Reports, 1888, F, pp. 17-18; Am. Geol., vol. 2, pp. 283-284.

On the use of the term "Taconic." Inter. Geol. Cong., Am. Committee Reports, 1888, B, p. 17; Am. Geol., vol. 2, p. 207.

1889. The general interior condition of the earth. Am. Geol., vol. 4, pp. 38-44.

On the origin of normal faults and of the structure of the basin range. Am. Jour. Sci. (3), vol. 38, pp. 257-263.

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. Bull. Geol. Soc. Am., vol. 2, pp. 323-330.

Address of welcome to the International Geological Congress, at Washington, D. C., 1891. Inter. Geol. Cong., Compte Rendu, 1893, pp. 53-56.

1893. Theories of the origin of mountain ranges. Am. Assoc. Adv. Sci., Proc., vol. 42, pp. 1-27; Jour. Geol., vol. 1, pp. 542-573; Sci. Am. Suppl., vol. 36, pp. 14768-14769, 14776-14778.

1895. The genesis of ore deposits. (Discussion of paper by F. Posepny.) Am. Inst. Min. Eng., Trans., vol. 24, pp. 996-1006.

Causes of the Gulf Stream. Science, vol. 2, pp. 188-189.

Critical periods in the history of the earth. Univ. of Cal., Dept. Geol. Bull., vol. 1, pp. 313-336; Am. Geol., vol. 16, pp. 317-318.

Review of Dana's Manual of Geology. Science, vol. 1, pp. 548-550.

Memoir of James D. Dana. Bull. Geol. Soc. Am., vol. 7, pp. 461-474.

1897. Earth-crust movements and their causes. Bull. Geol. Soc. Am., vol. 8, pp. 113-126; Science, vol. 5, pp. 321-330.

1898. Contribution to "a symposium on the classification and nomenclature of geologic time divisions." Jour. Geol., vol. 6, pp. 337-338.

The origin of transverse mountain valleys and some glacial phenomena in those of the Sierra Nevada. Univ. Chronicle, vol. 1, pp. 479-497.

1899. The Ozarkian and its significance in theoretical geology. Jour. Geol., vol. 7, pp. 525-544.

1900. A century of geology. Pop. Sci. Month., vol. 56, pp. 431-443, 546-556; Smith. Inst. Ann. Rept. for 1900, pp. 265-287.

Journal of ramblings in the high Sierra. Sierra Club. Bull., vol. 3, pp. (?).

An early geological excursion. Science, vol. 11, p. 221.

The reports of committees were then called for. These were submitted as follows:

REPORT OF THE COMMITTEE ON PHOTOGRAPHS

Our collection of photographs is now stored in my office in the U. S. Geological Survey, where it is convenient for access. No new material has been received for many years, and of late it has not been utilized to any great extent.

N. H. Darton,
Committee.

REPORT OF THE COMMITTEE ON GEOLOGICAL NOMENCLATURE

The Secretary, Arthur Keith, reported that no communications regarding names for geological formations had been received by the committee during the year, and that the committee asked to be discharged, inasmuch as for several years there had been no communications addressed to it.

On motion, this report was accepted and the committee was discontinued.

On motion, the Secretary was instructed to send a telegram of sympathy in his illness to President Becker.[1]

After listening to several announcements regarding the program for the meeting, the Society proceeded to the consideration of scientific papers.

---

[1] The following telegram was sent:

Geological Society directs me to send you its cordial greetings and its regrets that illness prevents your presence at its twenty-seventh annual meeting.

(Signed) Edmund Otis Hovey,
Secretary.

On Wednesday the following reply was received by letter:

Dear Mr. Secretary: I am grateful to the Geological Society for its sympathetic good wishes. Fortunately I feel sure of the success of the meeting, much as I should have liked an opportunity to contribute to it.

Cordially yours,

(Signed) George F. Becker,
President.

TITLES AND ABSTRACTS OF PAPERS PRESENTED IN GENERAL SESSION AND DISCUSSIONS THEREON

RELATION OF BACTERIA TO DEPOSITION OF CALCIUM CARBONATE

BY KARL F. KELLERMAN [1]

(Abstract)

At the suggestion of Dr. T. Wayland Vaughan, bacterial studies of water and bottom mud from the Great Salt Lake and sea-water and bottom deposits from the vicinity of Florida and the Bahamas were undertaken in the hope of supplementing the work of Vaughan,[2] of Drew,[3] and of Dole[4] in regard to the probable agencies concerned in the precipitation of calcium carbonate and the formation of oolites.

It has been possible to form calcium carbonate by the action of bacteria on various soluble salts of calcium, both in natural waters and in synthetic mixtures. The most important natural precipitation is probably the transformation of calcium carbonate by the combined action of ammonia, produced by bacteria either by the denitrification of nitrates or by the fermentation of protein, together with carbon dioxide, produced either by the respiration of large organisms or the fermentation of carbohydrates by bacteria. Both ordinary crystals of calcium carbonate and oolites may be produced by the growth of mixed cultures of bacteria, either in salt or fresh water. The zonal structure of the oolites of bacterial origin and of those found in nature in oolitic deposits appears to be exactly the same; undoubtedly this shows the similarity of the processes of their origin.

Read in full from manuscript.

CORAL REEFS AND REEF CORALS OF THE SOUTHEASTERN UNITED STATES, THEIR GEOLOGIC HISTORY AND SIGNIFICANCE

BY THOMAS WAYLAND VAUGHAN

(Abstract)

After briefly alluding to some of the more recent publications on coral reefs, the author stated what in his opinion were the necessary lines of investigation in order to understand the ecologic factors influencing coral-reef development, the constructional rôle of corals and other agents, and the series of geologic events which preceded any particular coral-reef development. The geologic history of the extensive coral reefs of the southeastern United States and near-by West Indian islands, which have been the subject of investigation for a number of years, was outlined, and the bearing they have on the theory of coral-reef formation was indicated.

The author stated his conclusions regarding the Florida coral reefs as fol-

[1] Introduced by T. Wayland Vaughan.

[2] T. W. Vaughan: Bull. Geol. Soc. Am., vol. 25, No. 1, p. 59. March, 1914. Also Publication No. 182, Carnegie Inst. of Washington, pp. 49-67.

[3] G. H. Drew: Publication No. 182, Carnegie Inst. of Washington, pp. 1-45.

[4] R. B. Dole: Publication No. 182, Carnegie Inst. of Washington, pp. 69-78.

lows: (1) Corals have played a subordinate part, usually a negligible part, in the building of the Floridian plateau; (2) every conspicuous development of coral reefs or reef corals took place during subsidence; (3) in every instance the coral reefs or reef corals have developed on platform basements which owe their origin to geologic agencies other than those dependent on the presence of corals.

The older Tertiary reefs and reef corals of Saint Bartholomew, Antigua, and Anguilla all grew on subsiding basements. The relatively small proportion of the contribution by corals to calcareous sediments in Florida, the Bahamas, and the West Indies was shown.

It was shown that the Floridian plateau was similar in configuration to the Mosquito bank off Nicaragua, to Campeche bank off Yucatan, and to Georges bank off Massachusetts; the east side of the Floridian plateau is similar to the continental shelf off Cape Hatteras. The platform which supports the reef along the east coast of Florida extends beyond the reef limits northward of Fowey Rock. The reef platform of the Great Barrier Reef of Australia is similar to the continental shelf of eastern North and Central America, and it continues south of the reef limits. Rosalind Bank, Caribbean Sea, was compared with Rangiroa, Paumotus, which is similar in essential features. The complex history of the coral-reef foundations in Florida, Antigua, Saint Martin, Anguilla, and Bermuda was described, and it was stated that the formation of the platforms could not be referred solely to Pleistocene time.

Attention was directed to the facts that around the Island of Saba, in which volcanic activity has so recently ceased that the crater is still preserved, there was scarcely any platform at all; that in the case of the young but slightly older volcanic island of Saint Kitts, the platform was narrow, while the geologically much older islands standing above the Antigua-Barbuda bank, the Saint Martin plateau, and the Virgin bank rise above platforms which are miles across and have an area many times greater than that of the present land surfaces. Width of platform is therefore indicative not of the amount of submergence, but of the stage attained by planation processes.

The conclusions were summarized as follows:

1. Critical investigations of corals as constructional geologic agents are bringing constantly increasing proof that they are not so important as was long believed, and that many of the phenomena formerly attributed to them must be accounted for by other agencies. Here it should be emphasized that the ecology of probably no other group of marine organisms is known nearly so thoroughly as that of corals.

2. All known modern offshore reefs which have been investigated grow on platforms which have been submerged in Recent geologic time.

3. No evidence has as yet been presented to show that any barrier reef began to form as a fringing reef on a sloping shore and was converted into a barrier by subsidence; but it is clear that many, if not all, barrier reefs stand on marginal platforms which already existed previous to Recent submergence and the formation of the modern reefs.

4. Study of the geologic history of coral-reef platforms has established that there were platforms in early Tertiary time on the site of many of the present-day platforms, and evidence has not as yet been adduced to prove long-continued, uninterrupted subsidence in any coral-reef area. There have been many oscillations of sealevel and Recent submergence is probably complicated

in many areas by differential crustal movement concomitant with increase in volume of oceanic water through deglaciation.

5. The width of a submerged platform bordering a land area is indicative not of the amount of submergence, but of the stage attained by planation processes. Other conditions being similar, the longer the period of activity of such processes, the wider will be the platform.

6. The principal value of the coral-reef investigation to geology consists not so much in what has been found out about corals as in the study of a complex of geologic phenomena, among which coral reefs are only a conspicuous incident.

Read in abstract from manuscript.

DISCUSSION

Dr. WAYLAND T. VAUGHAN, in reply to the question of Doctor Pilsbry as to the significance of the Funa Futi boring, stated that, because of inadequate knowledge of the stratigraphic distribution of the organisms encountered in the bore hole, the geologic age of the formation penetrated could not now be determined. He also stated that there were certain features of Funa Futi which indicated that there had probably been oscillations of sealevel.

Prof. A. W. GRABAU: Louis Agassiz in one of his early letters speaks of the importance of coralline algæ in the formation of reefs at Florida. He considered the nullipores more important than the corals in this connection.

Doctor VAUGHAN, in reply to Professor Grabau's remarks concerning the constructional rôle of coralline algæ along the Florida reef, stated that the coralline algæ, in his opinion, were subordinate in importance to corals, although they contribute relatively large amounts of calcium carbonate to the sea-bottom along the reef tract. In the shoal waters of southern Florida and the Bahamas bacteria are the most important agency whereby calcium carbonate is taken from the sea-water. The others, rated according to importance, are probably (1) foraminifera, (2) mollusks, (3) corals, and (4) coralline algæ.

CAUSES PRODUCING SCRATCHED, IMPRESSED, FRACTURED, AND RECEMENTED PEBBLES IN ANCIENT CONGLOMERATES

BY JOHN M. CLARKE

(Abstract)

The Devonian conglomerate lying beneath the fish-beds of Migonasha, Province of Quebec, is a characteristic "Nagelfluh" filled with scratched, fractured, and deeply impressed pebbles. Specimens exhibited indicate that the explanation of the phenomena of impression by solution, as suggested by Sorby, Heim, Kayser, and others, is inadequate, and that the effects described are in large part actually due to forcible contact resulting from internal friction. Some of the pebbles show unqualified evidence of glacial scratching, and the entire mass is regarded as an outwash from glacial moraine.

Presented in full from manuscript.

DISCUSSION

Dr. A. W. GRABAU: The last illustration shown resembles very closely the Nagelfluh of Salzburg—a fluvio-glacial deposit of late Pleistocene origin—and Doctor Clarke's comparison of these Devonic deposits with the Nagelfluh seems a very happy one. I would ask Doctor Clarke if indications of chatter marks, such as are common on the pebbles of the Old Red, are found in the pebbles of the Scaumenac region.

Doctor CLARKE replied that he did not think chatter marks were evident on these blocks.

The Society adjourned about 12.20 o'clock and reconvened in sections at 2.30 o'clock.

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE FIRST SECTION AND DISCUSSIONS THEREON

The first section met, with Vice-President Horace B. Patton as presiding officer and E. O. Hovey as Secretary, and took up the papers entered in the printed program under Group A: Dynamic, Structural, Glacial. Physiographic.

ORIGIN OF THE RED BEDS OF WESTERN WYOMING

BY E. B. BRANSON

(*Abstract*)

The Red Beds of western Wyoming are about 1,400 feet in thickness along the western outcrops and thin eastward. Eight hundred and ninety feet from the bottom they contain a formation, 40 to 60 feet thick, which is plainly of subaerial origin. Some 200 feet above this a highly cross-bedded sandstone about 60 feet thick seems to have originated from wind-blown materials. Near the top are extensive beds of gypsum up to 40 or 50 feet in thickness. All of the Red Beds in western Wyoming, excepting the subaerial formations above mentioned, seem to have been marine in origin, the evidence being: wide-spread deposition of gypsum, beds of sandstone of uniform thickness composed of uniform materials extending over wide areas, and with wide-spread ripple-markings on horizontal surfaces. The gypsum can not be a deposit from fresh water in inland basins, because no other carbonates are deposited or occur with the gypsum, because of the rarity of sedimentary impurities, because of the absence of sodium chloride and other salts, because of the excessive time required for deposition. There are no evidences of erosion of the near-lying rocks during the time when the gypsum was being deposited.

Read in full from manuscript.

DISCUSSION

Prof. A. W. GRABAU: I would question the interpretation of any part of the Red Beds as of marine origin. The absence of positive indications of subaerial origin, such as mud cracks, cross-bedding, etcetera, is not necessary evidence against the continental origin of such deposit. They may be river floodplains or playa deposits. The absence of marine organisms is far more significant.

Doctor BRANSON replied: When the deposition of the Red Beds began waters were probably already highly concentrated and unfavorable for life, and the increasing salinity of the waters may have soon rendered the interior seas uninhabitable for most forms of life, and on this account fossils would be few or entirely lacking in the deposits. That such increasing salinity came about is evidenced by the increase of lime in the sandstone from the bottom toward the top, by the limestone deposits at the 800-foot level, and by the gypsum deposits near the top.

Prof. H. E. Gregory took the chair at 2.55 o'clock.

NEW POINTS ON THE ORIGIN OF DOLOMITES

BY FRANCIS M. VAN TUYL [1]

(*Abstract*)

A careful study of the dolomites of the upper Mississippi Valley was undertaken for the Iowa Geological Survey during the field season of 1912. More recently a grant from the Esther Herrman Research Fund of the New York Academy of Sciences has made possible much more extensive studies of the dolomitic limestones of the Eastern and Central States. The present preliminary paper is intended merely to set forth some of the more important results of these studies.

Existing theories of the origin of dolomite were briefly considered, after which the problem was attacked from three standpoints, namely, the experimental evidence, the field evidence, and the petrographic evidence. The conclusion was reached that the great majority of the dolomites, ranging in age from the Cambrian to the present, have resulted from the replacement of limestones before they emerged from the sea. The replacement need not be accompanied by shrinkage, as formerly supposed, but may proceed according to the law of equal volumes, as enunciated by Lindgren. Furthermore, certain cases of apparent inter-stratification of limestone and dolomite cited as evidence in favor of some primary theory are rather pseudo-inter-stratifications, which have resulted from selective dolomitization. Examples of limestones mottled with dolomite were interpreted as representing an incipient stage in the process of alteration. Organic factors have exerted a selective influence in some cases of mottling, but in others the phenomenon is purely inorganic.

Read in full from manuscript.

[1] Introduced by Stuart Weller.

RANGE AND RHYTHMIC ACTION OF SAND-BLAST EROSION FROM STUDIES IN THE LIBYAN DESERT

BY WILLIAM H. HOBBS

(*Abstract*)

Although rock debris of a coarseness usually designated as sand is during sand storms elevated by the wind to considerable though as yet undetermined heights, there is evidence that the effective action of the sand-blast is limited to a zone extending from the surface to a height of a few feet only. It is this limited range which explains the characteristic mushroom rocks as well as the unsymmetrical low ridges, with steep windward and flat leeward slopes, which are found in many desert regions. Within the zone of effective action of the blast the air is given a rhythmic motion which accounts not only for the ripple-marks of dunes, but for a peculiar "ruffling" of the polished rock surface strikingly similar to the ruffled surface of a billow of water.

Presented by title in the absence of the author.

CORRASIVE EFFICIENCY OF NATURAL SAND-BLAST

BY CHARLES KEYES

(*Abstract*)

In the analysis of the effects of the erosive processes under the stimulus of aridity sharp distinctions are to be drawn between those products which are the result of weathering alone, those which are due to the transportative capacities of the winds, and those which are strictly corrasive in character or originate through natural sand-blast action.

The potency of natural sand-blast action is rendered particularly impressive by recent engineering difficulties imposed by blowing sands that in various parts of the world have had to be overcome. Since man has now entered vigorously and successfully on the conquest of the desert, which occupies more than one-fifth of the entire land surface of the globe, these difficulties in the arid regions multiply amazingly. The precautions taken to master them have an important geologic bearing.

As is well known, the small sand-jet driven by compressed air is one of the most efficient abrading tools at the service of man. In nature, also, there is a near approach to the artificial sand-blast in the action of the rapidly propelled sands of the desert. The extent of this action in arid lands attracts small attention until it begins to interfere with human plans and works. Any geological effects that the power may have are largely obscured until, by the elimination of the influences of the attendant powers, it is possible to quantitatively measure them.

When attention is particularly directed to the phenomenon, the abrading effect of wind-blown sands, especially in arid regions, is shown in many ways. Glass windows of houses on the windward side of sand wastes soon lose their transparency by the constant play of the sands against them. The rapidity with which the process takes place is indicated by the lantern lenses of lighthouses being rendered useless by the action of wind-driven sands during a single gale. When carefully examined, the exposed sides of the irons of desert railways are often found to be roughened and etched by continuous impinging sands. Short lengths of steel rail set for clearance posts in similar situations are frequently distinctly girdled just above the ground and brightly polished.

In the arid regions of Arizona and New Mexico telegraph wires and electric transmission cables are kept bright by the blown dusts. As noted by J. Walther, the telegraph wires of the Trans-Caspian railways have to be replaced about every decade because of the driven-sand action, which in that time reduces the size of the wires to one-fourth of the original. Railway service on the Sahara and other deserts meets with great obstacles due to the frequent terrific sandstorms. One of these difficulties is sought to be overcome by the replacement by spoked wheels of all solid wheels, because the latter under the incessant sand-blast are found to wear so thin within a year's time as to be unfit for further use.

The destructive effects of blown sands on buildings is noted by many observers. Wind corrasion of Heidelberg castle is often referred to. Injury to building stones in cities by blown sand is especially discussed by T. Egleston, who also calls attention to the fact of the gradual effacement of inscriptions on city tombstones by dust blown from the street. The great obelisk at Heliopolis, near Cairo, displays blown dust or sand effects by the complete obliteration of the deeply cut hieroglyphics on the south and west faces—the sides directed toward the prevailing winds off the Libyan Desert. Many Egyptian monuments are, according to W. M. F. Petrie, badly injured by abrasion due to wind-driven sands.

From a strictly geological angle the experimental aspects of sand-blast action are especially considered in a number of recently published papers. My own experiments were undertaken more for the purpose of establishing a rate of abrasion than of merely establishing the fact. Bottles, panes of glass, and rocks were exposed in situations where strong winds were driving the desert sands over the surface of the ground. One wine bottle planted in the soil, with top and bottom protected by cloth and an inch-wide band left in the middle, was forgotten for nearly two years. Chancing to come across it at the end of that period, it was found that the exposed band was entirely etched through the glass for a distance of one-third of the circumference of the bottle. Panes of glass covered with paraffine figures presented ground surfaces, wherever the wax was absent, that were distinctly visible after single severe sandstorms. Hard, homogeneous and fine-grained rock faces were quickly polished, while coarse-grained granitic rocks were unevenly etched, the quartz grains standing out in bold relief.

From the consideration of the local phenomena as mentioned, and the production of faceted pebbles, sapped bounders, undermined cliffs, and the accentuations of geologic structures, passage is made to some of the broader aspects of the formation by the same means of the positive features of relief which characterize desert regions—the production of cliff-lines, the origin of canyon reentrants, the growth of desert escarpments, the genesis of plateau plains, and the girdling of the desert ranges.

The rate of general sand-blast corrasion in arid lands is regarded as more rapid than that of general stream corrasion in humid countries. In addition, there are to be taken into account, in the consideration of the regional degradation of desert tracts, both the effects of insulation and of deflation.

Presented by title in the absence of the author.

FALSE FAULT-SCARPS OF DESERT RANGES

BY CHARLES KEYES

(Abstract)

Many of the conspicuous scarps bounding the mountain ridges of arid lands prove not to be features of faulting, as commonly supposed, nor to have any relationships with dislocations of any kind. When the major fault-lines of some of these mountain blocks are finally located, they are found usually to be not at the foot of the orographic slopes, but miles out on the adjacent plains. Although Dr. J. E. Spurr's recent statement that no one has ever seen such fault-planes among the Great Basin ranges may be too sweeping in character, it appears to be nevertheless a fact that the majority of the recorded cases require rigid verification before their accuracy may pass unchallenged.

In the case of certain desert ranges, as that of Fra Cristobel, an exceptionally rugged block of tilted limestones in central New Mexico, the scarplike face which rises out of the general plain of the Jornada del Muerto, is 500 feet high, but it is situated on the side of the mountain from which the strata strongly dip. In other instances the mountain ridges present the so-called fault-scarps on the side where the dips are into the mountain. Because of the fact that the blocks are apparently upraised more on this side, and thus tilted, the usual inference that there must be faulting to account for the phenomenon is not always correct. In still other cases, as the well known Sierra de los Caballos, the mountain ridge is bounded on both sides by notable scarp-faces. Finally, mountain blocks are not infrequently completely girdled.

The unbroken mountain block, which is oftentimes three to five times the width of the present mountain base, is found to be cut back on a level with the general plains surface in the same way that on an exposed shore of the ocean a great sea-cliff is formed.

This distinctly girdled belt appears to mark the zone of maximum lateral deflation. Varying hardness of the rocks, their diverse attitudes, and their relative arrangement or alternation seem to offer little resistance to the uniform extension of the surrounding plains. By means of the continual grinding action of moving or wind-driven sands, constant flaking of soilless rock surfaces, and deflation of comminuted rock-waste there appears to be, where plain and mountain meet, a narrow zone, just above the sloping surface of the former, where the destruction of the positive features of landscape goes on much faster than anywhere else.

At the base of the mountains the remarkable truncation of the transverse ribs, which is so characteristic of so many of the desert ranges, is believed to be not evidence of the existence of noteworthy faulting, as is so generally assumed to be the case, but a result of the sharp contest between wind and water to master the local features of land sculpturing.

Presented by title in the absence of the author.

STRATIGRAPHIC DISTURBANCE THROUGH THE OHIO VALLEY RUNNING FROM THE APPALACHIAN PLATEAU IN PENNSYLVANIA TO THE OZARK MOUNTAINS IN MISSOURI

BY JAMES H. GARDNER

(Abstract)

A line of disturbance in the earth's strata, which at some points consists of an anticline and at others of a fault zone, runs from Pennsylvania through the Ohio Valley to Missouri. Beginning as the Chestnut Ridge anticline in the Appalachian Plateau of Pennsylvania, it passes through West Virginia as the Chestnut Ridge and Warfield anticline, through Kentucky as the Cannel City-Campton-Irvine anticline, Kentucky River and Dividing Ridge fault, and Rough Creek uplift; thence across southern Illinois as the Shawneetown fault and Bald Hill uplift, crossing the Mississippi River to the Ozark arch. It lies south of the Ohio River and roughly parallels it, cutting across the Cincinnati geanticline in Kentucky. At three points along near its course there are known intrusions of peridotite dikes, namely, in Fayette County, Pennsylvania; Elliott County, Kentucky, and the west Kentucky-Illinois fluorspar district. This structural zone is now known throughout a distance of 560 miles.

Presented by title in the absence of the author.

PRELIMINARY PAPER ON RECENT CRUSTAL MOVEMENTS IN THE LAKE ERIE REGION

BY CHARLES E. DECKER[1]

(Abstract)

In northeastern Ohio and in the northwestern parts of Pennsylvania and New York there are numerous folds and faults exposed in the valleys of streams tributary to Lake Erie and in the lake cliffs. The purpose of the present study was to determine the extent, age, distribution, and significance of these movements.

Two points had already been brought out by this study. First, many of these movements have taken place in recent geological time. Second, while the area affected has not been completely outlined, the rocks of this area have suffered deformation in a manner not duplicated in the rocks of adjacent glaciated areas.

Evidence of recency was produced to show that many of the crustal movements are not only postglacial, but that they are later than the terraces and floodplains of the streams.

Read in full from manuscript.

Discussion

Dr. I. C. White: The region discussed in this paper all lies within the glaciated belt of soft, thin-bedded Devonian shales. I had occasion to examine

[1] Introduced by Richard R. Hice.

the same region during the progress of the Second Geological Survey of Pennsylvania, covering the region of Crawford and Erie counties, the latter of which borders Lake Erie. It was my conclusion that many of these minor folds, especially those with steep dips, were formed by the glacial ice, the boulders imbedded in its base creating much friction on the yielding shales. The absence of erosion of these folds would be no evidence against this theory of their formation, since there has been no erosion, except along the streams and gullies, since the Ice Age. Of course, along the streams the removal of overlying materials and the consequent release of tension would be a true cause for the very small flexures observed in such locations.

Dr. Richard R. Hice: Some at least of the faults involve a greater thickness of strata than suggested. At least one fault on Elk Creek extends downward a considerable depth, as is evidenced by gas flow. The folds near Meadville are due to release of load by the eroding streams. The rocks being under compress, they have "buckled up" when the stream eroded the overlying rocks.

Mr. F. B. Taylor: There are a number of folds of this type in the slides along the north side of Lake Ontario between Hamilton and Toronto. Several of them extend 200 or 300 yards. These particular folds lie in the surf-wasted zone of the Iroquois beach and appear certainly to be of more recent date than that beach.

Mr. Decker replied that the area under consideration (northeastern Ohio and northwestern Pennsylvania and New York) has suffered recent deformative movements in a manner not duplicated in adjacent glaciated areas, though they contain rocks of similar composition. This suggests that glaciation is not responsible for the deformation and much of it is certainly postglacial.

Further remarks were made by Messrs. H. F. Reid and H. M. Ami.

QUATERNARY DEFORMATION IN SOUTHERN ILLINOIS AND SOUTHEASTERN MISSOURI

BY EUGENE WESLEY SHAW

(Abstract)

That the Ozarks, at least the northeastern part, have suffered uplift since middle or late Tertiary time, and that this deformation was not a single brief movement but has proceeded, probably with interruptions, during part or all of several epochs, are indicated by the following facts:

1. Two terraces, formed by the dissection of valley tillings, rise toward the Ozarks, though in most of the valleys of southern Illinois this is downstream, and the form of the surface is such as to preclude the possibility that the streams have been reversed.

2. Well records show that the old valley bottoms underneath the fillings are also tilted up a little toward the Ozarks.

3. The two terraces appear to diverge slightly to the southwest, indicating some deformation between the times of valley filling that is, between the middle and late parts of the Pleistocene epoch.

4. The valleys and terraces become narrower to the southwest toward the

hill country, and in this narrowing do not show a close relation to rock hardness.

5. About the margin of the Ozarks a peneplain, probably of Tertiary age, has apparently been tilted rather sharply, so that it now slopes strongly toward the lowland to the northeast, and this slope is to a considerable degree independent of rock structure and drainage lines.

6. The surface features, the structure, and the buried peneplains of the upper end of the Mississippi embayment seem to show uplift since the Tertiary strata were laid down.

7. The position of the Mississippi River shows lack of adjustment, for it flows on the side of a trough, both structural and physiographic. The natural place for the river between St. Louis and Cairo is in the low, soft rock country 50 miles or more east of its present position, and the evidence is now practically conclusive that it was not forced out of such a course by a glacier, and also that it is not a superposed stream.

8. The drainage on the east side of the Mississippi is undergoing readjustment, the principal process being the development of many new small tributaries which are driving divides eastward.

9. Certain facts suggest that the valley of the Mississippi has in large part been carved in Pleistocene time, and apparently its youth and the topographic unconformity between it and the bordering surface forms, though due in part to enlargement of basin and perhaps glacial floods, can not be fully accounted for except through deformation.

10. The form of the valleys of the Ozarks is believed by the writer to be such as to indicate that for the most part they have been carved since late Tertiary time, and the lower parts of them in particular show evidence of comparatively recent uplift.

Some facts suggest that the deformation consisted in part of downwarp of the southern Illinois and western Kentucky lowlands; but however that may be, the downstream rise of terraces and buried valley bottoms seems susceptible of no interpretation other than relative uplift, and this, together with the fact that the other lines of evidence are accordant, are believed to put on a firm basis the conclusion that this region has suffered deformation in late Tertiary and Quaternary time.

Presented by title in the absence of the author.

OLD SHORELINES OF MACKINAC ISLAND AND THEIR RELATIONS TO THE LAKE HISTORY

BY FRANK B. TAYLOR

(Abstract)

The old shorelines of Mackinac Island have been studied recently in much more detail than formerly and have been placed on a large map with scale of 200 feet to one inch and contour interval of 10 feet. The work is being done by the Michigan Geological Survey and will be the subject of a report in the near future.

When mapped in this more complete way the beaches bring out with much

greater clearness than before the larger facts of the lake history as recorded in the northern lake basins.

The small ancient island which forms the hump on the back of the "great turtle" is surrounded on three sides by a compact and strongly developed series of gravel ridges—the upper group of the Algonquin beaches. On the east side the waves of the same time cut heavily into the ancient island, leaving a cliff of limestone over 100 feet high. The rock fragments torn from this side supplied the main bulk of the material for the beach ridges on the other sides. The lower limit of this group is just as sharply defined as the upper limit. The vertical interval covered by the group is about 35 feet, measured from the highest to the lowest beach crest, or nearly 50 feet to the base of the lowest. This highest beach is 809 feet above sealevel, or about 229 feet above Lake Huron. There is a little gravel about 3 feet higher, but it has not the form of a wave-made beach.

Below the base of the upper group a space covering a vertical interval of about 110 feet has only a few beaches, nearly all weak and fragmentary. These are the Battlefield and Fort Brady beaches of the late stages of Lake Algonquin. The upper part of this interval is heavily wave-washed and is mainly bare rock, or carries only very thin soil. This wave work was accomplished during the making of the upper group of Algonquin beaches.

Below the Fort Brady group of the Algonquin comes the Nipissing and lower beaches. These are strongly developed, and where beach building was favored they cover the entire slope from the Nipissing down. At Mackinac Island the vertical interval which they cover is about 50 feet; thus at Mackinac the record of the lake history is expressed in two strong groups of closely set beaches, with a relatively wide, nearly barren interval between—two zones of prolonged wave action separated by an interval showing very little wave action.

The two strong beach belts correspond to times of relatively permanent or slowly changing levels of the lake waters—to the second and third or two main stages of Lake Algonquin and to the transitional or two-outlet stage of the Nipissing Great Lakes, with a considerable part of the post-Nipissing or present stage. The barren zone between these belts corresponds to the time of the relatively rapid uplifting of the land in the closing stages of Lake Algonquin. These stages of relative stability and of rapid uplifting were worked out more fully in earlier studies covering much of the lake region, and the details on Mackinac Island agree with those results. The island is small, but it is relatively high, and stands in the midst of the northern waters like a monument bearing the record of the lake stages and uplifts that affected that region.

It has been held by some that strong beach ridges, like those of the Upper Algonquin group, mark as many pauses in the uplifting movement of the land; but this idea is apparently disproved by both of the heavy beach series on Mackinac Island. On the south side of the ancient island the Upper Algonquin group is represented by eleven or twelve beach ridges—by six strong ones and five or six weak ones—whereas on the west side about forty well defined ridges cover the same vertical interval. The forty ridges are spread over a wider horizontal area, but their average strength of development is less, as would be expected in a less exposed position, where wave action was weaker.

The same general comparison holds for the Nipissing-post-Nipissing series of beaches at the south and north ends of the island, the more numerous series at the north having been built by much less powerful waves than those at the south. It does not seem possible in this case to account for the individual ridges by pauses in uplift. Rather do they seem determined by the amplitude of the waves, the breadth and character of the subaqueous slope, the supply of beach-making material, and by other factors. The beaches and barren intervals of the Battlefield and Fort Brady groups seem more clearly related to variations in the rate of uplift. It seems certain, for example, that the strongest ridge of the Battlefield group marks a well defined pause, and it is even more certain that the strongly marked barren intervals do not record pauses.

Presented in abstract from notes.

SOME PECULIARITIES OF GLACIAL EROSION NEAR THE MARGIN OF THE CONTINENTAL GLACIER IN CENTRAL ILLINOIS

BY JOHN L. RICH

(*Abstract*)

Few specific observations are on record of the amount of erosion which the continental glacier accomplished on the plains of central United States, in the zone of predominant deposition near its margin, though the statement is often made that the amount was slight.[1]

The opening of an extensive limestone quarry at Fairmont, Vermilion County, Illinois, has brought to light definite evidence on this point and on the nature of the ice-movement here, 30 miles within the extreme limits of the early Wisconsin glacier (figure 1).

The quarry is in a bed of limestone about 20 feet thick, which appears to be a local lens in the midst of horizontal Pennsylvanian shales. Its site stands about 15 to 20 feet above the level of the surrounding plains; hence must have been, on the whole, more exposed to glacial erosion than were its surroundings. The limestone at the quarry is overlain by 8 to 15 feet of drift. Extensive stripping operations have revealed the surface of the rock round an elliptical area roughly ½ mile by ¾ mile in extent, giving most excellent opportunities for a study of glacial action.

The effects of underground water on the limestone are conspicuous. Joints have been enlarged by solution, and locally, at their intersections, caverns 3 or 4 feet in diameter have been developed.

---

[1] The following papers bear more or less directly on the problems under discussion:

W. H. Norton: Glaciated rock surfaces near Linn and near Quarry, Iowa. Proc. Iowa Acad. Sci., vol. 18, 1911, pp. 79-83.

Frank Carney: Glacial erosion on Kellys Island, Ohio. Bull. Geol. Soc. Am., vol. 20, 1910, pp. 640-645.

William H. Sherzer: Ice work in southeastern Michigan. Jour. Geol., vol. 10, 1902, pp. 194-216.

H. L. Fairchild: Ice-erosion theory a fallacy. Bull. Geol. Soc. Am., vol. 16, 1905, pp. 13-74.

Frank Leverett: The Illinois glacial lobe. Mon. U. S. Geol. Survey, vol. 38, 1899, pp. 85-87.

T. C. Chamberlin: Seventh Ann. Rept. U. S. Geol. Survey, especially page 187.

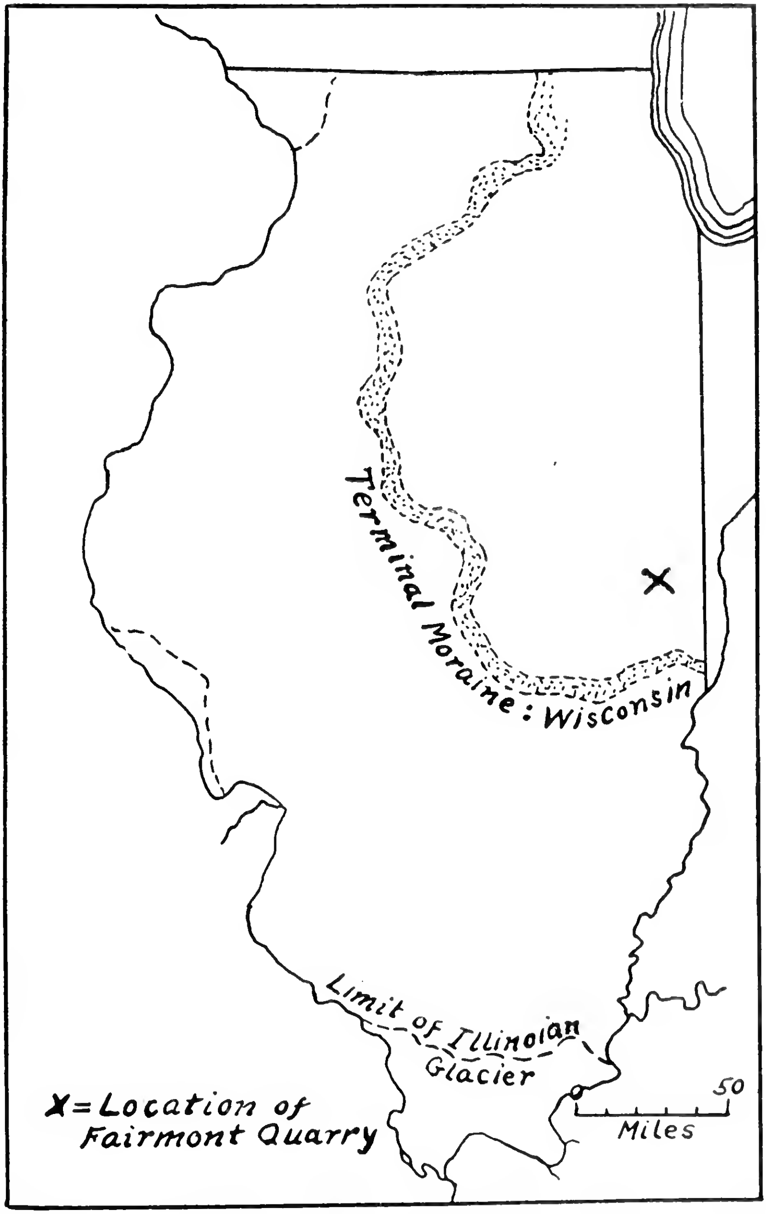


FIGURE 1. *Sketch Map of Illinois*

Showing location of Fairmont quarry with respect to limit of early Wisconsin glacier

The question arose whether these solution effects had been produced before or since the invasion of the region by the glacier. The perfectly fresh appearance of the striæ, as compared with the weathered, etched, and pitted surfaces of the joint cracks and caverns, pointed toward the preglacial[2] origin of the latter. So also did the fact that in several places caverns were cleanly cut across by the glacial surface (plate 7, figure 1). In one instance a workman, noticing that the rock sounded hollow, drove his crowbar through about one inch of striated limestone into a good-sized cavern. Decisive evidence on the point was secured when it was found, in one of the higher parts of the quarry, that glacial striæ descended to the depth of about a foot into one of the enlarged joints which happened to lie in a direction parallel to that of the ice-movement (plate 7, figure 2).

The pre-Wisconsin age of the solution phenomena having been established, it becomes possible to use these in estimating the character and amount of ice erosion which the limestone has suffered. When this line of investigation is followed it leads at once to the conclusion that erosion has been very unequal in different parts of the quarry. The surface of the limestone varies slightly in elevation, possibly as much as 10 feet within the area exposed. On the higher parts erosion has been intense enough to plane away all irregularities and to leave an almost perfectly smooth surface. It has not, however, been sufficient to obliterate the caverns or the solution channels along the joints. A conservative estimate would place the thickness of rock scoured away at not more than 2 to 4 feet. Over those parts of the quarry lying at intermediate levels a large part of the surface has been planed smooth, but the bottoms of the solution hollows have not been touched. Such a condition indicates very moderate erosion—not over 1 or 2 feet at most. In the lowest parts of the quarry the ice scarcely reached the rock. Only the highest projections were planed off. The surface, as revealed by stripping in one of the lowest parts of the quarry, resembles in every way that of weathered limestone in an unglaciated region (plate 7, figure 3).

In detail, as well as in broader features, the distribution of the eroded surfaces reveals the inability of the ice to descend into hollows, even where broad and shallow. Depressions 20 or more feet in diameter and less than 1 foot deep have escaped erosion, while the surrounding rocks have been planed off. Even the far sides of such depressions, where the erosive action should have been greatest, are commonly unstriated. In passing over smaller depressions, such as caverns or solution-enlarged joints, the ice seems not to have sagged downward in the least.

Such conditions show clearly that the ice behaved like a rigid plane, which actively eroded the higher projecting points, but was totally unable to descend into the depressions, even though they were broad and shallow. In the higher, more exposed parts of the quarry it bulged down slightly into solution channels, whose direction happened to be parallel to that of its movement; but it seems never to have descended into the transverse joints.

The ice doubtless rode over all these depressions on its own debris, but the significant feature is that it failed to clear this away and to scour down every-

[2] The word preglacial is used here in the sense of certainly pre-Wisconsin and possibly even pre-Illinoisan or pre-Kansan. No data are at hand to show how much of the solution should be attributed to interglacial and how much to strictly preglacial weathering.

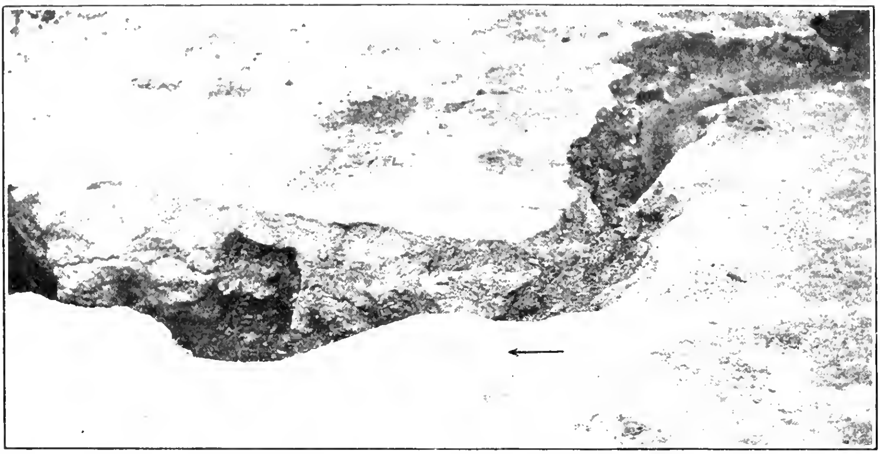


FIGURE 1.—CAVERN CUT ACROSS BY GLACIAL EROSION

Greatest width about 18 inches. Note sharp angle between glaciated and unglaciated surfaces even where cavern extends parallel to the striæ

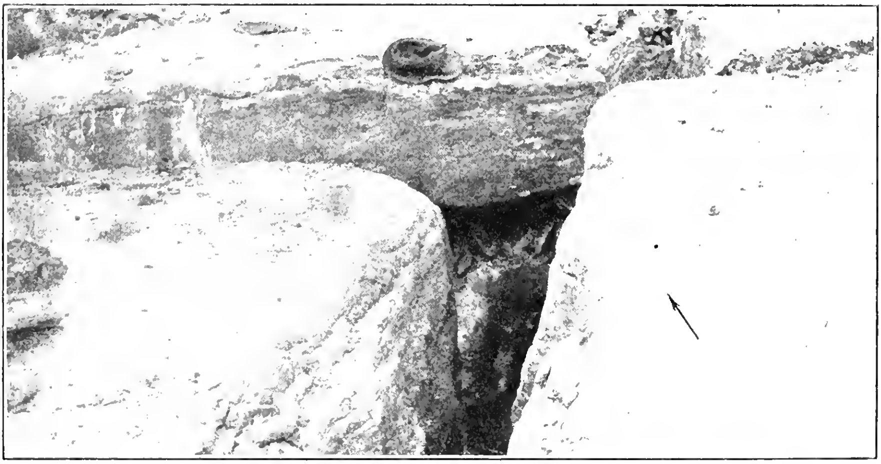


FIGURE 2.—AN ENLARGED JOINT CAVERN

Upper foot smoothed and striated by ice; proof of pre-Glacial age of solution effects

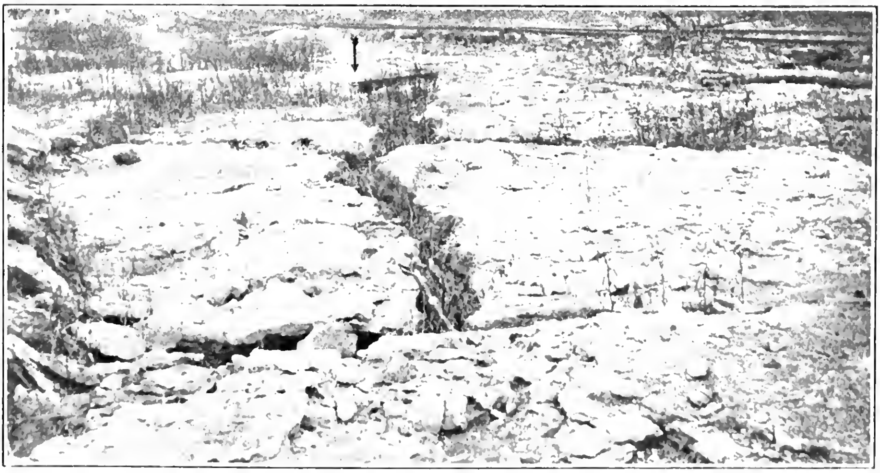


FIGURE 3.—WEATHERED SURFACE OF LIMESTONE REVEALED BY QUARRY STRIPPING

Note the enlarged joints; also the solution pits on the top surface of the limestone. The arrow points to the only spot within the field of view which was touched by the ice

PECULIARITIES OF GLACIAL EROSION IN CENTRAL ILLINOIS

where to live rock, in spite of irregularities in the surface, as it did in so many well known instances where it was thicker and its motion more vigorous.

The thinness of the ice in this submarginal area and its consequent insignificant weight, combined with a dominant translative element of motion, are thought to be responsible for these features. The effects are such as should be expected from a rigid mass of ice pushed bodily along from behind.

Since the quarry lies higher than its surroundings, erosion there doubtless represents a maximum for the region. If so, the lower, less exposed parts of the plain must have suffered exceedingly little, if any, erosion.

Read in full from manuscript.

Discussion

Mr. F. B. Taylor: The phenomena described by Mr. Rich is characteristic of a zone near the edge of the ice. At some other localities—Kellys Island, in Lake Erie; the Sibley quarry near Trenton, Michigan; on the Niagara escarpment near Pekin, New York, and on the Saugeen peninsula, in Ontario—the ice adapted itself to an irregular surface, either following narrow sinuous troughs or dipping down into shallow basins. These effects are apparently associated with relatively deep ice which was somewhat plastic and adapted itself to the hollows. Mr. Rich's pictures show an interesting exception, probably related to the thin marginal part of the ice.

Dr. C. A. Davis: In the vicinity of Marquette, Michigan, on the top of a rock hill within the city limits and 200 feet or more above Lake Superior, and in direct line of ice-movement—that is, facing the northeast—in 1906 there was seen an area of the schists of the region and an amphibolite dike on which the pre-Wisconsin weathering had not been removed by the erosion of the last ice-sheet, as shown by the surface of the schist, and especially by a small area on the surface of the dike, in which included quartz pebbles had weathered out for an inch or more in a shallow depression. The margins of the depression were beautifully glaciated, and the tops of the inclusions were truncated and striated; but the ice had not eroded to the bottom of the slight depression. Theoretically this should be a locality where ice erosion should have been heavy.

Mr. Rich asked if the term "solution pipe" was a good one to apply to solution-enlarged joints.

Further remarks were made by H. F. Reid and H. M. Ami.

NEW EVIDENCE OF THE EXISTENCE OF FIXED ANTICYCLONES ABOVE CONTINENTAL GLACIERS

BY WILLIAM HERBERT HOBBS

(Abstract)

In 1910, when the writer first assembled the evidence and promulgated the theory of nourishment of continental glaciers from the cirri through the agency of glacial anticyclones, the available evidence consisted of the following:

1. The generally centrifugal flow of surface air currents above the domes of inland ice.
2. The areas of relative calm over the central bosses of these ice domes.
3. The gradual working up of the glacial blizzards and their abrupt terminations in a sudden elevation of air temperatures (foehn effect).
4. The saturation of the air above the central areas of calm and the precipitation of snow or ice within the zone near the glacier surface.
5. The general paucity of other than wind-driven snow falling over the outer slopes of the ice domes.
6. The centripetal flow of upper air currents shown by the drift of clouds and of volcanic vapors.
7. The predominance of the cirri above inland ice, except at its margins.
8. The centrifugal drift of the snow from the central areas of continental glaciers and its accumulation in grabular form about their margins, and particularly at the base of outlet glaciers.

In the four years which have elapsed since this theory was promulgated the volume of evidence along most of these lines has been greatly augmented through the publication of scientific reports on expeditions carried out before the theory was published, but far more by the preliminary reports on new explorations within the two principal areas. These expeditions are notably the crossings of Greenland by De Quervain in 1912 and by Koch and Wegener in 1913, and the Antarctic expeditions of Captain Amundsen, Captain Scott, Lieutenant Filchner, and Sir Douglas Mawson. To the amplification of evidence along the above designated lines there has now been added the revelation of strong inversions of the atmosphere about the glacier margins and an upward extension of the outward flowing air currents, made known by ascents of kites and of pilot and registering balloons. The purpose of this paper was to draw attention to this new evidence.

Presented by title in the absence of the author.

ORIGIN OF MONKS MOUND

BY A. R. CROOK

(*Abstract*)

Monks Mound, the largest of the Cahokia group of mounds, situated 6 miles east of Saint Louis, has for many years been described by archeologists as the "largest artificial mound" in existence.

Twenty-five borings were made in the north and most abrupt side. 1. They showed different strata at different elevations. 2. These strata agree with similar elevations in the other mounds and with soil from the bluff 2 miles away. 3. Fossil hackberry seeds (*Celtis occidentalis*) and such gasteropods as *Pyramidula*, *Succinea*, *Helicina*, and *Physa* are found in beds. 4. A study of the physiography of the mounds makes clear that they occur along the divide between streams, and that their arrangement and individual forms are characteristic of the remnants of stream cutting.

Chemical and mineralogical study of the soil, as well as paleontological and physiographical investigations, indicate that the mounds are the remnants of

the glacial and alluvial deposits which at one time filled the valley of the Mississippi River in this region.

It may be well to inquire if all so-called mounds in the Mississippi Valley are not natural topographic forms.

Presented in abstract from notes.

Discussed by Messrs. John L. Rich and A. R. Crook.

CAN U-SHAPED VALLEYS BE PRODUCED BY REMOVAL OF TALUS?

BY ALFRED C. LANE

(Abstract)

The top of a talus slope accumulating at the foot of a vertical cliff of height (h) describes a convex curve, which, if n (the ratio of increase of volume occupied by a given weight of rock when broken into talus, usually 1.5 to 2) be 1, if s is the slope of repose, usually .6 to .7, and if y be measured from the foot of the cliff, x from the initial face, is a parabola $2hsx = y^2$. If n is not 1, the curve is similar, but has the more complex expression,

$$(1 - n)\ sx\ h = (y/h) + (n/\ (n - 1))\ nat.\ log\ (1 - (n - 1)\ y/nh)$$

A cross-section of a talus pile is like a jib or lateen sail, pteroid. Scenic curves may be found which seem to have this origin, but they are just the reverse of the U-shaped curves of many glacial valleys, which can not have been formed by the mere cleaning out of a widened I-shaped canyon (see figure 1).

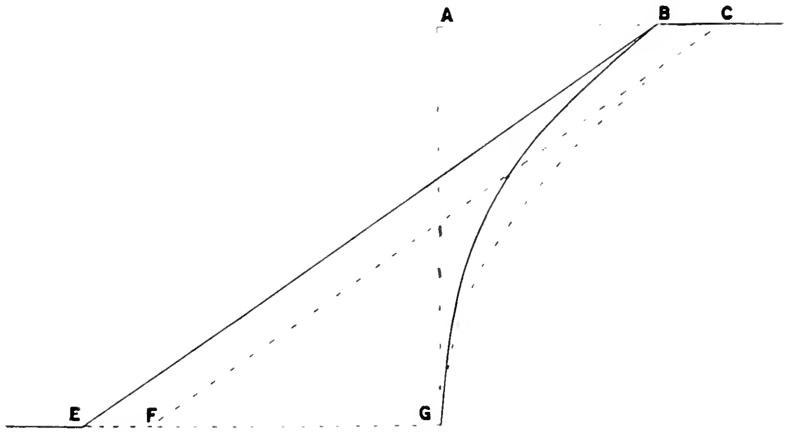


FIGURE 1. *Talus produced by the Retreat of the vertical Cliff AG, allowing for lateral Weathering only*

The slope of the angle of repose (35°) is taken as .7. CG is a parabola and CGF is the shape of cross-section, if the rock is supposed to occupy the same bulk in talus as in cliff—that is, CGF = AGC (n = 1). BGE is the shape of the section, if the rock in talus occupies twice the bulk that it does in the cliff, BGE = 2BGA (n = 2).

In real views showing somewhat this type of profile (see American Forestry, June, 1914, p. 395; Twentieth Ann. Rept., U. S. Geological Survey, part v, pl. ixb) the angle at BC is rounded, as the weathering is never purely lateral.

Presented by title in the absence of the author.

PHYSIOGRAPHIC STUDIES IN THE DRIFTLESS AREA

BY ARTHUR C. TROWBRIDGE

(*Abstract*)

Physiographic work done and in progress in northwestern Illinois, northeastern Iowa, southeastern Minnesota, and portions of Wisconsin, under the auspices of the University of Iowa, the University of Chicago, and the Geological Surveys of Iowa and Illinois, is yielding new data on the history of the driftless area.

The data so far gathered belong under three heads: (1) The Upland Plains, (2) The Glacial Drifts, and (3) The History of Drainage.

There are two upland plains, both of which are old peneplains. The highest and oldest one slopes from 1,500 feet above tide at Baraboo, Wisconsin, to 1,200 feet at Dubuque, Iowa, and cuts across from Huronian quartzite at Baraboo to Niagaran dolomite at Dubuque. Evidence points to the late Tertiary age of this plain. The younger peneplain has been traced from Jo Daviess County, Illinois, where it lies on Maquoketa shale and Galena dolomite at an altitude of 900 feet, to New Albin, Iowa, at which point it has an altitude of 1,100 feet and lies on the Prairie du Chien formation. Pre-Kansan glacial drift found on this plain in Iowa places its age as early Pleistocene.

The glacial drifts of the region include (1) pre-Kansan drift on the Pleistocene peneplain in Iowa, (2) Kansan Valley trains in tributaries to the Mississippi from the west, (3) Illinoisan drift on the east border of the driftless area in Illinois, (4) Wisconsin till in Wisconsin and fluvo-glacial material of the same age in the main valleys throughout the area, and (5) weathered till and fluvio-glacial material of unknown age and derivation at Bridgeport, Wisconsin.

A study of drainage lines has led to the discovery of new data on the Pleistocene history of the area. For instance, the Upper Iowa River in Iowa cut a valley 600 feet deep during the Aftonian interglacial epoch. Couler Valley, at Dubuque, has also an interesting history, which throws light on the duration of interglacial epochs. There is no evidence of a pre-Pleistocene Mississippi River. The Mississippi gorge was cut from a level of 900 feet at Dubuque to 276 feet at the same place, between Jerseyan and Wisconsin times, and the stream is now at grade on Wisconsin material 324 feet above its pre-Wisconsin level.

This work will be carried further during the coming and following years.

Presented by title in the absence of the author.

HEMICONES AT THE MOUTHS OF HANGING VALLEYS

BY CHARLES E. DECKER [1]

(*Abstract*)

On the south side of Lake Erie numerous small streams tributary to the larger creeks enter the main valleys through hanging valleys. Similarly, some of the small streams east of Erie, Pennsylvania, enter the lake through hang-

ing valleys. At the mouths of the hanging valleys projections occur into the main valleys or into the lake. These projections are here given the name of "hemicones." The purpose of this paper was to illustrate these hemicones and to briefly consider their origin.

Read in full from manuscript.

BLOCK DIAGRAMS OF STATE PHYSIOGRAPHY

BY A. K. LOBECK [1]

(Abstract)

The broader physiographic features of a state, or a large portion of a state, may best be portrayed by means of a block diagram which shows the relation of surface form to underground structure. The possibilities of this use of the block diagram method were illustrated by several specimen drawings.

Read by title, drawings being on view in exhibition room.

KILAUEA, A DROP-FAULT CRATER

BY GEORGE CARROLL CURTIS [2]

(Abstract)

On withdrawal of molten lava in the active pit of Halemaumau, support to the adjacent walls of frozen lava is lost and blocks of it subside, taking a form roughly concentric with that of the liquid lake. Such down-faulted masses are common within the eruption pit, its rim being stepped with series of corresponding lesser faults and cracks. The great caldera (Dutton) rim, of some 9 miles in circumference, 3 in diameter, and reaching nearly 300 feet in height, surrounds a floor or sink which appears to represent the "black ledges" or flow levels in the present pit of eruption, and large down-faulted blocks lie like giant steps along its extensive scarp.

Outside the main rim, interrupting the gentle slopes of the Kilauea cone, are other escarpments which appear of similar origin, one at half a mile and another at about a mile distant being the highest. The broad saddle between Kilauea and Kilauea Iki is a comparatively large dropped fault block, and a similar series of blocks and fissures occur in the several dormant surrounding crater pits. Kilauea is perhaps the best example of the drop-fault volcanic crater.

Presented by title in the absence of the author.

[1] Introduced by Richard R. Rice.

[2] Introduced by E. O. Hovey.

AGE AS THE DETERMINANT OF CHARACTER IN VOLCANOES

BY GEORGE CARROLL CURTIS [1]

(*Abstract*)

It has been held by some vulcanologists that a fragmental character of ejecta marks the closing stage of volcanic eruption. While this seems to apply in some localities, notably the Hawaiian group, the opposite was noted by the writer in other Pacific archipelagoes—in the Philippines, in Japan, and especially in Java—where a large number of fragmental volcanic cones in all stages are found, the most energetic, Smeroe and Bromo, being in constant activity. Pelé and Taal, whose eruptions and destruction of life had remarkable similarity, though composite cones, have been fragmental in their latest outbreaks, and many other like cases may be noted.

It appears that character of ejection is not always a criterion for determining the stage in the life history of a volcano.

Presented by title in the absence of the author.

COMPREHENSIVE CORAL ISLAND THEORY

BY GEORGE CARROLL CURTIS [1]

(*Abstract*)

Several one-way theories have been advanced for the true solution of coral atoll formation, Darwin's subsidence theory being the most widely accepted. A. Agassiz's views, based on the most extensive field observations yet made on coral reefs, seem to be the most inclusive. No single theory will fully account for all existing islands, though subsidence, platform building on reef talus, marine erosion, continental glaciation, and other factors, ably presented by eminent authorities, have undoubtedly entered into the construction of existing reefs. A year's study in South Pacific coral seas, with four years of coral island work, including the construction of the reliefs of Borabora and Funafute islands, has led to the tenet that similar results in coral formations may be brought about by quite different combinations of processes, and that the most plausible coral island theory for the time being is the multi-cause and vari-cause one.

Presented by title in the absence of the author.

EVIDENCE OF CONTINENTAL GLACIATION ON MOUNT KATAHDIN

BY GEORGE CARROLL CURTIS [1]

(*Abstract*)

Jackson, Bailey, Hamlin, Tarr, and other geologists have reported on the glaciation of the Mount Katahdin region, Professor Tarr's work being last and

[1] Introduced by E. O. Hovey.

naturally most comprehensive. He held that the Labrador ice-sheet passed completely over the mountain, basing his view on a few small erratics found near the summit. On a short visit this fall, the writer noted the angular character of the rock surfaces in the summit region and also the general absence of glacial drift, striation, and other signs of glaciation, though at 400 feet below the top such glacial effects were plentiful.

It seems from the data that, though the continental ice may have passed over this highest point in Maine (there is abundance of local Alpine glaciation in the heading valleys), evidence to establish complete overriding by the ice-sheet seems to be wanting. Katahdin has been at least an eminent nunatak.

Presented by title in the absence of the author.

NATURALISTIC LAND MODEL, THE "LAST WORD IN GEOLOGY"

BY GEORGE CARROLL CURTIS[1]

(*Abstract*)

Strange as it may appear on first consideration, one of the most inclusive subjects in earth science, calling for much detailed study and critical observation, broad, useful, and illuminating, is generally known only in its smallest and by far the least interesting aspect—the mechanical rather than rational side.

After the preliminary work of topographic mapping has been done, the most complete plotting finished, the culture, forest, vegetation, or other natural features added, the geology surveyed and placed upon the plan, the step which follows, in order to present the most complete representation of the earth's surface, is to gather the remaining data and render it all in the form of a naturalistic land model. In amount of facts, completeness, accuracy: in the matter of permanence and of characteristic natural expression, this medium—combining data of all other surveys with that especially required by its own demands seems to be entitled to the phrase "The last word in the earth sciences."

If it has been difficult for some geologists to see how there can be depth to such a subject, this may be due to old associations or to a habit of mind; but it is no fault of the nature of the naturalistic model. When one begins to realize that the reproduction of the face of the earth as it stands in the field is a definite problem in natural science and not, as it may have been hastily conceived, merely the mechanical raising of maps into relief, the whole aspect of the subject changes; it is seen to be rational, vital, and of unlimited possibilities. In this medium, so peculiarly neglected by geologists, the earth sciences have one of their greatest opportunities and a future which there is good reason to believe may surpass in general interest anything yet achieved in geology.

The first naturalistic relief of a land-form type made in this country has been brought about; it came through the efforts of biologists.[2] It was Alex-

[1] Introduced by E. O. Hovey.

[2] The coral island model of Borabora, Tahiti, installed in the Harvard Museum of Comparative Zoology in 1907

ander Agassiz, primarily a zoologist, who, after becoming the best informed authority on coral reefs, picked a second nugget from the field of geology in first introducing into an American museum a naturalistic model of a topographic type. Some geologists apparently do not realize the light in which their subject has been placed through lack of recognition of the need of expert direction in this subject, so fundamentally belonging to earth science; nor the credit lost by first recognition by other scientific bodies.[3] The crude reliefs that have characterized the works of American geologists, especially in government service, has presented geology in an unfavorable light and spread an impression of lack of accuracy and perception which does us injustice. What is by rights a most expressive and broadly interesting work has been shown in its smallest phase too arbitrary to attract the interest of any save a few specialists; and so geology has lost the unique advantage that might come from utilizing its best medium of exposition. One result is the maintenance of a low standard of land relief work throughout the many and varied channels where its uses are continually sought throughout the country. Government scientific bureaus are naturally looked to for standards, and failing to recognize expert work in a subject in which they are presumed to be authorized is bound to uphold poor standards, placing earth science in an unfavorable light. Is the interpretation of the earth's surface a matter so simple as to call for no such special training as is found necessary in the other arts? Can geologists think so poorly of their science as to hold that the training of mechanics is sufficient to interpret the intricate forms of the landscape, and is so mean a consideration of earth structure in accord with the spirit of modern nature study?

After architects, biologists, landscape gardeners, educators, and others into whose fields of labor this most inclusive branch of earth science has penetrated, have derived signal advantage from its promotion, it is interesting to note that now, for the first time, American geologists are entering this field so intimately a part of their work and the public need in earth study. The curator of the Harvard Geological Museum has taken this initial step among his fellow-geologists to bring a natural history specimen of a type of land form into an American geological museum. Three months were spent in a special survey for relief data of the crater of Kilauea, islands of Hawaii, and after nearly two years' continuous work under direction of a professional land modeler, the volcano is now approaching completion in the work of naturalistic relief.

Few realize the field study, planning, vast amount of laboratory work, and the expert direction (regardless of certain necessary technique gained only by long and costly experience) that expressive naturalistic relief involves; and yet when we consider for what it truly stands and can represent in its very completeness—not maps, but the field as it is and appears—we see that adequate results could not come otherwise. How many topographic reliefs in our museums today are based on the special surveys required for naturalistic models? And how many have been carried out for geology by expert land modelers? What encouragement has previously been given such workers by our earth scientists? How much has our government Geological Survey, to

[3] "Geographic sculpture" was first honored in this country by the American Social Science Association in 1914.

which the public looks for standards, done for the promotion of land relief work? How much notable work dignifies and illuminates American geology in our National Museum? Other institutions have fortunately proven by concrete example that nothing else is so capable of arousing as large an interest in earth science as the naturalistic relief.

As land reproduction in relief is one of the most inclusive subjects in the earth sciences, it is, old opinion notwithstanding, one of the larger subjects in geology and geography, and it is pertinent to note that some geologists now are beginning to see more clearly their great opportunity long overlooked. This insight should lead to a demand for more dignified work and help to change conditions (indirectly responsible for the large amount of unsatisfactory work in our museums, institutions, and expositions) which have made it practically impossible to do good work in this subject in our government bureaus. It may help to pave the way for geology to develop and utilize one of its best assets.

Presented by title in the absence of the author.

Section adjourned at 5 o'clock p. m.

SECOND SECTION

The Second Section did not convene on the afternoon of the first day on account of the desire felt by its members to participate in the meeting of the Paleontological Society.

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE THIRD SECTION AND DISCUSSIONS THEREON

The Third Section convened about 2.35 o'clock p. m., with H. P. Cushing in the chair and Ernest Howe serving as secretary. The section took up the reading of papers in Group C as follows: Petrologic, Mineralogic, and Economic.

PRE-CAMBRIAN IGNEOUS ROCKS OF THE PENNSYLVANIA PIEDMONT[1]

BY F. BASCOM

(Abstract)

Pre-Cambrian igneous rocks of the Pennsylvania Piedmont are pegmatite, rhyolite, granite (granitite, hornblende granitite, hornblende granite), granodiorite, quartz diorite, andesite, quartz norite, quartz gabbro, gabbro (norite, augite gabbro, anorthosite, hornblende gabbro), basalt, pyroxenite (websterite), and peridotite.

The application to them of the quantitative system of classification shows (*a*) that they form a remarkably continuous series from a persalic to a per-

[1] By permission of the Director of the U. S. Geological Survey.

femic magma, and (*b*) that a striking uniformity exists throughout the series in rangs and subrangs.

The uniformity denotes consanguinity; the distribution, through all the classes (class 1 to class 5), magmatic differentiation. No alkaline differentiates are found; neither feldspathoid nor soda-bearing pyroxenes are original constituents of any type. The differentiated magmas are almost without exception alkalicalcic, docalcic or percalcic, and presodic.

In areal distribution the acidic types are most abundant and the gabbroid types second in abundance; the most acidic and the most basic differentiates are least widely distributed.

The possible origin of a peculiar granodiorite through marginal assimilation by the gabbro of the acidic gneiss into which it intrudes was discussed, and some features of the anorthosite occurrence were presented.

Presented by title in the absence of the author.

MAGMATIC ASSIMILATION

BY F. BASCOM

(*Abstract*)

Near Strathcona, Vancouver Island, Canada, lime and magnesian silicates (epidote, chlorite, serpentine) have been developed in a diorite batholith to a distance of 1,400 feet from an included lens of limestone (40 to 50 feet wide); 750 feet south of the lens small irregular masses of limestone are included in the altered diorite, while three-fourths of a mile to the south the diorite is of a normal character. The rocks have been named the Sutton limestone and Wark diorite by C. H. Clapp (Memoir No. 13, Can. Geol. Survey).

Read by title, drawings being on view in exhibition room.

HYPERSTHENE SYENITE (AKERITE) OF THE MIDDLE AND NORTHERN BLUE RIDGE REGION, VIRGINIA

BY THOMAS L. WATSON AND JUSTUS H. CLINE

(*Abstract*)

Several seasons of field work by the Virginia Geological Survey in the middle and northern parts of the Blue Ridge and adjacent portions of the Piedmont plateau in Virginia have shown the dominant igneous rock of the granitoid type to be a quartz-bearing pyroxene syenite, the important facies of which is similar in composition to the akerites of Norway described by Brögger. This igneous mass, of which pyroxene syenite is the chief type, probably represents a pre-Cambrian batholithic intrusion exposed more or less continuously for a distance of 150 miles in a belt up to 20 miles or more in width.

Differentiation of the syenite mass has given rise to a variety of related rocks, some of which are of unusual types. Microscopic study of many thin sections shows the important minerals of the syenite in descending order of abundance to be soda-lime feldspar (albite to andesine-labradorite, chiefly

andesine), potash feldspar (orthoclase and microcline), pyroxene (hypersthene and some augite, diallage in part), quartz, hornblende, biotite, and usually considerable apatite and ilmenite or titaniferous magnetite. Hypersthene is a prominent mineral in each rock member of the series, and the presence of it together with that of abundant apatite and titaniferous iron oxides in places establishes the close petrographic relations of this large syenitic body to the smaller one of high phosphorus and titanium-bearing rocks of the Amherst-Nelson counties rutile district described in Bulletin III-A of the Virginia Geological Survey.

Complete chemical analyses have been made of representative specimens of the syenite collected from a half dozen or more different localities within the Virginia region. The norms calculated from these analyses show that the rocks are mostly alkalicalcic, belonging to tonalase, and of the sodipotassic subrang harzose. Two analyses yielded norms which fixed the position of the rock as amiatose and dacose, respectively, in the quantitative system.

Presented by title in the absence of the author.

PYRRHOTITE, NORITE, AND PYROXENITE FROM LITCHFIELD, CONNECTICUT

BY ERNEST HOWE

(*Abstract*)

Norites and pyroxenites from Litchfield County, Connecticut, are shown to contain pyrrhotite and chalcopyrite as constituents of magmatic origin. Two periods of crystallization are recorded, the separation of the sulphides, together with hornblende, biotite, and plagioclase, having taken place after olivine and pyroxene had crystallized and had suffered partial resorption. The late appearance of the sulphides in the crystallizing magma is attributed to the presence of mineralizers which held the sulphides in solution. The rocks are compared with those associated with the copper-nickel deposits of Sudbury, Ontario.

Presented in abstract from notes.

Remarks were made by Messrs. W. H. Emmons and reply made by the author.

SOME EFFECTS OF PRESSURE ON ROCKS AND MINERALS

BY JOHN JOHNSTON[1]

(*Abstract*)

A general discussion of the available experimental evidence bearing on the influence of pressure on the formation and behavior of rocks and minerals and of the conclusions which may justifiably be drawn from this evidence.

Presented in abstract from notes.

---

[1] Introduced by Arthur L. Day.

Discussion

Dr. C. N. Fenner pointed out that as regards the question of a eutectic composition of pegmatites several points must be held in mind. In the first place, the solutions from which pegmatites have been deposited undoubtedly contained not only water, but other volatile ingredients, each of which would by its presence affect the temperatures at which the quartz and feldspar would crystallize out, and also the relative proportions in which the two would appear. Moreover, where more than one kind of feldspar molecule is present the relations become much more complicated because of the formation of solid solutions, and the simple eutectic relations no longer hold.

Mr. J. P. Wintringham asked whether a graphic intergrowth was not to be taken as indicating a eutectic.

Mr. Johnston in reply pointed out that there appears to be no characteristic eutectic structure in silicate systems similar to that well known in metal systems, though such eutectic structure may appear in silicate systems containing volatile components, this being a point on which there is not laboratory evidence at present. Again, that though the eutectic is the temperature at which the last of the mixture solidifies, much of the material will in general have crystallized out before; that the eutectic is merely a special point on the curve, and that in all probability its importance is not so great as has been supposed, especially in view of the frequent occurrence of solid solutions.

Further remarks were made by W. Cross, W. H. Emmons, and J. E. Wolff.

PRIMARY CHALCOCITE IN THE FLUORSPAR VEINS OF JEFFERSON COUNTY, COLORADO

BY HORACE B. PATTON

(Abstract)

Several sharply defined veins, mainly of fluorspar, but also carrying considerable amounts of chalcocite and of other sulphides, have been opened in Jefferson County, Colorado. The veins have been worked for fluorspar and, to a lesser extent, for chalcocite. These are clean-cut fissure veins in Archean schist and gneiss, occurring in close proximity to granite intrusions. The association of fluorspar and chalcocite is unusual, and in this case the conditions seem to indicate that the chalcocite is of primary origin.

Presented in abstract extemporaneously.

RECENT REMARKABLE GOLD "STRIKE" AT THE CRESSON MINE, CRIPPLE CREEK, COLORADO

BY HORACE B. PATTON

(Abstract)

A recent very remarkable "strike" of gold telluride ore has been made in the Cresson mine at Cripple Creek. The conditions are very unusual for this

camp: first, because of the extraordinary richness and extent of the deposit; second, because of the depth of the ore shoot below the surface; third, because of very interesting geological conditions that are likely to throw considerable light on the origin of these tellurides. At a depth of 1,265 feet a large chamber was struck on November 25, 1914, the walls of which were heavily impregnated with calaverite. The chamber was lined with a white porous material that consisted mainly of celestite and that ran from $10,000 to $16,000 to the ton. Evidences point to the chamber being part of a watercourse rising from considerable depth.

Presented in abstract extemporaneously.

DISCUSSION

Dr. C. N. FENNER inquired whether there was not some similarity between the general relations of the main ore-pipe at the Cresson mine as described by Mr. Patton and those at the old Bassick mine in Custer County. In the latter also there was a main ore-pipe of elliptical cross-section filled with a breccia, whose pebbles were crusted with ore minerals.

Messrs. Whitman Cross and H. B. Patton took part in the discussion.

PLATINUM-GOLD LODE DEPOSIT IN SOUTHERN NEVADA

BY ADOLPH KNOPF

(Abstract)

The ore of the Boss gold mine in the Yellow Pine mining district, Nevada, has recently been shown to contain considerable platinum. The deposit occupies a vertical zone of fracturing in dolomite of Carboniferous age. The gangue consists mainly of fine-grained quartz, but streaks of bismuth-bearing plumbojarosite (a hydrous sulphate of lead and ferric iron) are found carrying as high as 111 ounces gold, 99 ounces platinum, and 16 ounces palladium. Some 600 feet from the mine is a small intrusion of granite porphyry, but no basic intrusives occur; in fact, none are known to occur in the whole district, which is the most productive lead and zinc district in Nevada.

Read in full from manuscript.
Remarks were made by Prof. W. H. Emmons.

ORGANIC ORIGIN OF SOME MINERAL DEPOSITS IN UNALTERED PALEOZOIC SEDIMENTS

BY GILBERT VAN INGEN

(Abstract)

The common association of galena, sphalerite, and some other minerals with reef deposits of early Paleozoic age was described, and a suggestion was offered that the reef-building organisms were directly responsible for the primary concentration of these minerals, and that deposits of the Joplin, Mis-

souri, and the Galena limestone type of Wisconsin and the Fenorite of the Mississippi Valley have had such an origin.

Read in full from manuscript.

DISCUSSION

MR. JOHN JOHNSTON: I understand that the blood of oysters and similar animals contains copper, this copper being to some extent analogous to the iron in the hæmoglobin of human blood.

DR. FRANK R. VAN HORN: I have been much interested in Professor Van Ingen's paper, which has treated a new subject from a paleontologic physiologic standpoint. For some years I have been of a similar opinion, which was arrived at on account of chemico-mineralogic reasons. The association of lead and zinc ores with dolomitic limestones is well known, from various parts of the Mississippi Valley as well as certain places in Germany. The association of lead with limestones can be explained by the isomorphism of the carbonates of calcium, barium, strontium, and lead in the minerals aragonite, witherite, strontianite, and cerussite. The association of zinc with limestones can be explained by the isomorphous calcite group, which consists of calcite, dolomite, magnesite, siderite, rhodochrosite, and, lastly, smithsonite, which is zinc carbonate. Doctor Van Ingen's reasons for assuming that the tissues of various mature animals absorb metallic salts will hold equally true for their shells and other hard parts which are secreted by the soft parts, and it is the hard parts which originally formed the limestone beds. It is very clear that there must have been a chemical rearrangement of compounds, since the metals are found now as sulphides and sulphates. We know that most limestone has been more or less dissolved and recrystallized. In this rearrangement the carbonates of the metals may likewise have been dissolved and subjected to reducing solutions which have resulted in galena, sphalerite, barite, and celestite.

Further remarks were made by Messrs. T. L. Watson and W. H. Emmons.

The section adjourned at 5.15 o'clock p. m.

PRESIDENTIAL ADDRESS

At 8 o'clock p. m. the Society convened in the lecture hall of the Academy of Natural Sciences and listened to the reading by Vice-President W. Lindgren of an abstract of the address of retiring President George F. Becker, entitled

ISOSTASY AND RADIOACTIVITY

Published as pages 171-204 of this volume.

The address was followed by the complimentary smoker given in honor of the Geological Society of America and the Paleontological Society by the local members of the former organization.

Session of Wednesday, December 30

The Society convened at 9.30 o'clock a. m. in general session, First Vice-President W. Lindgren in the chair.

REPORT OF AUDITING COMMITTEE[1]

The Auditing Committee begs to report that they have examined the papers and vouchers of the Treasurer and find them to be correct and in good order.

The investment securities will be examined at a later date.

J. M. Clarke,
H. L. Fairchild,
For the Committee.

The report was accepted.

The printed report of the Council was taken from the table and, on motion, accepted.

TITLES AND ABSTRACTS OF PAPERS PRESENTED IN GENERAL SESSION AND DISCUSSIONS THEREON

REVISION OF PRE-CAMBRIAN CLASSIFICATION IN ONTARIO

BY WILLET G. MILLER AND CYRIL W. KNIGHT

(Abstract)

During the past decade the authors have been engaged in detailed work on pre-Cambrian areas in various parts of the Province of Ontario. The results of this work, and that of other investigators, have made apparent the necessity for revising the age classification of the pre-Cambrian rocks, particularly in the use of the terms Huronian, Laurentian, and others. The following classification and nomenclature have therefore been adopted by the Ontario Bureau of Mines:

Keweenawan.

Unconformity.

Animikean.

Under this heading the authors place not only the rocks that have heretofore been called Animikie, but the so-called Huronian rocks of the "classic" Lake Huron area and the Cobalt and Ramsay Lake series. Minor unconformities occur within the Animikean.

Great unconformity.

[1] Under date of February 11, 1915, Edward B. Mathews reports that, acting as a member of the Auditing Committee of the Society, he examined the Society's securities in the hands of the Treasurer and found them to be as listed in the Treasurer's report under date of December 1, 1914.

(Algoman Granite and Gneiss.)

Laurentian of some authors, and the Lorrain granite of Cobalt, and the Killarney granite of Lake Huron, etc.

Igneous contact.

Timiskamian.

In this group the authors place sedimentary rocks of various localities that heretofore have been called Huronian and the Sudbury series of Coleman.

Great unconformity.

There is no evidence that this unconformity is of lesser magnitude than that beneath the Animikean.

(Laurentian Granite and Gneiss.)

Igneous contact.

Loganian.

Grenville (*sedimentary*), Keewatin (*igneous*).

The authors have found the Keewatin to occur in considerable volume in southeast Ontario and have determined the relations of the Grenville to it.

Investigations by the junior author during 1914 have shown that certain rocks of the "classic" Huronian area of Lake Huron, the "Thessalon greenstones," that heretofore have been placed with the Keewatin, are of much later age, being in intrusive contact with the Animikean, as defined in the above table.

Presented in abstract extemporaneously by the senior author.

Discussion

Prof. H. P. Cushing stated that the proposed classification was easily applicable in the Adirondacks, and that he had for some time felt that the Grenville was most probably to be correlated with the Keewatin, because of its similar relationship to the oldest granite invasion, the Laurentian. That, in Professor Cushing's opinion, in pre-Cambrian correlations the wide-spread intrusions furnish the safest guide; that in all likelihood the later intrusive masses of the Adirondacks are to be correlated with the Algoman.

Further remarks were made by Messrs. W. S. Bayley and W. Lindgren, and reply was made by Dr. W. G. Miller.

NORTH AMERICAN CONTINENT IN UPPER DEVONIC TIME

BY AMADEUS W. GRABAU

(*Abstract*)

The history of North America in the Upper Devonic has been worked out in some detail on the basis of physical stratigraphy combined with paleontology.

At the opening of the Upper Devonic marine waters were much restricted in North America, the greater part of the United States being exposed to active erosion of the previously deposited Hamilton or earlier formations, as

indicated by disconformities. The Tully-Genesee Sea was restricted to central New York, but extended northward over Canada. Appalachia, Atlantica (the Old Red Continent), and Mississippia were the chief continents. The evidence pointing to the gradual southward transgression of the sea over the eroded lands is clear. Three open marine water bodies existed throughout Upper Devonic time, each with their distinctive faunas: (1) The northern, extending from central New York across Ellsmere Land to the Urals; (2) the western or North Pacific, extending across part of Alaska; (3) the eastern or Atlantic. The latter entered the interior by way of a narrow strait between Appalachia and Atlantica, permitting the periodic invasion of the Atlantic or Tropidoleptus fauna. There may have been a fourth South Pacific water body extending into Nevada, but this is less certain. Three principal river systems are recognized in the lowland of Mississippia. These have furnished the black mud for the black shales which were deposited in embayments of diminished salinity. The eastern or Genesee beds are restricted to New York and the States just south. The base of the black shale of Ohio, Michigan, and Canada is younger than Genesee, as shown by stratigraphic and paleontologic evidence. The great fish fauna of these shales is shown, by its occurrence and distribution, to be primarily the fauna of these sluggish rivers projected at intervals into the brackish water of the embayments. The land flora of Mississippia is also preserved in these shales. The rivers of Appalachia and Atlantica also had their fish fauna, but these were of different types, their smaller size adapting them to these torrential streams. With them occurred the survivors of the Eurypterids, which also inhabited the rivers of the Paleozoic lands. The flora of Appalachia and Atlantica is likewise largely distinct from that of Mississippia. The deposits made by these rivers were partly preserved as sandy deltas and alluvial fans.

Presented in abstract extemporaneously.

Discussion

Prof. C. S. Prosser stated that in his belief the chart by Professor Grabau showed in general the changes in the character of the sediments of the Ohio shale in northern Ohio to the equivalent ones in northwestern Pennsylvania and western New York.

In Ohio there is a black shale in the Mississippian (called the Sanbury) separated by the Berea grit and Bedford formation from the subjacent Ohio shale. As these formations are followed across the Ohio River in Kentucky the Berea and Bedford rapidly thin until when about one-half the distance across the State the Ohio and Sanbury shales are separated by only a few inches of deposits representing the Berea and Bedford. It appears probable that farther south these two black shales come together and belong in both Devonian and Mississippian age.

Professor Prosser called attention to the extension of the Sherburne sandstone to the sandstone to the east in New York than indicated by Professor Grabau's diagram. He (Professor Prosser) has traced the Sherburne sandstone from the typical region in the Chenango Valley eastward across the Unadilla, Susquehanna, and Schoharie valleys, and then, after the change in strike of the Paleozoic formations of eastern New York, southward on the eastern side of the Catskill Mountains.

Remarks were made by Prof. H. P. Cushing, and reply by the author.

SYMPOSIUM ON THE PASSAGE FROM THE JURASSIC TO THE CRETACEOUS

The Society then merged into joint session with the Paleontological Society for the "Symposium on the passage from the Jurassic to the Cretaceous." The speakers and their contributions were as follows:

WILLIS T. LEE: The Morrison; an initial Cretaceous formation.

CHARLES C. MOOK: Origin and distribution of the Morrison.

R. S. LULL: Sauropoda and Stegosauria of the Morrison compared with those of South America, England, and Eastern Africa.

E. W. BERRY: The Paleobotanic evidence.

T. W. STANTON: The invertebrate fauna of the Morrison.

The abstracts and discussions of these papers will be found in the Proceedings of the Paleontological Society in this volume.

The general session adjourned at 12.35 o'clock p. m.

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE FIRST SECTION AND DISCUSSIONS THEREON

The First Section met at 2.30 o'clock, with John M. Clarke in the chair and D. W. Johnson serving as secretary.

TYPE OF RIFTED RELICT MOUNTAIN, OR RIFT-MOUNTAIN

BY JOHN M. CLARKE

(Abstract)

The Table Rolante, near Percé, Province of Quebec, is an uplifted relict of the Bonaventure (Devono-Carboniferous) conglomerate, bounded by sheer sides and resting almost horizontally on the upturned older paleozoics. It is believed that this rolling elevated plateau has been abruptly isolated by undermining through solution of the limestones on which it rests; that the sheer walls are not due to faulting, but to rifting along joint planes, and that by persistence of this process successive blocks of large size have sunk to lower levels.

Presented in abstract from notes.

DISCUSSION

MR. WILLIAM J. MILLER: During the summer of 1914 there came under my observation an example of rifting, the principle of which is very similar to that so well described by Doctor Clarke. In the Adirondacks, beautifully stratified Grenville rocks, some hundreds of feet thick, dip westward at 55° and rest against Chimney Mountain, consisting of syenite which rises nearly 1,000 feet above the surrounding country. On one summit of the mountain a block of Grenville one-quarter mile long has broken away from the main mass, leaving a rift 200 to 300 feet wide and 250 feet deep, with very steep walls. The rifted block dips 20° northeastward. It broke away along a joint plane, due to solution of underlying calcareous strata, in a manner similar to that explained by Doctor Clarke.

EVIDENCE OF RECENT SUBSIDENCE ON THE COAST OF MAINE

BY CHARLES A. DAVIS

(Abstract)

A few weeks during the summer of 1914 were spent on the shores of Damariscotta River and the adjoining bays and inlets, during which opportunities were found to study a rocky coastline for evidences of recent subsidence.

Three general classes of such evidence were found.

A. Botanical
- (1) Dead and dying trees and other fresh-water plants at and below the high tide level on all kinds of shores.
- (2) Forest beds containing stumps of trees outside the present shoreline down to and below tide level.
- (3) Salt marshes with fresh-water beds of peat below them.

B. Physiographic
- (1) The present form of the rock coast of the region.
- (2) The general existence of ancient weathering on the rocks extending from above high tide level to below low water.

C. Historic
- (1) Existence of walls, wharves, and other structures below high tide level.
- (2) Closing of springs formerly used by settlers by sea-deposited debris.

The paper recorded some of the more important facts discovered and described their occurrence.

Presented in abstract extemporaneously.

DISCUSSION

MR. JOHN L. RICH: Several of the trees and stumps which were shown as having been invaded by salt water occur on relatively steep slopes, covered, according to the account, by till. I should like to ask whether creep has been eliminated as a cause of the apparent rise of the water level. Conditions seem favorable for it here, and, moreover, several of the trees show a down hill inclination near the base, which is a very characteristic result of creep. A slow creeping of soil and trees down the slopes might well account for the phenomena shown.

Prof. D. W. Johnson analyzed the evidence presented by Doctor Davis and concluded that it could not properly be regarded as supporting the theory of recent coastal subsidence, for the reason that all the phenomena described by the author are frequently produced by normal retrogression of a vertically stable shoreline under wave attack and may be observed on lake shores where no changes of level are involved.

Further remarks were made by Messrs. H. Ami and Joseph Barrell.

BASIC ROCKS OF RHODE ISLAND: THEIR CORRELATION AND RELATIONSHIPS

BY A. C. HAWKINS AND C. W. BROWN

(Abstract)

Rhode Island as a whole is underlain by a great granite batholith, now sheared, of uncertain age, but of high antiquity, together with other sheared granite types lying to the east and west, of alleged different ages. In these stocks are found remnants of metamorphosed rocks, quartzites, quartzitic hornblende, and biotite schists of so-called sedimentary or combined sedimentary and igneous origin. In addition there appear several gabbroid stocks, more or less changed, but rather basic in type, which may in part be pre-granitic. Moreover, there appear trappean intrusions of four distinct types, such different ones as minette and Triassic diabase dikes. Of these four types, two are perhaps rather closely associated in age, but the others are more remote from each other.

From the field relations and from analyses of similar rocks, which show silica too low and lime and magnesia too high for sediments, it would seem that the so-called sedimentary biotite schists are distinctly of igneous contact origin, resulting from the intrusion of granites into earlier basic rocks more or less schistose. From the evidence along the borders of the new Carboniferous basin, the Woonsocket basin, extending southward from the Norfolk, it would appear that some of the granitic stocks asserted to be post-Carboniferous are really pre-Carboniferous in age.

Read in full from manuscript.

Discussion

Mr. Sidney Powers asked why the authors thought the Sterling to be pre-Carboniferous.

Mr. Hawkins replied that they had found that the Woonsocket basin sediments (presumably Carboniferous) rested unconformably on granites of Milford age on its borders and contained blue quartz grains evidently derived from the latter. They also found that the structure of the granite gneisses on the borders indicated a possible anticline on whose eroded crest the sediments were deposited. In response to Mr. Powers's request for proof of the intrusive nature of Westerly granites into Sterling granite gneiss, Mr. Hawkins stated that such contacts had been exposed in quarries at Bradford, Rhode Island.

Prof. C. P. BERKEY suggested that much of the larger curving gneissic structure observed by Messrs. Hawkins and Brown might have been due to original flow structure.

Mr. HAWKINS cited the observations of Loughlin (Bulletin 492, U. S. Geological Survey), who found crushing in the grains of the Sterling, and said that he and Professor Brown had observed shearing in included fragments in the granite, such shearing being apparently post-inclusion.

ACADIAN TRIASSIC

BY SIDNEY POWERS[1]

(Abstract)

The Acadian Triassic is exposed on both sides of the Bay of Fundy. In New Brunswick the Triassic occurs on the west side of the Island of Grand Manan, and also at Split Rock (near Gardner's Creek), Quaco, Martin Head, and Waterside. In Nova Scotia the Triassic borders Minas Basin and the Bay of Fundy.

The Newark group is divided into the following formations, whose thicknesses are estimated:

	Feet
Scots Bay formation	25–(2,000?)
North Mountain basalt	800–1,000
Annapolis formation:	
Blomidon shale	500–1,000
Wolfville sandstone	2,000–2,500
	3,325–6,500

Interbedded with the Annapolis formation, approximately at the horizon of the Blomidon shale, are the Five Island volcanics, consisting of tuffs, agglomerates, and basalt flows.

The Scots Bay formation consists of calcareous gray to green sandstone and shale, carrying fish remains. It rests directly on the North Mountain basalts and is conformable with them. The formation is preserved in small synclines at Scots Bay. The North Mountain basalt consists of flows of varying thickness. At Cape D'Or, in a 556-foot flow, evidence of gravitative differentiation of the feldspar and augite and of variation of both grain and specific gravity with depth have been found. The Annapolis formation is composed of red beds, and in the sandstones at Martin Head plant remains have been found.

The structure of the Acadian Triassic comprises monoclinal tilting toward the northwest and gentle folding. Faulting is abundant, but most of the faults have a small displacement. The major faults are at the base of the Cobequid Mountains, on the north side of the Triassic around Minas Basin, and on the northwest side of the New Brunswick areas. The hook in North Mountain, from Cape Blomidon to Cape Split, is a pitching syncline, cut off on the north by a fault. Another important syncline is found at Quaco, New Brunswick.

Presented in full extemporaneously.

[1] Introduced by R. A. Daly.

Discussion

Dr. C. N. Fenner inquired as to the character of the contacts in those exposures where the basalt sheets rest directly on older rocks not belonging to the Triassic, especially as to whether the basement rocks were absolutely bare or whether there was some small amount of detrital material between the basalt and the floor on which it rests.

Prof. J. Volney Lewis: Some of the basalt sheets in the Newark formation of New Jersey are undoubtedly composite, but the evidence on which successive flows are distinguished is not in every case clear cut and decisive. In some places a platy jointing or bedlike parting is very deceptive. I should like to ask Mr. Powers on what basis he was able to separate the members of the multiple basalt which he has described and shown to us from the Bay of Fundy.

Dr. John M. Clarke stated that he believed the term Caledonian should be used in preference to Shickshock and Brunswickian as a name for the mid-Devonic disturbance.

GEOLOGICAL HISTORY OF THE BAY OF FUNDY

BY SIDNEY POWERS[1]

(Abstract)

The Bay of Fundy lies along orographic axes which appear to have existed since the beginning of the Cambrian period. Transgressions of the seas in Cambrian, Ordovician, Silurian, and Lower Devonian times are recorded in small remnants of sedimentary rock, but there is a lack of evidence to show that the sea at any of these times occupied the entire Fundy region.

A disturbance of Middle Devonian age folded the Lower Paleozoic rocks with a trend similar to that of the pre-Cambrian axes. Minas Basin was formed as a structural unit at this time by the folding of the Cobequid Mountains. The Nova Scotian granites, and probably the igneous rocks of the Cobequids, were intruded at this time

During a portion of the Mississippian period, sedimentation continued in the northern part of the Fundy region. In the Pennsylvanian period, the Union-Riversdale and Mispec-Little River formations were deposited along the axes of Minas Basin and a portion of the Bay of Fundy. After the Millstone grit and the Coal Measures had been deposited north of the Cobequid Mountains, another disturbance folded these Lower Pennsylvanian sediments.

The period of deformation in mid-Pennsylvanian (Conemaugh?) time is correlated with the Armorican-Variscan disturbance of Europe, as the Middle Devonian disturbance is correlated with the Caledonian of Europe. In the Armorican-Variscan disturbance the Union Riversdale and Mispec-Little River sediments were greatly folded, while the Coal Measures, north of the Cobequids, were not greatly disturbed. The main axis of folding was east-west from Saint John through Truro.

Following the mid-Pennsylvanian disturbance came active erosion and the deposition of the Upper Pennsylvanian-Permian New Glasgow conglomerate

[1] Introduced by R. A. Daly.

north of the Cobequids and of its equivalent, the Carboniferous conglomerate, south of the Cobequids, along the axis of Minas Basin.

At the close of deposition, with a slight disturbance in the Permian, a peneplain was developed in the Fundy region, and on the surface of this peneplain the Triassic sediments were laid in a shallow geosyncline. Block tilting and faulting closed the Newark stage and changed the geosyncline into a region of erosion. During the long period of erosion two peneplains have probably been developed and uplifted by middle and late Tertiary time.

Presented in full extemporaneously.

Remarks were made by Dr. W. C. Alden.

The section adjourned.

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE SECOND SECTION

On the conclusion of the presidential address of the Paleontological Society, at 3.30 o'clock p. m., the reading of papers of Group B was commenced, with Vice-President Van Ingen of the Paleontological Society presiding.

ALEXANDRIAN ROCKS OF NORTHEASTERN ILLINOIS AND EASTERN WISCONSIN

BY T. E. SAVAGE

(Abstract)

The early Silurian strata in northeastern Illinois and eastern Wisconsin were described and their fossils listed and discussed. The so-called "Clinton Iron ore" bed was shown to belong in the Ordovician system as the upper member of the Maquoketa of this region. The lower part of the Mayville limestone of Wisconsin contains an Edgewood fauna and is considered the equivalent in time of the Edgewood formation of Illinois and Missouri. The upper strata of the Mayville limestone furnished fossils characteristic of the Sexton Creek (Brassfield) limestone of Illinois and are regarded as representing a northward extension of that formation.

Read in full from manuscript.

The paper was discussed by Messrs. Ulrich and Grabau, with reply by the author.

OLENTANGY SHALE AND ASSOCIATED DEPOSITS OF NORTHERN OHIO

BY CLINTON R. STAUFFER

(Abstract)

A recent study of the section and fossils of the Olentangy shale to the south and east of Sandusky, Ohio, indicates that it represents the lower part of the Hamilton beds of Ontario. The Prout limestone, which lies immediately be-

neath the Huron shale in that region, represents the Encrinal limestone of the Thedford, Ontario, region and probably also the similar layer along Eighteen-mile Creek in New York. The thinning in the Hamilton beds from Thedford southward to Sandusky is therefore either by disappearance of the upper portion of the Hamilton, thus allowing the Huron to rest directly on the Encrinal limestone, or the lower part of the Huron shale itself must represent the upper Hamilton beds. Indications to the southward from Sandusky are that the Huron is continually lapping over on older beds, while the fossils in the lower Huron south and east of Sandusky indicate that this deposit is about the age of the black shale at Kettle Point, Ontario. The Huron shale, therefore, rests unconformably on the Encrinal or Prout limestone of northern Ohio and the whole upper Hamilton is wanting.

Presented by title in the absence of the author.

DIASTROPHIC IMPORTANCE OF THE UNCONFORMITY AT THE BASE OF THE BEREA SANDSTONE IN OHIO

BY H. P. CUSHING

(Abstract)

By description of the character of the unconformity at the base of the Berea sandstone in Ohio the attempt was made to show that the break between the Berea and the underlying Bedford shale must be a trifling one, involving no great lapse of time, and hence of slight diastrophic importance.

Read in full from manuscript.

Discussed by Messrs. David White, Charles S. Prosser, and A. W. Grabau. The discussion was discontinued so that the papers by Messrs. Ulrich and Grabau could be considered together with this one.

KINDERHOOKIAN AGE OF THE CHATTANOOGAN SERIES

BY E. O. ULRICH

(Abstract)

Recent discoveries in Tennessee and Missouri tend to show that the shale and sandstone formations comprised in the Chattanoogan series, as defined by the author in 1912, are really younger than was then supposed. Judging from the data then in hand, the Chattanoogan was wholly removed from the Devonian system and placed as a new series at the base of the Waverlyan (Lower Mississippian) system. With the new evidence, it now appears that the Chattanoogan is approximately contemporaneous with the Kinderhookian series of the Mississippi Valley. The principal data on which this conclusion is based are as follows:

1. In Tennessee and Kentucky the Chattanoogan shale is commonly succeeded by the New Providence shale. At many other places in these States, particularly in Tennessee, the top of the Chattanooga is in contact with the Fort Payne chert. At a few places, however, a third formation—the Ridge-

top shale—rests on the black shale of the Chattanooga. Of these three post-Chattanoogan formations the Ridgetop shale is the oldest, the New Providence shale next younger, and the Fort Payne chert the youngest. The last is of the age of the Keokuk limestone of the Mississippi Valley. Locally its basal part may include beds corresponding to late Burlington. The New Providence shale corresponds in age to the Fern Glen formation of Missouri and Arkansas. Weller and others classify the Fern Glen as late Kinderhookian, but the author regards it as Lower Burlington, or at least as post-Kinderhookian; hence, early Osagian.

So long as the Chattanoogan was regarded as Devonian, and therefore as distinctly older than the Kinderhookian series, the Ridgetop shale was assumed to be an early Kinderhookian deposit. Fossil evidence from the concerned beds was both scanty and of undetermined significance. In the past two or three years, however, reasonably good collections of fossils have been made from three zones in the Ridgetop shale. These fossils prove conclusively that the formation, instead of being early Kinderhookian in age, in fact represents a very late facies of this epoch.

2. The contact between the Chattanoogan and succeeding formations generally indicates a break in sedimentation, except in those sections in which the Ridgetop shale is developed. In these no evidence of discontinuity has been discovered. As the fossils of the Ridgetop shale indicate a late Kinderhookian age, this continuity of deposition properly leads to the inference that the underlying black Chattanoogan shale also is, at least in part, of early Mississippian age.

3. Black shale containing *Sporangites*, and evidently of Chattanoogan age, was discovered during the past year by Prof. Stuart Weller in Sainte Genevieve County, Missouri. This bed of shale overlies the Glen Park limestone, which, farther north, overlies the Louisiana limestone. Faunally and lithologically the Louisiana corresponds best with an upper member of the typical Kinderhook sections at Kinderhook, Illinois, and Burlington, Iowa. This transgressing, presumably upper part of the Chattanoogan, is thus proved to be late Kinderhookian in age.

4. South and west of Irvine, Kentucky, the Chattanooga shale is an indivisible stratigraphic unit. The upper part of this unit is generally conceded to be of Mississippian (Sunbury) age. We now learn that the top of the formation corresponds in position approximately to the top of the Kinderhook, and is therefore much younger than the base of the Mississippian in the Mississippi Valley. In seeking to fix the latter boundary in Kentucky and Tennessee, we may follow the principle of drawing the line at the first important break in sedimentation beneath the part of known late Kinderhookian age. Accordingly, and in the absence of competent evidence of contrary significance, the base of the Mississippian in these States should be drawn at the base of the Chattanoogan. That this principle is properly applicable in this case is indicated by both stratigraphic and faunal evidence.

5. The strongest and most widely recognizable physical break between undoubted Devonian and equally well accredited Mississippian deposits in Ohio, Indiana, Illinois, Iowa, Missouri, Arkansas, Oklahoma, Kentucky, Tennessee, and Alabama occurs at the base of the Chattanoogan or Kinderhookian series. Commonly the base of this series is marked by a sandy conglomerate; and,

except in certain limited areas where it is underlain by similar Devonian shale, the lithologic break is conspicuous. This break, moreover, marks a strong transgression unconformity which brings the Chattanoogan in contact with many widely differing older formations, ranging in age from Ordovician to late Devonian. The recent tendency to limit the Mississippi in Ohio and adjacent States at, or at an horizon supposedly corresponding to, the base of the Berea sandstone is regarded as impractical and generally impossible, except in Ohio, and as inharmonious with long-established practice in the Mississippi Valley and in New York. This imperfectly considered effort would subordinate a highly important and perhaps universally recognizable diastrophic boundary to one that is but locally definable and on the whole of greatly inferior taxonomic significance.

6. The Louisiana limestone in Missouri and the Chonopectus sandstone at Burlington, Iowa, are underlain by gray or black shales which have been and are yet commonly referred to the basal part of the Kinderhookian series. These basal shales correspond in position with the Cleveland and Huron shales of Ohio, and on this ground alone may be correlated with them.

7. In Missouri these basal shales contain fossils. None of the species are of unquestionable Devonian types. On the other hand, a large proportion of their number, especially of the invertebrates near the top, is identified with otherwise typical Louisiana limestone species. The shale contains also remains of fish which are closely allied to, and perhaps in part identifiable with, Huron shale species. Fossils occur in these shales also at Burlington. Here they have a more decidedly Mississippian aspect than pertains to the succeeding Chonopectus fauna.

8. Remains of Arthrodirian fishes, especially *Dinichthys*, occur at different horizons in the Chattanoogan series, the first being near the base, the last at the very top. The last being unquestioned Mississippian, it follows that *Dinichthys*, at least, is not confined to Devonian formations. Indeed, the evidence in hand indicates that most of the genera of fishes found in Upper Devonian rocks range upward into the Mississippian. None of the Chattanoogan fishes, however, are specifically identical with any of those found in undoubted Devonian rocks.

9. The evidence of the plants is much the same in tenor as that of the fishes; but here it seems that at least one long-ranging (Genesee and Portage) species passes without recognizable modification into the lower part of the Chattanoogan. This apparent Devonian alliance, however, is offset by another plant which unites these lower Chattanoogan beds with one at the extreme top of the series, which all agree is of Mississippian age. Only a few plants are as yet known from the Chattanoogan series. With the exception of the first (*Pseudobornia inornata*) and possibly another, all of the species are confined to this series; or, if represented elsewhere by identical or closely allied forms, these occur in beds that are either definitely known to be of post-Devonian ages or in deposits about which geologists have differed as to whether they should be called Devonian or Mississippian.

10. Minute teeth and plates, known as conodonts, are rather generally distributed in the black shales of the Chattanoogan series and are doubtless the most abundant of its fossils. American authors commonly have compared these with the conodonts of the Genesee shale described by Hinde, forgetting

entirely that such teeth occur also in Carboniferous beds in England, Scotland, Russia, and America. Granting that some of the Chattanoogan conodonts are not readily distinguishable from the late Devonian species, it is nevertheless true that on the whole these two microfaunas are far from identical. On the contrary, it is chiefly among the Mississippian conodonts of Europe and America that the middle and lower Chattanoogan species find their closest allies.

11. Though the general aspect of some of the American faunas of early Mississippian age, especially those in which the pelecypods and corals predominate, like the Conewangs ("Bradfordian") of New York and Pennsylvania, the Bedford of Ohio, the Ridgetop of Tennessee, the Chonopectus sandstone of Iowa, and the Chouteau of Missouri, is decidedly Devonian, the fact that these Devonian reminders are holdovers, in every instance sufficiently modified to be distinguished, must not be ignored. Except the strange types which subsequently invaded from other faunal realms, the Devonian faunas which entered the North American continental basins from the Atlantic and Gulf of Mexico are but earlier developmental facies of the Mississippian faunas of the same basins. Naturally, then, the Devonian characteristics are still obviously displayed in these near descendants. But it is the new things, like *Productus*, which have never been seen in standardized pre-Mississippian formations, that tell the truth unmistakably. As such unquestioned Mississippian types are found in the Mississippi Valley beneath, in, and between each and every one of the pseudo-Devonian faunas mentioned, the assignment of the whole of the Kinderhookian beds in the Mississippi Valley seems fully warranted. Granting this proposition, the case may be said to be established no less firmly with respect to the Chattanoogan series by the physical and faunal relations shown to exist between the latter and the Kinderhookian.

Read in full from manuscript.

The section adjourned at 5 o'clock p. m.

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE THIRD SECTION AND DISCUSSIONS THEREON

The Third Section met at 2.10 o'clock p. m., with Vice-President H. B. Patton in the chair and E. O. Hovey acting as secretary.

ORIGIN OF THE IRON ORES AT KIRUNA, SWEDEN

BY REGINALD A. DALY

(Abstract)

Field data collected in the summer of 1914 suggest that the Kiruna ores, forming probably the largest high-grade iron-ore bodies now being worked in any country, are differentiates *in situ* from a magma, most of which has solidified as the adjacent quartz porphyry. That keratophyric porphyry, like the older syenite porphyry of the district, is believed to be of intrusive origin. The two porphyries together appear to represent a fine example of a composite (double) laccolith, injected into a thick, chiefly volcanic series of bedded rocks

After the injection of the quartz porphyry the magnetite-apatite ores separated out of its magma in small, nodular units. Many of these units settled to the bottom of the quartz porphyry magma, forming the main ore bodies at the contact with the somewhat older, underlying syenite porphyry. Many other units, now angular as well as round, were frozen in at higher levels; these are the ore inclusions of the visible quartz porphyry—bodies which some authors have hitherto regarded as xenoliths, thereby obscuring the genetic problem.

Presented by title in the absence of the author.

ORIGIN OF THE ROCKY MOUNTAIN PHOSPHATE DEPOSITS

BY ELIOT BLACKWELDER

(Abstract)

The author presents this as a preliminary statement concerning the origin of the Rocky Mountain phosphate deposits.

Among the world's known deposits of lime-phosphates at least six genetic varieties have been clearly recognized:

Primary:

Pegmatitic (for example, Norway), Guano (for example, Redonda Island), Marine sediments (for example, Tunis).

Secondary or Metamorphic:

Surface residual concentrations (for example, Quercy), Phosphatized limestone and other rocks (for example, Florida "hard phosphate"), Detrital deposits (for example, Florida "river pebble").

The voluminous Permian (?) phosphate strata of Wyoming, Idaho, and adjacent States are marine sediments analogous to dolomite and limestone. Some points about their origin have already been establishe[illegible] , Girty, Gale, or other observers. These are considered, and to them are added other safe inferences as to the conditions of origin. The Rocky Mountain phosphatic beds apparently resemble those of Algeria-Tunis, Belgium, Wales, Sweden, and Tennessee (Devonian only); but are unlike those of Estremadura (Spain), southern France, Norway, Florida, the Carolinas, and the Peruvian Islands. They belong, therefore, to the third class above noted. The foreign deposits most resembling those of the Rocky Mountains have been carefully studied, and the best interpretations of them, appropriately modified, seem to apply quite as well to our western beds. Omitting arguments, the chief points in the partial explanation thus far elaborated are the following: In the ocean special conditions of currents, temperature, etcetera, not yet understood, may have induced the wholesale killing of animals over a large area and accumulation of the putrefying matter on the sea-floor in moderate and shallow depths. Anerobic decomposition produced ammoniacal solutions which dissolved the solid calcium phosphate present in bones, teeth, brachiopod shells, and tissues. The putrefactive conditions also prevented the existence of sessile bottom organisms, and most calcareous shells descending from the surface were probably dissolved by the abundant carbonic acid arising from the decay. For physico-chemical reasons, already partly understood, the phosphatic materials

were quickly redeposited in the form of hydrous calcium carbo-phosphates, locally filling, incrusting, and replacing shells, teeth, bones, etcetera, but especially forming oolithoid granules of colophanite, and finally a phosphatic cement among all the particles. The granular texture is ascribed chiefly to physico-chemical conditions like those which result in oolithoid greenalite, limonite, aragonite, etcetera. After having been formed in quiet water, some of the granules were reached by bottom-scouring currents and incorporated in clastic deposits, and in some instances were even strewn over eroded rock surfaces, and so became constituents of basal conglomerates.

One of the chief outstanding problems relating to the origin of the western deposits is the nature of the environment capable of supplying the inferred successive layers of animal carcasses. This calls for more exact paleogeographic data than are now available, although plausible suggestions may be presented. Other problems lie in the domain of sea-bottom physics and chemistry and relate to the exact cycle of changes between dissolved apatite washed in from the land and the final precipitation of colophanite on the sea-floor.

Presented by title in the absence of the author.

REGIONAL ALTERATION OF OIL SHALES

BY DAVID WHITE

(*Abstract*)

The examination of "oil rocks," such as cannels and richly bituminous shales which yield petroleums on distillation, lying in or beneath coal-bearing formations, shows that the organic matter of the shales, etcetera, is, in general, regionally altered and carbonized together with the coals, the alteration of the organic debris by the dynamic agencies being parallel in both. A study of the distribution of petroleums and their salient features seems to show that: (1) No commercial pools of oil are to be found in regions where the coals in or above the oil-bearing formations have reached the stage of carbonization at which the fixed carbon (proximate analysis) exceeds 75 per cent of the pure coal, though gas pools diminishing in importance may lie beyond; (2) in regions of complete anthracitization the carbonaceous matter in the associated shales is correspondingly fixed; (3) the oils of pools in regions of relatively high fixed carbon in the rocks are, in general, highest in saturated hydrocarbons, and so highest in hydrogen and lowest in gravity; (4) in passing into zones of successively lesser alteration of the organic debris the oils are of lower rank and the unsaturated and heavier hydrocarbons are, on the whole, more and more in evidence, the lowest grades of oils being found in formations in which the solid fuels are lignitic in rank; (5) while the residues of the organic debris are progressively altered, with the elimination of oxygen, nitrogen, and hydrogen, with some carbon, to composites progressively richer in carbon, the liquid distillates in the rocks as the alteration advances become richer in hydrogen—that is, while the carbonaceous residues in the rocks become more distinctly carbonized their liquid hydrocarbon distillates become more fully hydrogenized, the processes being in a way complementary.

Occurrences of abnormally high grade oil in low grade regions are probably

due either to filtration or to migration from more altered rocks below. In cases of igneous rock metamorphism the effects may be erratic, distillates in small quantities being occluded in the magma, which also may contain inclusions of the mother rock. The limitation of commercial oil pools to regions of not too advanced alteration of the buried carbonaceous deposits bears unfavorably on the "inorganic" theory of the origin of petroleum.

Presented by title in the absence of the author.

OIL POOLS OF SOUTHERN OKLAHOMA AND NORTHERN TEXAS

BY JAMES H. GARDNER

(Abstract)

The Wheeler and Healdton oil pools in southern Oklahoma and the Petrolia and Electra pools in northern Texas owe their origin to distinct folding of strata within the influences of the Arbuckle and Wichita Mountains in southern Oklahoma. Prominent structural features have been produced subsequent to the deposition of the so-called Permian Red Beds which, near the uplifts, lie unconformably on Pennsylvanian and lower beds. The main oil-bearing sands lie in the Pennsylvanian with the exception of the Wheeler pool, which bears oil from the basal member of the Red Beds. Structure contour maps of the Wheeler and Healdton fields compare with Udden's map of the Petrolia field and are typical of the main pools of northern Oklahoma and southern Kansas. Underground stratigraphy from comparison of well logs shows persistence of certain beds useful in the correlation of the oil sands in this newly developed region which offers many possibilities of undeveloped production.

Read in full from manuscript by Arthur M. Miller in the absence of the author.

NATURAL GAS AT CLEVELAND, OHIO

BY FRANK R. VAN HORN

(Abstract)

For many years gas has been found in the Upper Devonian Ohio shales at depths of 600 to 800 feet. From 1905 to 1908 drilling was tried at depths of 2,600 to 2,800 feet in the region west of Cleveland, but with little success. One well is reported to have produced 250,000 cubic feet daily, but most of them were left uncapped. Nothing more was done until about three years ago, when several wells were drilled inside the city limits with considerable success. Early in 1914 a boom developed, and now probably 600 wells have been drilled or are partly finished. All reach about 2,700 feet to the Clinton formation, which is never more than 14 feet thick. It is very difficult to obtain any accurate records, but the reported volume ranges from 10 million cubic feet in some to dry holes in others. Pressures range from 200 to 1,100 pounds per square inch. The writer knows of one well which came in March with over four million cubic feet. In May it was producing but one million cubic feet at a pressure of 350 pounds. Now it has dropped to 100,000 feet

daily. As yet there is no proof of any geological structure to cause the accumulation, which seems to be in a very limited area. The close spacing of the drill holes, which often does not exceed 100 feet, will probably result in a rapid exhaustion of the supply.

Read in full from manuscript.

Remarks were made by Messrs. W. Lindgren and R. S. Woodward, and reply by the author.

ORIGIN OF THICK SALT AND GYPSUM DEPOSITS

BY E. B. BRANSON

(Abstract)

The main difficulties in explaining the origin of thick salt and gypsum deposits which are not in association are: (1) in accounting for basins deep enough to hold the necessary volume of water; (2) in explaining the rarity of other salts in the deposits; (3) in accounting for the absence of salt deposits above the gypsum; (4) in explaining the absence of sedimentary impurities, and (5) in accounting for the absence of fossils. These difficulties are met by a modified bar hypothesis, which assumes that on the drying up of large interior seas the waters became isolated into smaller basins, with marginal basins overflowing on account of receiving the drainage formerly coming into the larger seas, and that in the overflow concentrated waters were brought to the innermost isolated basins, and evaporation from these caused rapid deposition of salt or gypsum. The absence of interbedding of salt and gypsum may be due to the gypsum having been precipitated out before the highly concentrated waters entered the innermost basins.

Read in full from manuscript.

Discussion

Prof. L. V. Pirsson desired to point out that if he understood the purpose of the paper, it seemed to him that the matter of the lateral circulation of saline solutions of differing concentration and density had not been sufficiently discussed. If there were a primary basin of concentration which brought the sea-water to one-fifth the original volume, when fresh water from the drainage basin came in on this it would, from its lower density, float on the heavier solution and rise to the basin rim. An example of this is seen in the Amazon, whose fresh water floats over the sea-water to a great distance out in the ocean when the overflow from the first basin took place. If this is due to seasonal precipitation, it would be largely of fresh water carrying some of the denser solution with it, especially toward the end of the overflow; or, in other words, it is hard to see how the dense solution could be moved out of its basin into the second one without mixing and consequent dilution.

Professor Pirsson also pointed out that in a suitable arrangement of salt lake, bar, and bay, where evaporation was greatest over the latter, it was conceivable that there might be an inward surface current into the bay, a sinking of the concentrating saline water, and an outward bottom current of the denser solution. When the concentration had reached a proper point, there might then be precipitated on the bottom of the bay a single salt, such as gypsum. This process might go on until all the gypsum of the lake was concentrated on the bottom of the bay.

Further remarks were made by Dr. H. M. Ami and the author.

CRYSTALLINE MARBLES OF ALABAMA[1]

BY WM. F. PROUTY

(Abstract)

The crystalline marbles of Alabama occur in a long, narrow, and rather well defined valley, which extends through Talladega and into Coosa County, a distance of about 35 miles. The width of the marble-bearing portion of the valley varies from one-fourth to one and one-half miles. The dip of the marble in this belt is in an easterly direction and at about thirty degrees. To the southeast of the marble occurs the Ocoee phyllite mass, from which the marble is separated for most of the distance by a thrust fault of variable throw. The strike of the marble is consequently often different from the trend of the valley, and the age of the marble at different places varies from Cambrian to Ordovician.

The present development is mainly in the central and southwestern portions, where there is a greater thickness of the marble.

The marble is highly crystalline, medium to fine grained, with markedly interlocking crystals and unusual translucency. Beds of talcose schist constitute the main impurity. A number of grades of marble are marketed, ranging from statuary-white through cream-white and blue-toned to the varieties showing considerable clouding or banding by the greenish-toned schist. The marble is largely used for interior decoration and commands a high price.

The crustal movements in the field are well shown, locally, in the "slicks," drag-folds, and elongated crystals, and the field offers interesting opportunity for the study of the relation of movements to unsoundness. The development work shows the benefit of careful prospecting for lines of unsoundness and directing operations to conform to the lines of structural weakness.

Presented by title in the absence of the author.

The section adjourned at 3.58 o'clock p. m.

ANNUAL DINNER

The annual dinner of the Society was held at the Hotel Walton, about 140 persons participating. E. O. Hovey acted as toastmaster, and the speakers of the evening were W. Lindgren, H. F. Osborn, C. D. Walcott, C. R. Van Hise, W. W. Atwood, and F. R. Van Horn.

[1] By permission of the State Geologist of Alabama.

SESSION OF THURSDAY, DECEMBER 31

The Society convened at 9.37 o'clock a. m., with Vice-President H. B. Patton in the chair.

After sundry announcements by the Secretary, the Society proceeded to the consideration of scientific papers.

TITLES AND ABSTRACTS OF PAPERS PRESENTED IN GENERAL SESSION AND DISCUSSIONS THEREON

PRESENT CONDITION OF THE VOLCANOES OF SOUTHERN ITALY

BY H. S. WASHINGTON AND A. L. DAY

(Abstract)

A brief description of the general condition and state of activity at Vesuvius, Etna, Vulcano, and Stromboli, as observed during the summer of 1914.

Presented in full extemporaneously by the senior author.

RECENT ERUPTIONS OF LASSEN PEAK, CALIFORNIA

BY J. S. DILLER

(Abstract)

Lassen Peak, in northeastern California, at the southern end of the Cascade Range, has long been considered an extinct volcano, but has recently shown signs of rejuvenescence. The first of the recent outbreaks occurred at 5 p. m., May 30, 1914, and since then many eruptions have occurred. The nature of this remarkable phenomenon was illustrated and discussed.

Read in full from manuscript.

Remarks on the paper were made by Messrs. W. J. Miller, J. S. Diller, and H. B. Patton.

PHYSIOGRAPHIC STUDY OF THE CRETACEOUS-EOCENE PERIOD IN THE ROCKY MOUNTAIN FRONT AND GREAT PLAINS PROVINCES

BY GEORGE H. ASHLEY

(Abstract)

The study of the rocks, especially of the coal beds, the structure and the life in the provinces named, appears to indicate that Upper Cretaceous time in that region was occupied by a single movement of subsidence, somewhat irregular, but on the whole persistent; that this was followed by a period of general and differential uplift, to be followed in turn by renewed subsidence, interrupted locally from time to time by pronounced movements of differential uplift. Comparison is made between this interpretation and the assumed con-

ditions in the eastern United States and certain deductions drawn as to the point in the time scale at which the first general uplift occurred.

Presented in abstract extemporaneously.

RELATION OF PHYSIOGRAPHIC CHANGES TO ORE ALTERATIONS

BY WALLACE W. ATWOOD

(*Abstract*)

While a land-mass is being dissected, the ground water table is slowly lowered through that mass until, at the peneplain and baselevel stages, the ground water table remains almost stationary for long periods of time. During successive cycles of erosion the position of the baselevel of erosion in the land-mass being dissected must change, and, if climatic conditions remain constant, such changes are necessarily accompanied by changes in the position of the ground water table. If the land-mass is elevated, the baselevel will be lowered through the land, and the ground water table will be slowly lowered. When a land-mass is depressed the baselevel of erosion and the ground water table are elevated throughout that land-mass. Moist climates will raise the ground water table and dry periods lower that table. As the ground water table is raised or lowered, the zones in which the chemical changes associated with the secondary alteration of ore deposits take place are varied in thickness.

These facts indicate that physiographic studies may be profitably applied in the study of ore alterations, and conversely that the record of ore alterations may furnish important data bearing on the physiographic evolution of the districts concerned.

The study of secondary ores by various investigators has called for intensive physiographic studies. During the past season field-work was done in the vicinity of Butte, Montana, and Bingham Canyon, Utah, to determine the relationship of physiographic evolution to the secondary enrichment of ores in those regions. In this paper the problem of the application of physiography to the investigation of secondary ores was defined and some of the results of the past season's field-work were presented.

Presented in abstract extemporaneously.

GRAPHIC PROJECTION OF PLEISTOCENE CLIMATIC OSCILLATIONS

BY CHESTER A. REEDS

(*Abstract*)

Penck's curve, as presented on page 1168 of "Die Alpen im Eiszeitalter" (1909), expresses graphically the climatic oscillations of the alpine district for Pleistocene and post-Pleistocene time. The key to the four glaciations and the three interglacial stages indicated in the curve was found in the four outwash deposits of glacio-fluvial streams on the northern foreland of the Alps in the vicinity of Ulm and Munich. Along the present stream valleys the glacio-fluvial deposits are arranged in terraces, the oldest occupying the highest position and the youngest the lowest level. When the key was carried in

mind to the French and Italian Alps, the remarkable association of these deposits on the northern foreland was found to be applicable throughout. Hence the names of four small tributaries of the Danube which cross the outwash deposits on the Bavarian plateau—Günz, Mindel, Riss, and Würm—were applied by Penck and Brückner to the 1st, IInd, IIIrd, and IVth glaciations. The deposits of the IIIrd or Riss glaciation in the Swiss and French Jura extend farther out on the foreland than the deposits of the other glacial advances, but in other districts the morainal deposits of the IInd or Mindel stage extend beyond that of any other; hence it is regarded as the most extensive of the four alpine glaciations. The morainal and outwash deposits of the Ist or Günz glaciation are least in evidence, while those of the IVth or Würm glaciation, the last, are most in evidence.

That the temperature of the alpine region was considerably colder during the stages of glaciation than during the interglacial stages and the Present, which is at the close of the retreating hemicycle of the last glaciation, is shown conclusively by the depressed snow-lines. Penck has determined their position in the Alps for all four glaciations. They have a distribution parallel to that of the present snow-line, but occupying lower levels, namely, Günz, 1,200 meters; Mindel, 1,350 meters; Riss, 1,300 meters, and Würm 1,200 meters below the present snow-line. During the interglacial stages the snow-line was approximately 300 meters higher than the present one. From the Höttinger breccia, near Innsbruck, Penck determined that there was a temperature variation of 1° C. for every 200-meter change in the altitude of the snow-line.

The unit of measurement which Penck used in estimating the duration of the Pleistocene period is the retreating hemicycle of glaciation of the IVth or Würm stage, better known as the post-Glacial period. In the alpine district Penck and Brückner found that in this retreating hemicycle there were three minor advances, called the Bühl, Gschnitz, and Daun stadia. These advances were preceded by a prominent minor retreat—the Achen oscillation. From the lignite deposits of Dürnten, the deposits of the Muota deltas, and the turf deposits in many of the glacial swamps it has been possible to estimate the duration of this hemicycle of glaciation in years, as follows:

Subdivisions of post-Glacial Time

	Years
Achen oscillation	9,000
Bühl advance and retreat	5,000
Gschnitz advance and retreat	4,000
Daun advance and retreat	3,000
Age of Copper	1,000
Post-Copper time	3,000
Total	25,000

The estimate on the duration of post-Glacial time in America is based chiefly on the recession of the waterfalls of Niagara and Saint Anthony. Recently Coleman[1] made an estimate based on the rate of wave erosion on the shores of Lake Ontario and glacial Lake Iroquois. Twenty-five thousand years is a fig-

[1] A. P. Coleman: Proceedings Twelfth Intern. Geol. Cong., Canada, 1913.

ure which falls within the estimates made by Coleman, Taylor, Lyell, Chamberlin, and Salisbury. It is a bit under those of Fairchild, Sardeson, and Spencer and above those of Gilbert and Upham. It is considered a conservative figure.

Estimated Duration of Pleistocene Oscillations

Post-Glacial	1	25,000	25,000	1	20,000	20,000
IVth Glacial	1	25,000	50,000	1	20,000	40,000
3rd Interglacial	4	100,000	150,000	3	60,000	100,000
IIIrd Glacial	1	25,000	175,000	1	20,000	120,000
2nd Interglacial	8	200,000	375,000	12	240,000	360,000
IInd Glacial	1	25,000	400,000	1	20,000	380,000
1st Interglacial	3	75,000	475,000	5	100,000	480,000
Ist Glacial	1	25,000	500,000	1	20,000	500,000
Pre-transitional	1	25,000	525,000	1	20,000	520,000
	Units	Years	Totals	Units	Years	Totals
	Reeds 1914			Penck 1909		

Penck states that it must have been 16,000 to 24,000 years from the Bühl stadium to the present, with 20,000 years as an average, and 25,000 to 40,000 years from the beginning of the Achen retreat to the present. In selecting a figure, however, which shall be used as a unit of measurement in calculating the duration of the entire Pleistocene period, he chooses 20,000 years as the length of post-Würm time.

The correlation of the mountain glaciations of the Alps with those of the Scandinavian continental ice-fields of Pleistocene time has not been worked out in all regions, but there is sufficient information at hand to say that there were four advances of the continental ice over northern Europe which correspond to the periods of ice-advance on the alpine forelands. Geikie remapped in 1914 the IInd, IIIrd, and IVth glaciation distribution in Europe. G. de Geer delimited the retreating stages of the IVth glaciation in the Scandinavian peninsula in 1912.

A correlation of American with European glacial deposits has been made by Leverett. By considering with Leverett[2] the so-called Iowan glaciation contemporaneous with the Illinoisan, it is possible to correlate the Günz glaciation

[2] F. Leverett: Zeitschrift fur Gletcherkunde, vol. iv, 1910, pp. 282-283.

with the Nebraskan, the Kansan with the Mindel, the Illinoisan with the Riss, and the Wisconsin, early and late, with the Würm. There are corresponding interglacial stages. With the time units of Chamberlin and Salisbury[3]—2, 4, 8, 16—in mind for the duration of the last three glaciations, based on the degree of weathering of American glacial deposits, it is possible to construct a curve similar to Penck's, but differing in length and the number of units assigned to the interglacial stages. In tabular form the data appear as on page 108.

Presented in abstract from notes.

GEOLOGIC DEPOSITS IN RELATION TO PLEISTOCENE MAN

BY CHESTER A. REEDS

(Abstract)

The present known distribution of Pleistocene man through southern Europe, the Mediterranean border, and Java points to the conclusion that this early man lived along river courses, on the adjacent uplands, in caves and grottoes which overlooked well defined river valleys, and on the seashore. Human remains have been found entombed in a few caves within the region of mountain glaciation—for example, Freudenthal, Kesslerloch, and Schweizersbild, in Switzerland—but most of the finds have been made in the southern non-glaciated portions of Europe. The vicissitudes and the ameliorations of climate during the glacial and interglacial stages no doubt caused southward or northward migrations of peoples or encouraged congestion in the limestone caverns of Belgium, France, Germany, and northern Spain. With the repeated formation of continental ice-sheets on the Scandinavian plateau during periods of glaciation and their movement outward in all directions across the adjacent basins and lowlands of northern Europe, together with the appearance of ice-caps on the high mountains of southern Europe, the lowering of the snow-line on the mountain slopes, the development of snow-caps on plateaus of but moderate relief, the extension of the glaciers into aprons and tongues on the piedmont areas, and the choking of the river valleys with ice and deposits, glacial man must have felt that snow and ice were the governing forces. The warmer interglacial epochs were more to his liking. In the present terrace and loess deposits along the river courses and in the cave and grotto fillings eight human culture stages have been delimited within recent years. They have been called, beginning at the bottom, pre-Chellean, Chellean, Acheulean, and Mousterian as Lower Paleolithic, and Aurignacian, Solutrean, Magdalenian, and Azylian-Tardenoisan as Upper Paleolithic. In the cavern and grotto deposits of the Dordogne, southern France, most of the culture stages appear in regular geologic sequence one above the other. Human remains and culture stations of Glacial, inter-Glacial, or post-Glacial age have been found in approximately three hundred different localities.

Presented in abstract from notes.

[3] Chamberlin and Salisbury: Text Book of Geology, vol. III, 1906, p. 414.

PHYSIOGRAPHIC FEATURES OF WESTERN EUROPE AS A FACTOR IN THE WAR

BY DOUGLAS W. JOHNSON

(Abstract)

Every military campaign is controlled to some extent by the surface features of the country over which the contending armies must move. The physiography of a region may therefore profoundly affect both the detailed movements of armies and the general plans of campaign. An examination of the physiographic features of western Europe in the light of recent events enables one to comprehend more fully the strategic importance of many places mentioned in war dispatches and throws valuable light upon the question as to why the neutrality of Belgium was violated.

Presented in abstract extemporaneously.

VOTE OF THANKS

The following vote of thanks was passed:

The Geological Society of America desires to express its most cordial thanks to the Academy of Natural Sciences of Philadelphia for hospitality extended to the Society on the occasion of its twenty-seventh annual meeting.

The Society desires further to express to its local committee its high appreciation of the indefatigable labors which have resulted in one of the most successful meetings in the Society's history and for the generous hospitality manifested by the provision of daily luncheons and the general smoker of Tuesday evening.

JOHN BOYD THACHER PARK: THE HELDERBERG ESCARPMENT AS A GEOLOGICAL PARK

BY GEORGE F. KUNZ

(Abstract)

A most important benefaction to the State of New York is the beautiful John Boyd Thacher Park, opened with appropriate ceremonies September 14, 1914. During the winter of 1913-1914 the American Scenic and Historic Preservation Society cooperated with Mrs. Emma Treadwell Thacher, widow of John Boyd Thacher, to realize her generous purpose of donating to the State a superb trust of 350 acres of land for a public park, as a memorial of her husband, and in March, 1914, a bill was introduced and passed in the legislature accepting the gift and constituting the American Scenic and Historic Preservation Society the custodian. The park embraces the most picturesque and geologically interesting part of the Helderberg range in Albany County.

The remarkable geologic formations to be seen in this park include one of the finest exposures of the Upper Silurian and Devonian strata in the country and offer classic types of several formations, as is shown by the designations

"Helderberg limestone" and "Helderberg group"; the rocks contain a great number of characteristic fossils, especially of marine forms. On the slope appear Hudson shales, and flaggy sandstones of the Hamilton formation crown Countryman Hill. The deep amphitheater at Indian Ladder has been worn out by the water of a small stream.

There is now a small museum and library in the park, and the Geological Survey has set up a bench-mark. It is hoped that very soon the cottage building for the reception of guests will be completed, so as to afford comfortable shelter for visiting geologists who wish to study this Mecca of geologists. The library would be glad to receive geological publications having any bearing on the local conditions; such mail should be addressed to the Curator of John Boyd Thacher Park, East Berne, New York.

Presented by title in the absence of the author.

The next paper was on address made by Mr. Diller as retiring Vice-President of Section E of the American Association for the Advancement of Science, under the title

RELIEF OF OUR PACIFIC COAST

BY J. S. DILLER

(Abstract)

The continental feature bordering the Pacific coast of the United States is a mountain belt of surpassing grandeur and composed in general of two lines or ranges of mountain elevations with a depression between. For the most part the two lines of mountains appear to be parallel with each other and the coast, the Sierra Nevada and the Cascade ranges on the east and the Coast ranges, including the Klamath Mountains of California and Oregon and the Olympic Mountains of Washington, on the west, from the Mexican line to that of British Columbia. Cross-folds connect the side ranges and separate the great valley of California from the Willamette Valley of Oregon.

The Sierra Nevada is composed of folded sediments and igneous rocks of various ages, from Silurian to Jurassic, and faulted and tilted as one great block, with long gentle slope to the west and steep slope to the east.

The Cascade Range is essentially volcanic and due mainly to volcanic upbuilding, though partly to uplifting, from Mount Adams, in Washington, to Lassen Peak, in California; but beyond these limits the older crystalline rocks rise to the surface.

The Klamath Mountains are in large measure like the Sierra Nevada in their rocks, although more fossiliferous, but differ in structure, being characterized by broadly curved thrust-faults with the overthrust into the concave curve and thus toward the Pacific Ocean.

The Coast Ranges of California and Oregon are composed almost wholly of Mesozoic and Tertiary rocks. In California the Coast Range rocks are greatly crushed and faulted, but in Oregon the compression has been much less intense.

The section adjourned at 1 o'clock p. m.

TITLES AND ABSTRACTS OF PAPERS PRESENTED BEFORE THE SECOND SECTION

On Thursday morning the Second Section continued the reading of papers, meeting in conjunction with the Paleontological Society, as follows:

DEVONIAN OF CENTRAL MISSOURI

BY E. B. BRANSON AND D. K. GREGER

(Abstract)

The Devonian of central Missouri consists of five thin formations. The lowest of these, which occurs in the eastern part of central Missouri, contains a fauna closely related to that of the Jeffersonville limestone of Indiana. In the western part of the area a thin formation of about the same age contains no species in common with the eastern formation, but bears a fauna closely related to that of the Otis beds of Iowa. The Callaway limestone lies unconformably on both formations and is followed in the western part of the area by the Craghead Creek shale, and both formations bear faunas similar to those of the Upper Devonian of Iowa. In northeastern Missouri the formation bearing the Jeffersonville fauna is succeeded by a thin black shale, the main fauna of which consists of lingulas and dinichthyids.

Presented in abstract extemporaneously by the senior author.

Discussed by Messrs. Schuchert and Savage, with replies by Professor Branson.

On account of their connection with the black shale problem, Professor Grabau was requested at this point to give two papers listed under the Paleontological Society's program.

OLENTANGY SHALE OF CENTRAL OHIO AND ITS STRATIGRAPHIC SIGNIFICANCE

BY AMADEUS W. GRABAU

(Abstract)

In its typical localities the Olentangy shale is intimately associated with the Huron shale, this latter representing merely a change in facies, without interruption of stratigraphic continuity. The Olentangy clearly belongs to the Upper Devonic, resting disconformably on limestones of Lower Hamilton age. The shales and limestones classed as Olentangy in northern Ohio are, however, early Hamilton, and considerably older than the Olentangy. This name should therefore not be used for strata of Hamilton age, but instead the name Prout series is proposed for the northern Ohio deposits of Hamilton age.

Presented in abstract extemporaneously.

HAMILTON GROUP OF WESTERN NEW YORK

BY AMADEUS W. GRABAU

(Abstract)

The various subdivisions originally made by the author for the Hamilton of Eighteen Mile Creek have been correlated with a similar number of subdivisions in central New York by the New York Survey. The validity of this correlation will be considered and the facts suggesting that an error has been made will be given. A new series of names for these subdivisions will be prepared. A brief comparison with the Traverse group of Michigan will be made.

Presented in abstract extemporaneously.

Discussion

A general and extended discussion of the black shale problem then followed, which was participated in by Messrs. David White, Edward M. Kindle, I. C. White, Charles S. Prosser, A. W. Grabau, E. O. Ulrich, H. P. Cushing, M. Y. Williams, and A. F. Foerste.

EXTENSION OF MORRISON FORMATION INTO NEW MEXICO

BY N. H. DARTON

(Abstract)

During the past few years the author has examined nearly the entire outcrop zone of the Red Beds and their contact with overlying rocks. It has been found that in the northern half of the State the Red Beds are overlain by deposits having all the characteristics of the Morrison formation in Colorado, and in part of the area the outcrop is continuous from one State into the other.

Presented by title in the absence of the author.

GEOLOGICAL RECONNAISSANCE OF PORTO RICO

BY CHARLES P. BERKEY

(Abstract)

This paper was based on work of exploration continued for a month during the season of 1914 under the joint support of the New York Academy of Sciences and the insular government of Porto Rico. The primary purpose of the reconnaissance was to determine the character and structural relations of the principal geologic formations of the island and to carry forward investigations far enough to indicate some of the problems that should be made the objects of special study in work which is to follow. Systematic observations were made on two lines entirely across the island in sufficient detail to furnish data for general geologic cross-sections. These sections have been drawn and illustrate the fundamental structure of the island, as well as the geologic basis of its relief.

There are two fundamentally different series of formations separated by an unconformity. The older series is a complex of tuffs, shales, conglomerates, and limestones, cut in a complex way by very numerous and occasionally very large intrusive masses, chiefly of dioritic composition. In many parts of the island these beds show complicated structural relations and much disturbance. The younger series is of Tertiary age and is essentially a succession of marls and limestone reefs and shale beds of considerable variety, but not affected at all by igneous activity or very complicated dynamic disturbances.

Peculiar erosional effects are produced in certain districts where this latter formation is the underlying rock, and in some districts the inner margin of the limestone belt, which is usually a narrow strip along the coast, develops into a pronounced cuesta form. The unconformity between the two great series is represented by an obscurely marked peneplain, which bevels across all of the complicated structures of the older series; but, except in the immediate vicinity of the limestone margin, there is scarcely a trace of this plain to be seen, because of the maturity of dissection.

A large number of photographs were taken to represent the characteristic features, and a collection of typical rocks and fossils was made which are now being studied.

Presented in abstract extemporaneously.

Discussed by Messrs. Charles Schuchert and Gilbert van Ingen.

RELATION OF CRETACEOUS FORMATIONS TO THE ROCKY MOUNTAINS IN COLORADO AND NEW MEXICO

BY WILLIS T. LEE

(*Abstract*)

The paper presented evidence that the unconformity in the Rocky Mountain region, known as the post-Laramie, post-Vermejo, or post-Cretaceous, according to locality, is of such magnitude and extent as appropriately to constitute the Cretaceous-Tertiary boundary for this region. In opposition to the view that highlands or large "islands" persisted in the Rocky Mountain region throughout Cretaceous time, the facts now available indicate that the Dakota sandstone was laid down on a baseleveled surface, and that it originally extended continuously over the present mountainous area of Colorado and New Mexico; also that the succeeding beds of Upper Cretaceous age covered this area. Whatever surface warpings may have occurred during Cretaceous time, there seems to have been formed in the Rocky Mountain region no barrier that seriously interfered with the free distribution of the sediments in the interior Cretaceous sea. When the post-Laramie uplift occurred these sediments must have been removed before the pre-Cretaceous rocks could furnish the pebbles found in the basal conglomerate of the post-Laramie formations. If the Cretaceous sedimentaries extended over the mountains with anything like the thicknesses found on either side and also within the mountains, the uplift necessary to obtain these pebbles indicates an orogenic movement of such magnitude as to denote the close of the long period of Cretaceous quiescence and to inaugurate the tumultuous period of orogenic disturbances of the Tertiary.

Presented in abstract extemporaneously.

POST-ORDOVICIAN DEFORMATION IN THE SAINT LAWRENCE VALLEY, NEW YORK

BY GEORGE H. CHADWICK

(*Abstract*)

On the Canton quadrangle the Cambrian and Ordovician strata are notably undulatory, the low anticlines trending with the Saint Lawrence Valley. These Paleozoic structures bear some evident relations to the belts of pre-Cambrian rocks underlying. The more intense disturbances represent pinchings within pre-Cambrian valleys cut along Grenville limestone belts.

Presented by title in the absence of the author.

Adjourned at 12.30 o'clock p. m.

Register of the Philadelphia Meeting, 1914.

FELLOWS

William C. Alden
Henry M. Ami
George H. Ashley
Wallace W. Atwood
Joseph Barrell
Florence Bascom
R. S. Bassler
W. S. Bayley
Charles P. Berkey
Edward W. Berry
E. B. Branson
Amos P. Brown
Barnum Brown
B. S. Butler
Stephen R. Capps
William B. Clark
John M. Clarke
H. F. Cleland
A. J. Collier
Alja R. Crook
Whitman Cross
E. R. Cummings
Henry P. Cushing
N. H. Darton
Charles A. Davis
Edward V. d'Invilliers
J. S. Diller
C. R. Eastman
Herman L. Fairchild
Clarence N. Fenner
August F. Foerste
C. E. Gordon
Charles H. Gordon
Amadeus W. Grabau
Walter Granger
Herbert E. Gregory
George P. Grimsley
Baird Halberstadt
Chris A. Hartnagel
C. W. Hayes
Richard R. Hice
Arthur Hollick
Ernest Howe
E. O. Hovey
L. Hussakof
Douglas W. Johnson
George F. Kay
J. F. Kemp

E. M. Kindle
Cyril W. Knight
S. H. Knight
Adolph Knopf
F. H. Knowlton
Henry B. Kummel
Willis T. Lee
J. Volney Lewis
Richard S. Lull
S. W. McCallie
George C. Martin
W. C. Mendenhall
George P. Merrill
Arthur M. Miller
Benjamin L. Miller
W. G. Miller
William J. Miller
Fred H. Moffit
Ida H. Ogilvie
Henry F. Osborn
Sidney Paige
Horace B. Patton
R. A. F. Penrose, Jr.
George H. Perkins
Louis V. Pirsson
Joseph E. Pogue
Joseph H. Pratt
Charles S. Prosser
A. H. Purdue
Percy E. Raymond
Harry Fielding Reid
William N. Rice
John L. Rich
Heinrich Ries
T. E. Savage
F. C. Schrader
Charles Schuchert
E. H. Sellards
William J. Sinclair
Joseph T. Singewald, Jr.
Burnett Smith
George Otis Smith
Philip S. Smith
C. H. Smyth, Jr.
J. Stanley-Brown
Timothy W. Stanton
Lloyd W. Stephenson
Ralph W. Stone
George W. Stose
Charles K. Swartz
Mignon Talbot
Frank B. Taylor
M. W. Twitchell
Joseph B. Umpleby
Frank R. Van Horn
Gilbert Van Ingen
Thomas W. Vaughan
C. D. Walcott
Henry S. Washington
Thomas L. Watson
Walter Harvey Weed
Carroll H. Wegemann
Lewis G. Westgate
G. R. Wieland
A. W. G. Wilson
John E. Wolff
David White
I. C. White

FELLOW-ELECT

R. J. Holden

In addition to the foregoing, there were registered at the meeting 7 members of the Paleontological Society, 6 members of the American Association for the Advancement of Science, and 62 visitors, including wives of members and specially invited assistants and students.

OFFICERS, CORRESPONDENTS, AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1915

President:

Arthur P. Coleman, Toronto, Canada

Vice-Presidents:

L. V. Pirsson, New Haven, Conn.
H. P. Cushing, Cleveland, Ohio
Edward O. Ulrich, Washington, D. C.

Secretary:

Edmund Otis Hovey, American Museum of Natural History, New York, N. Y.

Treasurer:

Wm. Bullock Clark, Johns Hopkins University, Baltimore, Md.

Editor:

J. Stanley-Brown, 26 Exchange Place, New York, N. Y.

Librarian:

F. R. Van Horn, Cleveland, Ohio

Councilors:

(Term expires 1915)

Whitman Cross, Washington, D. C.
Willet G. Miller, Toronto, Canada

(Term expires 1916)

R. A. F. Penrose, Jr., Philadelphia, Pa.
W. W. Atwood, Cambridge, Mass.

(Term expires 1917)

Charles K. Leith, Madison, Wis.
Thomas L. Watson, Charlottesville, Va.

MEMBERSHIP, 1914

CORRESPONDENTS

Charles Barrois, Lille, France. December, 1909.
W. C. Brögger, Christiania, Norway. December, 1909.
Giovanni Capellini, Bologna, Italy. December, 1910.
Baron Gerhard De Geer, Stockholm, Sweden. December, 1910.
Sir Archibald Geikie, Hasslemere, England. December, 1909.
Albert Heim, Zürich, Switzerland. December, 1909.
Emanuel Kayser, Marburg, Germany. December, 1909.
W. Kilian, Grenoble, France. December, 1912.
J. J. H. Teall, London, England. December, 1912.
Emil Tietze, Vienna, Austria. December, 1910.

FELLOWS

*Indicates Original Fellow (see article III of Constitution)

Cleveland Abbe, Jr., U. S. Weather Bureau, Washington, D. C. August, 1899.
Frank Dawson Adams, McGill University, Montreal, Canada. Dec., 1889.
George I. Adams, Pei Yang University, Tientsin, China. December, 1902.
José Guadalupe Aguilera, Instituto Geologico, Mexico, Mexico. Aug., 1896.
William Clinton Alden, U. S. Geological Survey, Washington, D. C. December, 1909.
Truman H. Aldrich, Birmingham, Ala. May, 1889.
John A. Allan, University of Alberta, Strathcona, Canada. December, 1914.
R. C. Allen, State Geologist, Lansing, Mich. December, 1911.
Henry M. Ami, Geological and Natural History Survey of Canada, Ottawa, Canada. December, 1889.
Frank M. Anderson, State Mining Bureau, 2604 Ætna St., Berkeley, Cal. June, 1902.
Robert Van Vleck Anderson, 71 Richmond Terrace, Whitehall, S. W., London, England. December, 1911.
Ralph Arnold, 923 Union Oil Building, Los Angeles, Cal. December, 1904.
George Hall Ashley, U. S. Geological Survey, Washington, D. C. Aug., 1895.
Wallace Walter Atwood, Harvard University, Cambridge, Mass. Dec., 1909.
Rufus Mather Bagg, Jr., Lawrence College, Appleton, Wis. December, 1896.
Harry Foster Bain, 420 Market St., San Francisco, Cal. December, 1895.
Manley Benson Baker, School of Mining, Kingston, Ontario. Dec., 1911.
S. Prentiss Baldwin, 2930 Prospect Ave., Cleveland, Ohio. August, 1895.
Sydney H. Ball, 71 Broadway, New York City. December, 1905.
Joseph A. Bancroft, McGill University, Montreal, Canada. December, 1914.
Erwin Hinckley Barbour, University of Nebraska, Lincoln, Neb. Dec., 1896.
Joseph Barrell, Yale University, New Haven, Conn. December, 1902.
George H. Barton, Boston Society of Natural History, Boston, Mass. August, 1890.
Florence Bascom, Bryn Mawr College, Bryn Mawr, Pa. August, 1894.
Ray Smith Bassler, U. S. National Museum, Washington, D. C. Dec., 1906.
Edson Sunderland Bastin, U. S. Geological Survey, Washington, D. C. December, 1909.

William S. Bayley, University of Illinois, Urbana, Ill. December, 1888.
*George F. Becker, U. S. Geological Survey, Washington, D. C.
Joshua W. Beede, Indiana University, Bloomington, Ind. December, 1902.
Robert Bell, Geological Survey, Department of Mines, Ottawa, Canada. May, 1889.
Charles P. Berkey, Columbia University, New York, N. Y. August, 1901.
Edward Wilber Berry, Johns Hopkins University, Baltimore, Md. Dec., 1909.
Samuel Walker Beyer, Iowa Agricultural College, Ames, Iowa. Dec., 1896.
Arthur B. Bibbins, Goucher College, Baltimore, Md. December, 1903.
Eliot Blackwelder, University of Wisconsin, Madison, Wis. Dec., 1908.
John M. Boutwell, 1323 De la Vine St., Santa Barbara, Cal. Dec., 1905.
John Adams Bownocker, Ohio State University, Columbus, Ohio. Dec., 1904.
*John C. Branner, Leland Stanford, Jr., University, Stanford University, Cal.
Edwin Bayer Branson, University of Missouri, Columbia, Mo. Dec., 1911.
Albert Perry Brigham, Colgate University, Hamilton, N. Y. December, 1893.
Reginald W. Brock, University of British Columbia, Vancouver, B. C. December, 1904.
Alfred Hulse Brooks, U. S. Geological Survey, Washington, D. C. Aug., 1899.
Amos P. Brown, University of Pennsylvania, Philadelphia, Pa. Dec., 1905.
Barnum Brown, American Museum of Natural History, New York, N. Y. December, 1910.
Charles Wilson Brown, Brown University, Providence, R. I. Dec., 1908.
Henry Andrew Buehler, Rolla, Mo. December, 1909.
Bert S. Butler, U. S. Geological Survey, Washington, D. C. December, 1912.
G. Montague Butler, School of Mines, Corvallis, Oregon. December, 1911.
Charles Butts, U. S. Geological Survey, Washington, D. C. December, 1912.
De Lorme Donaldson Cairnes, Geological Survey Branch, Department of Mines, Ottawa, Canada. December, 1912.
Fred Harvey Hall Calhoun, Clemson College, S. C. December, 1909.
Frank C. Calkin, U. S. Geological Survey, Washington, D. C. Dec., 1914.
Henry Donald Campbell, Washington and Lee University, Lexington, Va. May, 1889.
Marius R. Campbell, U. S. Geological Survey, Washington, D. C. Aug., 1892.
Charles Camsell, Geological Survey of Canada, Ottawa, Canada. December, 1914.
Stephen Reid Capps, Jr., U. S. Geological Survey, Washington, D. C. Dec., 1911.
Frank Carney, Granville, Ohio. December, 1908.
Ermine C. Case, University of Michigan, Ann Arbor, Mich. December, 1901.
George Halcott Chadwick, University of Rochester, Rochester, N. Y. December, 1911.
Rollin T. Chamberlin, University of Chicago, Chicago, Ill. December, 1913.
*T. C. Chamberlin, University of Chicago, Chicago, Ill.
Clarence Raymond Claghorn, Tacoma, Wash. August, 1891.
Charles H. Clapp, University of Arizona, Tucson, Arizona. December, 1914.
Frederick G. Clapp, 502 Fitzsimons Bldg., Pittsburgh, Pa. December, 1905.
*William Bullock Clark, Johns Hopkins University, Baltimore, Md.
John Mason Clarke, Albany, N. Y. December, 1897.
Herdman F. Cleland, Williams College, Williamstown, Mass. Dec., 1905.

J. MORGAN CLEMENTS, 20 Broad St., New York City. December, 1894.
COLLIER COBB, University of North Carolina, Chapel Hill, N. C. Dec., 1894.
ARTHUR P. COLEMAN, Toronto University, Toronto, Canada. December, 1896.
GEORGE L. COLLIE, Beloit College, Beloit, Wis. December, 1897.
ARTHUR J. COLLIER, U. S. Geological Survey, Washington, D. C. June, 1902.
*THEODORE B. COMSTOCK, Van Nuys Bldg., Los Angeles, Cal.
EUGENE COSTE, 1943 11th St., West, Calgary, Alberta, Canada. Dec., 1906.
ALJA ROBINSON CROOK, State Museum of Natural History, Springfield, Ill. December, 1898.
*WILLIAM O. CROSBY, Massachusetts Institute of Technology, Boston, Mass.
WHITMAN CROSS, U. S. Geological Survey, Washington, D. C. May, 1889.
GARRY E. CULVER, 1104 Wisconsin St., Stevens Point, Wis. December, 1891.
EDGAR R. CUMINGS, Indiana University, Bloomington, Ind. August, 1901.
*HENRY P. CUSHING, Adelbert College, Cleveland, Ohio.
REGINALD A. DALY, Harvard University, Cambridge, Mass. December, 1905.
EDWARD SALISBURY DANA, Yale University, New Haven, Conn. Dec., 1908.
*NELSON H. DARTON, U. S. Geological Survey, Washington, D. C.
CHARLES ALBERT DAVIS, U. S. Bureau of Mines, Washington, D. C. Dec., 1910.
*WILLIAM M. DAVIS, Harvard University, Cambridge, Mass.
ARTHUR LOUIS DAY, Geophysical Laboratory, Carnegie Institution, Washington, D. C. December, 1909.
DAVID T. DAY, U. S. Geological Survey, Washington, D. C. August, 1891.
BASHFORD DEAN, Columbia University, New York, N. Y. December, 1910.
ORVILLE A. DERBY, Serv. Geol. & Mineral. d'Brazil, Praia Vermillia, Rio de Janeiro, Brazil. December, 1890.
FRANK WILBRIDGE DE WOLF, Urbana, Ill. December, 1909.
*JOSEPH S. DILLER, U. S. Geological Survey, Washington, D. C.
EDWARD V. D'INVILLIERS, 518 Walnut St., Philadelphia, Pa. December, 1888.
RICHARD E. DODGE, Teachers' College, New York, N. Y. August, 1897.
NOAH FIELDS DRAKE, Fayetteville, Arkansas. December, 1898.
JOHN ALEXANDER DRESSER, 10 Forest Ave., Saulte Ste. Marie, Ontario, Canada. December, 1906.
CHARLES R. DRYER, Oak Knoll, Fort Wayne, Ind. August, 1897.
*EDWIN T. DUMBLE, 1306 Main St., Houston, Texas.
ARTHUR S. EAKLE, University of California, Berkeley, Cal. December, 1899.
CHARLES R. EASTMAN, American Museum of Natural History, New York, N. Y. December, 1895.
EDWIN C. ECKEL, Munsey Building, Washington, D. C. December, 1905.
*BENJAMIN K. EMERSON, Amherst College, Amherst, Mass.
WILLIAM HARVEY EMMONS, University of Minnesota, Minneapolis, Minn. December, 1912.
JOHN EYERMAN, Oakhurst, Easton, Pa. August, 1891.
HAROLD W. FAIRBANKS, Berkeley, Cal. August, 1892.
*HERMAN L. FAIRCHILD, University of Rochester, Rochester, N. Y.
OLIVER C. FARRINGTON, Field Museum of Natural History, Chicago, Ill. December, 1895.
NEVIN M. FENNEMAN, University of Cincinnati, Cincinnati, Ohio. Dec., 1904.
CLARENCE NORMAN FENNER, Geophysical Laboratory, Washington, D. C. December, 1911.

Cassius Asa Fisher, 711 Ideal Building, Denver, Colo. December, 1908.
August F. Foerste, 128 Rockwood Ave., Dayton, Ohio. December, 1899.
Myron Leslie Fuller, 185 Spring St., Brockton, Mass. December, 1898
Henry Stewart Gane, Wonalancet, New Hampshire. December, 1896.
James H. Gardner, 212 Clinton Bldg., Tulsa, Oklahoma. December, 1911.
Russell D. George, University of Colorado, Boulder, Colo. December, 1906
*Grove K. Gilbert, U. S. Geological Survey, Washington, D. C.
Adam Capen Gill, Cornell University, Ithaca, N. Y. December, 1888.
L. C. Glenn, Vanderbilt University, Nashville, Tenn. June, 1900.
James Walter Goldthwait, Dartmouth College, Hanover, N. H. Dec., 1909.
Charles H. Gordon, University Library, University of Tennessee, Knoxville, Tenn. August, 1893.
Clarence E. Gordon, Massachusetts Agricultural College, Amherst, Mass. December, 1913.
Charles Newton Gould, 408 Terminal Bldg., Oklahoma City, Okla. December, 1904.
Amadeus W. Grabau, Columbia University, New York, N. Y. December, 1898.
Walter Granger, American Museum of Natural History, New York, N. Y. December, 1911.
Ulysses Sherman Grant, Northwestern University, Evanston, Ill. Dec., 1890.
John Sharshall Grasty, University of Virginia, University, Va. Dec., 1911.
Louis C. Graton, Harvard University, Cambridge, Mass. December, 1913.
Herbert E. Gregory, Yale University, New Haven, Conn. August, 1901.
George P. Grimsley, Geological Survey of West Virginia, Martinsburg, W. Va. August, 1895.
Leon S. Griswold, Plymouth, Mass. August, 1902.
Frederic P. Gulliver, 1112 Morris Bldg., Philadelphia, Pa. August, 1895.
William F. E. R. Gurley, University of Chicago, Chicago, Ill. Dec., 1914.
Arnold Hague, U. S. Geological Survey, Washington, D. C. May, 1889.
Baird Halberstadt, Pottsville, Pa. December, 1909.
Gilbert D. Harris, Cornell University, Ithaca, N. Y. December, 1903.
John Burchmore Harrison, Georgetown, British Guiana. June, 1902.
Chris. A. Hartnagel, State Museum, Albany, N. Y. December, 1913.
John B. Hastings, 1480 High St., Denver, Colo. May, 1889.
*Erasmuth Haworth, University of Kansas, Lawrence, Kans.
C. Willard Hayes, 47 Parliament St., London, England. May, 1889.
Ray Vernon Hennen, West Virginia Geological Survey, Morgantown, W. Va. December, 1914.
Oscar H. Hershey, Kellogg, Idaho. December, 1909.
Richard R. Hice, Beaver, Pa. December, 1903.
Frank A. Hill, 1315 Mahantango St., Pottsville, Pa. May, 1889.
*Robert T. Hill, Federal Bldg., Los Angeles, Cal.
Richard C. Hills, Denver, Colo. August, 1894.
Henry Hinds, U. S. Geological Survey, Washington, D. C. December, 1912.
*Charles H. Hitchcock, Honolulu, Hawaiian Islands.
William Herbert Hobbs, University of Michigan, Ann Arbor, Mich. August, 1891.
*Levi Holbrook, P. O. Box 536, New York, N. Y.
Roy J. Holden, Virginia Polytechnic Institute, Blacksburg, Va. Dec., 1914.

William Jacob Holland, Carnegie Museum, Pittsburgh, Pa. December, 1910.
Arthur Hollick, Staten Island Association of Arts and Sciences, New Brighton, S. I. August, 1898.
*Joseph A. Holmes, U. S. Bureau of Mines, Washington, D. C.
Thomas C. Hopkins, Syracuse University, Syracuse, N. Y. December, 1894.
William Otis Hotchkiss, State Geologist, Madison, Wis. December, 1911.
*Edmund Otis Hovey, American Museum of Natural History, New York, N. Y.
Ernest Howe, 77 Rhode Island Ave., Newport, R. I. December, 1903.
George D. Hubbard, Oberlin College, Oberlin, Ohio. December, 1914.
Lucius L. Hubbard, Houghton, Mich. December, 1894.
Walter F. Hunt, University of Michigan, Ann Arbor, Mich. December, 1914.
Ellsworth Huntington, Yale University, New Haven, Conn. Dec., 1906.
Louis Hussakof, American Museum of Natural History, New York, N. Y. December, 1910.
Joseph P. Iddings, Brinklow, Md. May, 1889.
John D. Irving, Yale University, New Haven, Conn. December, 1905.
A. Wendell Jackson, 432 Saint Nicholas Ave., New York, N. Y. Dec., 1888.
Robert T. Jackson, 195 Bay State Road, Boston, Mass. August, 1894.
Thomas Augustus Jaggar, Jr., Hawaiian Volcano Observatory, Territory of Hawaii, U. S. A. December, 1906.
Mark S. W. Jefferson, Michigan State Normal College, Ypsilanti, Mich. December, 1904.
Edward C. Jeffrey, Harvard University, Cambridge, Mass. December, 1914.
Albert Johannsen, University of Chicago, Chicago, Ill. December, 1908.
Douglas Wilson Johnson, Columbia University, New York, N. Y. Dec., 1906.
Alexis A. Julien, South Harwich, Mass. May, 1889.
Frank James Katz, U. S. Geological Survey, Washington, D. C. Dec., 1912.
George Frederick Kay, State University of Iowa, Iowa City, Iowa. Dec., 1908.
Arthur Keith, U. S. Geological Survey, Washington, D. C. May, 1889.
*James F. Kemp, Columbia University, New York, N. Y.
Charles Rollin Keyes, 944 Fifth St., Des Moines, Iowa. August, 1890.
Edward M. Kindle, Victoria Memorial Museum, Ottawa, Canada. Dec., 1905.
Edwin Kirk, U. S. Geological Survey, Washington, D. C. December, 1912.
Cyril Workman Knight, Toronto, Ontario, Canada. December, 1911.
Adolph Knopf, U. S. Geological Survey, Washington, D. C. December, 1911.
Frank H. Knowlton, U. S. National Museum, Washington, D. C. May, 1889.
Edward Henry Kraus, University of Michigan, Ann Arbor, Mich. June, 1902.
Henry B. Kümmel, Trenton, N. J. December, 1895.
*George F. Kunz, 401 Fifth Ave., New York, N. Y.
George Edgar Ladd, State College, N. M. August, 1891.
Lawrence Morris Lambe, Department of Mines, Ottawa, Canada. Dec., 1911.
Henry Landes, University of Washington, University Station, Seattle, Wash. December, 1908.
Alfred C. Lane, Tufts College, Mass. December, 1889.
Esper S. Larsen, Jr., U. S. Geological Survey, Washington, D. C. Dec., 1914.
Andrew C. Lawson, University of California, Berkeley, Cal. May, 1889.
Willis Thomas Lee, U. S. Geological Survey, Washington, D. C. Dec., 1903.
James H. Lees, Iowa Geological Survey, Des Moines, Iowa. December, 1914.
Charles K. Leith, University of Wisconsin, Madison, Wis. Dec., 1902.

ARTHUR G. LEONARD, State University of North Dakota, Grand Forks, N. Dak December, 1901.

FRANK LEVERETT, Ann Arbor, Mich. August, 1890.

JOSEPH VOLNEY LEWIS, Rutgers College, New Brunswick, N. J. Dec., 1906.

WILLIAM LIBBEY, Princeton University, Princeton, N. J. August, 1899.

WALDEMAR LINDGREN, Massachusetts Institute of Technology, Boston, Mass. August, 1890.

MIGUEL A. R. LISBOA, Irrigation and Water Supply Service, Rio de Janeiro, Brazil. December, 1913.

FREDERICK BREWSTER LOOMIS, Amherst College, Amherst, Mass. Dec., 1909.

GEORGE DAVIS LOUDERBACK, University of California, Berkeley, Cal. June, 1902.

ROBERT H. LOUGHRIDGE, University of California, Berkeley, Cal. May, 1889.

ALBERT P. LOW, Department of Mines, Ottawa, Canada. December, 1905.

RICHARD SWANN LULL, Yale University, New Haven, Conn. December, 1909.

SAMUEL WASHINGTON McCALLIE, Atlanta, Ga. December, 1909.

HIRAM DEYER McCASKEY, U. S. Geological Survey, Washington, D. C. December, 1904.

RICHARD G. McCONNELL, Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.

JAMES RIEMAN MACFARLANE, Woodland Road, Pittsburgh, Pa. August, 1891.

WILLIAM McINNES, Geological and Natural History Survey of Canada, Ottawa, Canada. May, 1889.

PETER McKELLAR, Fort William, Ontario, Canada. August, 1890.

GEORGE ROGERS MANSFIELD, 2039 Park Road N. W., Washington, D. C. December, 1909.

CURTIS F. MARBUT, Bureau of Soils, Washington, D. C. August, 1897.

VERNON F. MARSTERS, San Juancito, Honduras, C. A. August, 1892.

GEORGE CURTIS MARTIN, U. S. Geological Survey, Washington, D. C. June, 1902

LAWRENCE MARTIN, University of Wisconsin, Madison, Wis. December, 1909.

EDWARD B. MATHEWS, Johns Hopkins University, Baltimore, Md. Aug., 1895.

FRANCOIS E. MATTHES, U. S. Geological Survey, Washington, D. C. December, 1914.

W. D. MATTHEW, American Museum of Natural History, New York, N. Y. December, 1903.

THOMAS POOLE MAYNARD, 1622 D. Hurt Bldg., Atlanta, Ga. December, 1914.

P. H. MELL, 165 East 10th St., Atlanta, Ga. December, 1888.

WALTER C. MENDENHALL, U. S. Geological Survey, Washington, D. C. June, 1902.

JOHN C. MERRIAM, University of California, Berkeley, Cal. August, 1895.

*FREDERICK J. H. MERRILL, 624 Citizens' National Bank Bldg., Los Angeles, Cal.

GEORGE P. MERRILL, U. S. National Museum, Washington, D. C. Dec., 1888.

HERBERT E. MERWIN, Geophysical Laboratory, Washington, D. C. Dec., 1914

ARTHUR M. MILLER, State University of Kentucky, Lexington, Ky. Dec., 1897

BENJAMIN L. MILLER, Lehigh University, South Bethlehem, Pa. Dec., 1904

WILLET G. MILLER, Toronto, Canada. December, 1902.

WILLIAM JOHN MILLER, Smith College, Northampton, Mass. December, 1909.

FRED HOWARD MOFFIT, U. S. Geological Survey, Washington, D. C. Dec., 1912.

G. A. F. MOLENGRAAF, Technical High School, Delft, Holland. December, 1913.

HENRY MONTGOMERY, University of Toronto, Toronto, Canada. Dec., 1904.

Elwood S. Moore, Pennsylvania State College, State College, Pa. Dec., 1911.
Malcolm John Munn, Clinton Bldg., Tulsa, Okla. December, 1909.
*Frank L. Nason, West Haven, Conn.
David Hale Newland, Albany, N. Y. December, 1906.
John F. Newsom, Leland Stanford, Jr., University, Stanford University, Cal. December, 1899.
William H. Norton, Cornell College, Mount Vernon, Iowa. December, 1895.
Charles J. Norwood, State University, Lexington, Ky. August, 1894.
Ida Helen Ogilvie, Barnard College, Columbia University, New York, N. Y. December, 1906.
Cleophas C. O'Harra, South Dakota School of Mines, Rapid City, S. Dak. December, 1904.
Daniel Webster Ohern, University of Oklahoma, Norman, Okla. Dec., 1911.
Ezequiel Ordonez, 2 a General Prim 43, Mexico, D. F., Mex. August, 1896.
Edward Orton, Jr., Geological Survey of Ohio, Columbus, Ohio. Dec., 1909.
Henry F. Osborn, American Museum of Natural History, New York, N. Y. August, 1894.
Sidney Paige, U. S. Geological Survey, Washington, D. C. December, 1911.
Charles Palache, Harvard University, Cambridge, Mass. August, 1897.
William A. Parks, University of Toronto, Toronto, Canada. December, 1906.
*Horace B. Patton, Colorado School of Mines, Golden, Colo.
Frederick B. Peck, Lafayette College, Easton, Pa. August, 1901.
Richard A. F. Penrose, Jr., 460 Bullitt Bldg., Philadelphia, Pa. May, 1889.
George H. Perkins, University of Vermont, Burlington, Vt.; State Geologist. June, 1902.
Joseph H. Perry, 276 Highland St., Worcester, Mass. December, 1888.
Olaf August Peterson, Carnegie Museum, Pittsburgh, Pa. December, 1910.
William Clifton Phalen, U. S. Geological Survey, Washington, D. C. December, 1912.
Alexander H. Phillips, Princeton University, Princeton, N. J. Dec., 1914.
Louis V. Pirsson, Yale University, New Haven, Conn. August, 1894.
Joseph E. Pogue, Northwestern University, Evanston, Ill. December, 1911.
Joseph Hyde Pratt, North Carolina Geological Survey, Chapel Hill, N. C. December, 1898.
Louis M. Prindle, U. S. Geological Survey, Washington, D. C. Dec., 1912.
*Charles S. Prosser, Ohio State University, Columbus, Ohio.
William Frederick Prouty, University of Alabama, University, Ala. December, 1911.
*Raphael Pumpelly, Newport, R. I.
Albert Homer Purdue, State Geological Survey, Nashville, Tenn. Dec., 1904.
Frederick Leslie Ransome, U. S. Geological Survey, Washington, D. C. August, 1895.
Percy Edward Raymond, Museum of Comparative Zoölogy, Cambridge, Mass December, 1907.
Chester A. Reeds, American Museum of Natural History, New York, N. Y. December, 1913.
Harry Fielding Reid, Johns Hopkins University, Baltimore, Md. Dec., 1892.
William North Rice, Wesleyan University, Middletown, Conn. August, 1890.
John Lyon Rich, University of Illinois, Urbana, Ill. December, 1912.

Charles H. Richardson, Syracuse University, Syracuse, N. Y. Dec., 1899.
George Burr Richardson, U. S. Geological Survey, Washington, D. C. December, 1908.
Heinrich Ries, Cornell University, Ithaca, N. Y. December, 1893.
Elmer S. Riggs, Field Museum of Natural History, Chicago, Ill. Dec., 1911.
Jesse Perry Rowe, University of Montana, Missoula, Mont. December, 1911.
Rudolph Ruedemann, Albany, N. Y. December, 1905.
John Joseph Rutledge, Experiment Station, Pittsburgh, Pa. Dec., 1911.
Orestes H. St. John, 1141 Twelfth St., San Diego, Cal. May, 1889.
*Rollin D. Salisbury, University of Chicago, Chicago, Ill.
Frederick W. Sardeson, University of Minnesota, Minneapolis, Minn. December, 1892.
Thomas Edmund Savage, University of Illinois, Urbana, Ill. December, 1907.
Frank C. Schrader, U. S. Geological Survey, Washington, D. C. Aug., 1901.
Charles Schuchert, Yale University, New Haven, Conn. August, 1895.
Alfred Reginald Schultz, U. S. Geological Survey, Washington, D. C. December, 1912.
William B. Scott, Princeton University, Princeton, N. J. August, 1892.
Arthur Edmund Seaman, Michigan College of Mines, Houghton, Mich. December, 1904.
Henry M. Seely, Middlebury College, Middlebury, Vt. May, 1889.
Elias H. Sellards, Tallahassee, Fla. December, 1905.
Joaquim Candido da Costa Seña, State School of Mines, Ouro Preto, Brazil. December, 1908.
Millard K. Shaler, 4 Bishopsgate E. C., London, England. December, 1914.
George Burbank Shattuck, Vassar College, Poughkeepsie, N. Y. Aug., 1899.
Eugene Wesley Shaw, U. S. Geological Survey, Washington, D. C. Dec., 1912.
Solon Shedd, State College of Washington, Pullman, Wash. Dec., 1904.
Edward M. Shepard, 1403 Benton Ave., Springfield, Mo. August, 1901.
Will H. Sherzer, State Normal School, Ypsilanti, Mich. December, 1890.
Bohumil Shimek, University of Iowa, Iowa City, Iowa. December, 1904.
Hervey Woodburn Shimer, Massachusetts Institute of Technology, Boston, Mass. December, 1910.
Claude Ellsworth Siebenthal, U. S. Geological Survey, Washington, D. C. December, 1912.
*Frederick W. Simonds, University of Texas, Austin, Texas.
William John Sinclair, Princeton University, Princeton, N. J. Dec., 1906.
Joseph Theophilus Singewald, Johns Hopkins University, Baltimore, Md. December, 1911.
Earle Sloan, Charleston, S. C. December, 1908.
Burnett Smith, Syracuse University, Skaneateles, N. Y. December, 1911.
Carl Smith, U. S. Geological Survey, Washington, D. C. December, 1912.
*Eugene A. Smith, University of Alabama, University, Ala.
George Otis Smith, U. S. Geological Survey, Washington, D. C. Aug., 1897.
Philip S. Smith, U. S. Geological Survey, Washington, D. C. Dec., 1909.
Warren Du Pré Smith, University of Oregon, Eugene, Oregon. Dec., 1909.
W. S. Tangier Smith, Lodi, Cal. June, 1902.
*John C. Smock, Trenton, N. J.
Charles H. Smyth, Jr., Princeton University, Princeton, N. J. Aug., 1892.

Henry L. Smyth, Harvard University, Cambridge, Mass. August, 1894.
Arthur Coe Spencer, U. S. Geological Survey, Washington, D. C. Dec., 1896.
*J. W. Spencer, 2019 Hillyer Place, Washington, D. C.
Frank Springer, U. S. National Museum, Washington, D. C. December, 1911.
Josiah E. Spurr, Bullitt Bldg., Philadelphia, Pa. December, 1894.
Joseph Stanley-Brown, 26 Exchange Place, New York, N. Y. August, 1892.
Timothy William Stanton, U. S. National Museum, Washington, D. C. August, 1891.
Clinton Raymond Stauffer, University of Minnesota, Minneapolis, Minn. December, 1911.
Lloyd William Stephenson, U. S. Geological Survey, Washington, D. C. December, 1911.
*John J. Stevenson, 215 West 101st St., New York, N. Y.
Ralph Walter Stone, U. S. Geological Survey, Washington, D. C. Dec., 1912.
George Willis Stose, U. S. Geological Survey, Washington, D. C. Dec., 1908.
William J. Sutton, Victoria, B. C. August, 1901.
Charles Kephart Swartz, Johns Hopkins University, Baltimore, Md. December, 1908.
Stephen Taber, University of South Carolina, Columbia, S. C. Dec., 1914.
Joseph A. Taff, 781 Flood Building, San Francisco, Cal. August, 1895.
Mignon Talbot, Mount Holyoke College, South Hadley, Mass. Dec., 1913.
James E. Talmage, University of Utah, Salt Lake City, Utah. Dec., 1897.
Frank B. Taylor, Fort Wayne, Ind. December, 1895.
*James E. Todd, 1224 Rhode Island St., Lawrence, Kans.
Cyrus Fisher Tolman, Jr., Leland Stanford, Jr., University, Stanford University, Cal. December, 1909.
Arthur C. Trowbridge, State University of Iowa, Iowa City, Iowa. December, 1913.
*Henry W. Turner, 209 Alaska Commercial Building, San Francisco, Cal.
William H. Twenhofel, University of Kansas, Lawrence, Kans. Dec., 1913.
Mayville William Twitchell, State Geological Survey, Trenton, N. J. December, 1911.
Joseph B. Tyrrell, Room 534, Confederation Life Building, Toronto, Canada. May, 1889.
Johan A. Udden, University of Texas, Austin, Texas. August, 1897.
Edward O. Ulrich, U. S. Geological Survey, Washington, D. C. Dec., 1903.
Joseph B. Umpleby, U. S. Geological Survey, Washington, D. C. Dec., 1913.
*Warren Upham, Minnesota Historical Society, Saint Paul, Minn.
*Charles R. Van Hise, University of Wisconsin, Madison, Wis.
Frank Robertson Van Horn, Case School of Applied Science, Cleveland, Ohio. December, 1898.
Gilbert van Ingen, Princeton University, Princeton, N. J. December, 1904.
Thomas Wayland Vaughan, U. S. Geological Survey, Washington, D. C. August, 1896.
Arthur Clifford Veatch, 7 Richmond Terrace, Whitehall, S. W., London, England. December, 1906.
*Anthony W. Vogdes, 2425 First St., San Diego, Cal.
*M. Edward Wadsworth, School of Mines, University of Pittsburgh, Pittsburgh, Pa.

*CHARLES D. WALCOTT, Smithsonian Institution, Washington, D. C.
THOMAS L. WALKER, University of Toronto, Toronto, Canada. Dec., 1903.
CHARLES H. WARREN, Massachusetts Institute of Technology, Boston, Mass. December, 1901.
HENRY STEPHENS WASHINGTON, Geophysical Laboratory, Washington, D. C. August, 1896.
THOMAS L. WATSON, University of Virginia, Charlottesville, Va. June, 1900.
CHARLES E. WEAVER, University of Washington, Seattle, Wash. Dec., 1913.
WALTER H. WEED, 29 Broadway, New York, N. Y. May, 1889.
CARROLL HARVEY WEGEMANN, U. S. Geological Survey, Washington, D. C. December, 1912.
SAMUEL WEIDMAN, Wisconsin Geological and Natural History Survey, Madison, Wis. December, 1903.
STUART WELLER, University of Chicago, Chicago, Ill. June, 1900.
LEWIS G. WESTGATE, Ohio Wesleyan University, Delaware, Ohio.
DAVID WHITE, U. S. National Museum, Washington, D. C. May, 1889.
*ISRAEL C. WHITE, Morgantown, W. Va.
GEORGE REBER WIELAND, Yale University, New Haven, Conn. December, 1910.
FRANK A. WILDER, North Holston, Smyth County, Va. December, 1905.
*EDWARD H. WILLIAMS, JR., Woodstock, Vt.
*HENRY S. WILLIAMS, Cornell University, Ithaca, N. Y.
IRA A. WILLIAMS, Oregon School of Mines, Corvallis, Ore. December, 1905.
BAILEY WILLIS, U. S. Geological Survey, Washington, D. C. December, 1889
ALFRED W. G. WILSON, Department of Mines, Ottawa, Canada. June, 1902.
ALEXANDER N. WINCHELL, University of Wisconsin, Madison, Wis. Aug., 1901.
*HORACE VAUGHN WINCHELL, 505 Palace Building, Minneapolis, Minn.
*ARTHUR WINSLOW, 131 State St., Boston, Mass.
JOHN E. WOLFF, Harvard University, Cambridge, Mass. December, 1889.
JOSEPH E. WOODMAN, New York University, New York, N. Y. Dec., 1905.
ROBERT S. WOODWARD, Carnegie Institution of Washington, Washington, D. C. May, 1889.
JAY B. WOODWORTH, Harvard University, Cambridge, Mass. December, 1895.
CHARLES WILL WRIGHT, Ingurtosu, Arbus, Sardinia, Italy. December, 1909.
FREDERIC E. WRIGHT, Geophysical Laboratory, Carnegie Institution, Washington, D. C. December, 1903.
*G. FREDERICK WRIGHT, Oberlin Theological Seminary, Oberlin, Ohio.
GEORGE A. YOUNG, Geological Survey of Canada, Ottawa, Canada. Dec., 1905.

CORRESPONDENTS DECEASED

HERMAN CREDNER. Died July 22, 1913.
A. MICHEL-LÉVY. Died September, 1911.
H. ROSENBUSCH. Died January 20, 1914.
EDWARD SUESS. Died April 20, 1914.
TH. TSCHERNYSCHEW. Died Jan. 15, 1914.
FERDINAND ZERKEL. Died June 11, 1912.

FELLOWS DECEASED

* Indicates Original Fellow (see article III of Constitution)

*CHAS. A. ASHBURNER. Died Dec. 24, 1889.
ALFRED E. BARLOW. Died May 28, 1914.
CHARLES E. BEECHER. Died Feb. 14, 1904
ALBERT S. BICKMORE. Died Aug. 12, 1914.
WM. PHIPPS BLAKE. Died May 21, 1910.
AMOS BOWMAN. Died June 18, 1894
ERNEST R. BUCKLEY. Died Jan. 19, 1912.
*SAMUEL CALVIN. Died April 17, 1911
FRANKLIN R. CARPENTER. Died April 1, 1910.

*J. H. Chapin. Died March 14, 1892.
*Edward W. Claypole. Died Aug. 17, 1901.
George H. Cook. Died Sept. 22, 1889.
*Edward D. Cope. Died April 12, 1897.
Antonio Del Castillo. Died Oct. 28, 1895.
*James D. Dana. Died April 14, 1895.
George M. Dawson. Died March 2, 1901.
Sir J. Wm. Dawson. Died Nov. 19, 1899.
Clarence E. Dutton. Died Jan. 4, 1912.
*William B. Dwight. Died Aug. 29, 1906.
*George H. Eldridge. Died June 29, 1905.
*Samuel F. Emmons. Died March 28, 1911.
Wm. M. Fontaine. Died April 29, 1913.
*Albert E. Foote. Died October 10, 1895.
*Persifor Frazer. Died April 7, 1909.
*Homer T. Fuller. Died Aug. 14, 1908.
N. J. Giroux. Died November 30, 1891.
*Christopher W. Hall. Died May 10, 1911.
*James Hall. Died August 7, 1898.
John B. Hatcher. Died July 3, 1904.
*Robert Hay. Died December 14, 1895.
*Angelo Heilprin. Died July 17, 1907.
David Honeyman. Died October 17, 1889.
*Edwin E. Howell. Died April 16, 1911.
*Horace C. Hovey. Died July 27, 1914.
Thomas S. Hunt. Died Feb. 12, 1892.
*Alpheus Hyatt. Died Jan. 15, 1902.
Thomas M. Jackson. Died Feb. 3, 1912.
*Joseph F. James. Died March 29, 1897.
Wilbur C. Knight. Died July 28, 1903.
Ralph D. Lacoe. Died February 5, 1901.
J. C. K. Laflamme. Died July 6, 1910.
Daniel W. Langton. Died June 21, 1909.
*Joseph Le Conte. Died July 6, 1901.
*J. Peter Lesley. Died June 2, 1903.
Henry McCalley. Died Nov. 20, 1904.
*W J McGee. Died September 4, 1912.
Oliver Marcy. Died March 19, 1899.
Othniel C. Marsh. Died March 18, 1899.
James E. Mills. Died July 25, 1901.
*Henry B. Nason. Died January 17, 1895.
*Peter Neff. Died May 11, 1903.
*John S. Newberry. Died Dec. 7, 1892.
William H. Niles. Died Sept. 12, 1910.
*Edward Orton. Died October 16, 1899.
*Amos O. Osborn. Died March, 1911.
*Richard Owen. Died March 24, 1890.
Samuel L. Penfield. Died Aug. 14, 1906.
David P. Penhallow. Died Oct. 20, 1910.
*Franklin Platt. Died July 24, 1900.
William H. Pettee. Died May 26, 1904.
*John W. Powell. Died Sept. 23, 1902.
*Israel C. Russell. Died May 1, 1906.
*James M. Safford. Died July 3, 1907.
*Charles Schaeffer. Died Nov. 23, 1903.
*Nathaniel S. Shaler. Died April 10, 1906.
Ralph S. Tarr. Died March 21, 1912.
William G. Tight. Died Jan. 15, 1910.
Charles Wachsmuth. Died Feb. 7, 1896.
Thomas C. Weston. Died July 20, 1910.
Theodore G. White. Died July 7, 1901.
*Robert P. Whitfield. Died April 6, 1910.
*George H. Williams. Died July 12, 1894.
*J. Francis Williams. Died Nov. 9, 1891.
Arthur B. Wilmott. Died May 8, 1914.
*Alexander Winchell. Died Feb. 19, 1891.
*Newton Winchell. Died May 1, 1914.
Albert A. Wright. Died April 2, 1905.
William S. Yeates. Died Feb. 19, 1908.

Summary

Correspondents	10
Original Fellows	46
Elected Fellows	334
Membership	390
Deceased Correspondents	6
Deceased Fellows	78

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 129-140 MARCH 31, 1915

PROCEEDINGS OF THE FIFTEENTH ANNUAL MEETING OF THE CORDILLERAN SECTION OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT SEATTLE, WASHINGTON, MAY 21 AND 22, 1914.[1]

GEORGE D. LOUDERBACK, *Secretary*

CONTENTS

[1] Manuscript received by the Secretary of the Geological Society June 22, 1914.

Session of Thursday, May 21

The Fifteenth Annual Meeting of the Cordilleran Section of the Geological Society of America was held in conjunction with the Pacific Association of Scientific Societies, at the University of Washington, Seattle, Washington, May 21 and 22, 1914, in room 3, Science Hall. In the absence of the chairman, the meeting was called to order at 10.15 a. m. by the secretary of the section. Prof. A. C. Lawson was elected temporary chairman.

It was voted that the business session be held at 1.30 p. m., and that the morning be devoted to the reading of scientific papers. The secretary reported that the nominations sent in by mail were too scattering to definitely indicate a nomination for chairman for the ensuing year, and moved that a nominating committee be appointed to report at the business session. The motion was seconded and carried and the temporary chairman appointed Louderback, Weaver, and Saunders as such committee.

The following papers were then presented in the order given:

PRE-PLEISTOCENE GEOLOGY IN THE VICINITY OF SEATTLE

BY CHARLES E. WEAVER

(Abstract)

The larger part of Seattle is heavily covered over with deposits of glacial drift. From the western foothills of the Cascades a prominent structural upwarp extends northwesterly through Seattle into Kitsap County. Along the axis of this uplift the older Tertiary formations are exposed. They consist of approximately 4,000 feet of Eocene sedimentaries and volcanics containing a Tejon fauna and productive coal measures. Overlying these are at least 7,000 feet of Lower Miocene sandstones and shales. These strata have been folded. A prominent anticlinal axis extends along the line of uplift. On the north and south flanks of this fold north and south minor anticlinal and synclinal folds have been developed. During the late Tertiary these were subjected to vigorous erosion and during the Pleistocene were glaciated.

Presented from notes and illustrated by geologic map.

Discussion

In reply to question by Mr. Bretz, the author explained that the south limb of the anticline was covered and its detailed structure not known. Answering question by Merriam, he stated that the Miocene involved includes the lowest zone. In reply to question by Louderback, author held that there were no pre-Eocene lavas involved, as at certain localities fossiliferous Eocene strata are found below the lowest lavas.

PLEISTOCENE OF WESTERN WASHINGTON

BY J. HARLEN BRETZ

(Abstract)

An early Pleistocene gravel deposit, the Satsop formation, is widely distributed along the Washington coast and in the Chehalis Valley. The Satsop formation is not found in the Puget Sound region, where glacial deposits cover most of the country.

Two glaciations are known in western Washington—the Admiralty and the Vashon. A thick formation of stratified drift, the Admiralty sediments, was deposited during the retreat of the Admiralty ice. During the succeeding inter-Glacial epoch the Puyallup epoch, these deposits were eroded by streams to form valleys now constituting Puget Sound. No truly interglacial deposits are known in Puget Sound. The region appears to have been fully a thousand feet higher during this inter-Glacial epoch than during the preceding Admiralty or the following Vashon epochs.

The Vashon glacier failed throughout most of the region to modify materially the topography produced during the Puyallup epoch. During its retreat a series of glacial lakes formed in the valleys of inter-Glacial age. The region at this time lay 50 or 75 feet lower than at present.

Postglacial diastrophism embraces a complete oscillation of the Puget Sound region, the sea having stood at least 290 feet above present tide at some time subsequent to the Vashon epoch.

Except for outwash of both Admiralty and Vashon age in certain valleys of the Chehalis system, no events other than stream erosion are known to record the later Pleistocene epochs in southwestern Washington.

Presented without notes and illustrated by lantern slides.

The author replied to several questions raised by Lawson.

The section adjourned for lunch at 11.55 to reconvene at 1.30.

The afternoon session was called to order by the temporary chairman at 1.55, and the minutes of the Fourteenth Annual Session were read and approved.

ELECTION OF OFFICERS

After the report of the Nominating Committee, the following were elected as section officers for the year 1914-1915:

H. Foster Bain, *Chairman.*
George D. Louderback, *Secretary.*
Charles E. Weaver, *Councilor.*

SUMMER MEETING

The secretary announced the decision of the Geological Society of America to accept the invitation of the Cordilleran Section and hold a special session in California in August, 1915. It is planned to hold the meetings at the University of California, Berkeley, and at least one session at Stanford University. In consideration of this, the section voted to hold no separate meeting in 1915, but to use its efforts to make the meeting of the General Society a success.

AFFILIATION WITH THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

The secretary announced the proposed organization of a Pacific Division of the American Association for the Advancement of Science and explained its constitution, and also brought up the matter of affiliation of the Cordilleran Section with this Pacific Division. It was pointed out that, according to the constitution of the Pacific Division, if the Cordilleran Section became affiliated, no geological section would be established by the division; but that programs in geology and the organization of geology on the coast would be left entirely in the hands of the Cordilleran Section; also that the section would not be obliged to meet with the division if in its judgment it would be better for the coast geologists to meet elsewhere or at a different time; also that it would in no way effect the section's relationship to the Geological Society of America.

The section voted in favor of affiliation with the Pacific Division of the American Association for the Advancement of Science, gave its delegates full power to act, and to sign the constitution if in their judgment the rights and position of the section were fully protected.

It was voted that, if the chairman of the section was not present to represent the section at the Pacific Association's Executive Committee Meeting, the temporary chairman be given the above powers to represent and act for the section.

There being no further business, the scientific program was taken up and the following papers presented:

STRUCTURE OF PIERCE COUNTY COAL FIELD OF WASHINGTON

BY JOSEPH DANIELS

(Abstract)

The Pierce County coal field, the Puyer formation of Eocene age, consists of a broad, abnormal anticlinorium, having a main persistent anticlinal axis and a series of minor anticlinal and synclinal axes, all of which pitch to the north. A known series of 12,000 to 14,000 feet is thus exposed in a chain of isolated mines which develop the seams along a north-south line, thus exposing the upper part of the series in the northern mines and the lower part in the southern portion of the field. The flexing of the strata has been accompanied

by overthrust faulting giving displacement of 1,500 feet, and normal faulting showing horizontal displacement of 1,200 feet.

Presented from notes and illustrated by maps and sections.

Discussion

In reply to question by Professor Lawson, author stated that the so-called pivotal faults were in form as if produced by rotation of block about a pivot, but really not so formed. Answering question by Louderback, he explained that all of the faults described were thrust faults, except the two major normal faults; also that faults were more abundant on the steeper limbs of the anticlines.

TERTIARY ROCKS OF OAHU

BY C. H. HITCHCOCK

(*Abstract*)

Basalt constitutes the foundations of the mountains of the Waianae and Koolau ranges, reaching the altitudes of 4,000 and 3,300 feet. The first named occupy the southwest border and the second named extend parallel to the eastern coast. The sedimentary members rest on the Koolau range, dipping gently to the southwest. The sides of both ranges near the ocean are precipitous, the one having been eroded by storms from the southwest and the other by the trade-wind rains from the northeast. The rainfall may exceed 175 inches on the summits and diminish to 2 or 3 feet adjacent to the ocean. There are sediments attaining a thickness of 1,000 feet resting on the basalt, as made known by well borings. The water flows from the base of the sediments, rising 30 to 40 feet above the sealevel.

The uppermost rock is limestone carrying many oyster-shells of *Ostrea retusa* Sby., now extinct, and therefore esteemed to be of Pliocene age. No other shell has yet been proved to be extinct. Below the limestone is a coarse conglomerate more or less continuous from Diamond Head to near Barbers Point. Beneath the conglomerate are masses of clay and volcanic ashes extending to the base of the series. The succession of strata is not uniform in contiguous wells. As a rule, limestones abound near the top and the clays near the bottom.

The government is endeavoring to establish a dry dock on the eastern of the Pearl River locks. Borings indicate that the materials penetrated consist of volcanic ashes, loose limestones, clays, silts, and other fluviatile deposits. The ashes came from the extinct craters Makalapa and Salt Lake to the northeast.

After the dry dock had been completed the water was pumped out and the cement floor and sides were not strong enough to prevent rupture by the pressure from below. As firm rock can not be reached within 500 feet from the surface, a much stronger cement base must be built into the floor and walls to resist the pressure from below.

Dikes of basalt penetrate the lavas along the summit of the Koolau range

and act as dams to prevent the flow of water from the east to the west, as now understood.

There are more than 100 artesian wells in the area of the Pliocene sediments.

Paper presented without notes.

Discussion

In reply to question by Doctor Merriam, author discussed the number of species represented in the supposed Pliocene, and claimed that only one was definitely known to be extinct. Answering questions by Louderback, he said that no deeper strata of possibly earlier age are known, and that no fauna similar to the *Ostrea retusa* existed on the islands at the present time.

Professor Lawson pointed out that the water found behind the dikes might not be diverted flows, but natural reservoirs in which water was standing at the time it was tapped, and compared some mine waters found behind gouge.

PLEA FOR UNIFORMITY AND SIMPLICITY IN PETROLOGIC NOMENCLATURE

BY G. MONTAGUE BUTLER

(*Abstract*)

In the nomenclature of no other science is there probably so much confusion and uncertainty as in petrology and petrography. This is especially true as regards the macroscopic classification of igneous rocks.

A practical system is a necessity to mining engineers and field geologists, and uniformity of nomenclature is undoubtedly highly desirable. The Geological Society of America can well consider and decide this matter, as it has done in the case of fault nomenclature.

The classification adopted should fulfill the following conditions:

1. The terms used should be old, well known ones so far as possible, and the meanings assigned to them should correspond with common usage where this is practicable.

2. The distinctions should be based only on features readily recognizable in the field.

3. The meanings attached to the various names should not be so comprehensive as to vitiate the usefulness of such names.

4. The classification should be of such a nature that it may be readily extended, so as to include rocks whose identification depends on microscopic investigation.

Such a classification is offered. In it the igneous rocks are divided according to textural distinctions, which result from solidification under different conditions into three series, and the criteria of each series are given.

The identification of individual rock species is then based on the recognition of constituent minerals, and in the case of aphanitic rocks on color luster and other features.

In conclusion, the practical value of the conception of rock types is presented and the placing of emphasis on such types is defended, although it is admitted that precautions must be taken to prevent the growth of misconceptions in the minds of students when this practice is followed.

Read from manuscript.

Discussion

Professor Louderback pointed out that while all recognized the desirability of uniformity, the difficulty was in agreeing on any uniform system. The system proposed by the athor is not strictly a petrologic system, but a field classification, and the question arises as to whether such classification is to be complete in itself or shall simply attempt to approximate a more refined classification, which latter shall determine the definitions. In the former case the names used by author might each have two definitions, thus perpetuating confusion. In the latter case the field classification would be merely approximate and temporary until more accurate determination could be made. It was also pointed out that the strict use of the author's tables would yield results at variance with the standard nomenclature based on microscopic and chemical analysis. The great bulk of the andesites the augite andesites, for example would by the table be placed among the basalts. The table uses physical characteristics for major groups, but uses names based on field occurrence, and instances were cited of common western types where volcanic flows would be called intrusives and vice versa. Agreement was had with the author that an oversimplified system, such as has been presented by certain American petrographers for field uses, is of no practical value. It slurs over important distinctions which can usually easily be made.

The meeting adjourned for the day at 4.15 p. m.

Session of Friday, May 22.

The meeting was called to order at 9.55 a. m. by the chairman, President Branner, and the scientific program was continued as follows:

GEOLOGIC STRUCTURE IN WESTERN WASHINGTON

BY CHARLES E. WEAVER

(Abstract)

The geologic structure in western Washington consists of three nearly parallel predominant upwarps and three intervening downfolds extending from the Cascade Mountains to the Pacific Ocean. Major and minor anticlinal and synclinal folds have been developed parallel and transverse to these. The predominating trend of all folds in the western half of the State and on Vancouver Island is approximately north 60 west. The minor folds on the flanks of the major folds are nearly north and south. The initiation of movements producing such structure appears to have been at or near the close of the Jurassic. It was intensified toward the close of the Tertiary.

Presented without notes and illustrated by structural maps.

Discussion

Professor Louderback asked to have explained the relation between the northwest-southeast axes of folding and the Cascade uplift, in particular whether they might not correspond to pre-Sierran deformation and Sierran faulting in the California region. The author replied that he believed they were formed contemporaneously and as parts of the same general movement.

EOCENE OF THE COWLITZ VALLEY, WASHINGTON

BY CHARLES E. WEAVER

(*Abstract*)

The Eocene of Washington is extensively developed in that portion of the Cowlitz Valley situated in Lewis and Cowlitz counties. From the town of Winlock southward to Castle Rock there is a series of interbedded marine, brackish water and fresh water sediments having a thickness of at least 8,000 feet. These strata have a northwest to southeast strike, with a low dip to the northeast. In the lower portion of the series numerous layers of basaltic lava and tuff are intercalated. About one mile north of Vader a minor local fold has been developed on the northeasterly pitching flank of the series. On the basis of marine faunas, no distinction can be made between the upper and lower portion of the formation. The fauna is typically Tejon.

Presented without notes and illustrated by diagrams and maps.

Discussion

Doctor Branner expressed his approval of the fact that the author used the engineer's methods of determining the relative positions of the outcrops studied instead of relying on maps that could not be depended on.

RELATION OF THE TERTIARY GEOLOGICAL SCALE OF THE GREAT BASIN TO THAT OF THE PACIFIC COAST MARGINAL PROVINCE

BY J. C. MERRIAM

(*Abstract*)

Although we are acquainted with the nearly complete series of geological formations on both sides of the Sierra Cascade Range, there are very few places at which any definite connection between the two sets of deposits has been recognized. A satisfactory interpretation of West American Geology must include reasonably certain determination of the time relations between the Great Basin and the marginal marine provinces.

Correlation between the two regions is based partly on lithologic evidence, partly on the study of crustal movements and on the evidence of paleontology. The paleontologic materials used in these correlations up to the present time have been almost exclusively plant remains. Very recently remains of land vertebrates found in the marginal marine province have offered an exceptional opportunity for correlation.

The present paper presents a summation of the results in the study of this problem.

Presented without notes and illustrated by lantern slides.

DISCUSSION

In reply to question by Professor Louderback, the author stated that the Rattlesnake of eastern Oregon corresponds to the Jacalitos of the Coalinga district, California.

RELATION BETWEEN THE TERTIARY SEDIMENTARIES AND LAVAS IN KITTITAS COUNTY, WASHINGTON

BY E. J. SAUNDERS

Presented from notes and illustrated by maps and sections.

DISCUSSION

Doctor BRANNER asked as to the occurrence of coal in relation to the formations described. Doctor Merriam asked if the base of the Keechelus were older than the Ellenburg basalt. Mr. Weaver suggested that the Keechelus may there represent part of the series, due to overlapping. In reply to question by Professor Lawson as to size of dikes, the author stated that they ranged from about 3 to 40 feet thick, and the space occupied by them may represent 10,000 to 20,000 feet. The mechanism by which this amount of space was made available was not clear. The dikes lie across the axes of the folds.

The section adjourned at 12.10 for lunch.

The meeting was resumed at 1.48 p. m., with Chairman Branner in the chair, and proceeded with the scientific program as follows:

OREGON BUREAU OF MINES AND GEOLOGY

BY IRA A. WILLIAMS

(*Abstract*)

While California on the south and Washington on the north have been for years spending considerable amounts of money in the investigation of their mineral resources, Oregon, as a State, has, until the present year, invested but $2,000 in a study of its mineral resources. The 1913 Legislature formally established the Oregon Bureau of Mines and Geology and provided an appropriation of $40,0000 for carrying on its work for two years. According to the act creating the Bureau, its duties cover a study of all of the geological resources of the State and the publication of reports relating to these resources. It is expected also to conduct studies of the geological formations of Oregon.

In the past year four parties have been in the field among the mining sections of the State. Investigations of the ceramic materials and of the building

stones are also under way. A large scale relief map of Oregon is being constructed, and a treatise covering the scattered geological data concerning Oregon is also in preparation.

The laboratory equipment in all departments of the State University and of the Oregon Agricultural College have been made available for the use of the Bureau by the authorities of these two institutions.

Aside from the regular work outlined, a number of special problems have been presented to the Bureau. Assistance has been rendered a large mining company in working out some of its metallurgical problems. About three months' time was spent by a representative of the Bureau at the plant of this company. Through the Bureau an anthracite coal project, which proved to be based on a heavy deposit of black volcanic glass and in which several thousand dollars had been invested, was finally cleared up. An investigation of the possibility of using an acid volcanic tuff in the manufacture of Portland cement at a point in eastern Oregon also promises to afford some valuable results.

Presented from manuscript.

Discussion

Professor Hitchcock explained the State Survey methods in the New England States, especially in New Hampshire. Doctor Branner discussed the organization of the Geological Survey of Brazil and the plans of the new Oregon Bureau.

RÔLE OF SEDIMENTATION IN DIASTROPHISM AND VULCANISM

BY F. M. HANDY

Read from manuscript, in absence of author, by H. C. Culver.

The section adjourned at 2.50 in view of the meeting of the Seismological Society, which was to be held at 3.

The annual dinner, held in conjunction with the Paleontological and Seismological Societies and under the auspices of the Le Conte Geological Club, was held Friday evening, at 7 p. m., at the Faculty Club of the University of Washington. After the dinner the following paper was presented:

BASIN RANGE FAULTING IN THE NORTHWESTERN PART OF THE GREAT BASIN

BY GEORGE D. LOUDERBACK

(Abstract)

The major and certain minor ranges from the Sierra Nevada to the Humboldt were discussed and stratigraphic evidence was presented which indicates that

the faulting which was the prime agent in producing the present scarps occurred in late Geological time, probably Pliocene or early Pleistocene. It was further pointed out that this was the prevailing type of origin of the present ranges throughout this and adjacent areas. Physiographic evidence also serves to indicate that the present mountain fronts were generated by a continuous series of elevations, and that it is improbable that they were produced by two or more widely separated uplifts, with long periods of rest between.

The forms of the scarps were discussed and terracing of the scarps shown, in such cases as were examined, to be due to step faulting. The indications are that these scarps have not suffered great denudation, and that the upper portions have not migrated far back from their original positions. In a number of important occurrences cited there has been practically no recession of the base.

The evidence at hand indicates that the faulting was in general essentially normal faulting, and it was pointed out that the occurrence of occasional thrusts in a large area of normal faults or the passage of normal faults into flexures is to be expected. Flexures and occasional thrusts do not necessarily mean general compression action, and the idea of deformation with expansion is accepted as the best interpretation of the phenomena of the northwestern Basin region.

An extension of the results to certain other parts of the Great Basin region was also made.

Presented without notes and illustrated by maps, lantern slides, and blackboard diagrams.

Discussion by Branner, Merriam, Lawson, and Weaver.

At the conclusion of this paper the section adjourned *sine die*.

Register of the Seattle Meeting

FELLOWS

John C. Branner
G. Montague Butler
Arthur J. Collier
C. H. Hitchcock
Henry Landes
Andrew C. Lawson
George D. Louderback
John C. Merriam
Charles E. Weaver
Ira A. Williams

Visitors and other geologists taking part in the meeting were:

J. H. Bretz
A. C. Culver
Joseph Daniels
Milnor Roberts
E. J. Saunders

There were also present a number of students and other visitors. Altogether the attendance was as follows: Thursday morning session, 33; Thursday afternoon, 18; Friday morning, 40; Friday afternoon, 14.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 141-170 MARCH 31, 1915

PROCEEDINGS OF THE SIXTH ANNUAL MEETING OF THE PALEONTOLOGICAL SOCIETY, HELD AT PHILADELPHIA, PENNSYLVANIA, DECEMBER 29, 30, AND 31, 1914.

R. S. BASSLER, *Secretary*

CONTENTS

Session of Tuesday, December 29

President Henry Fairfield Osborn called the general session of the Society to order at 2 o'clock, December 29, in the library of the Philadelphia Academy of Sciences. After some introductory remarks by the President, the business session of the Society was opened with the reading of the report of the Council by the Secretary.

REPORT OF THE COUNCIL

To the Paleontological Society in Sixth Annual Meeting assembled:

The first meeting of this year's Council was held at Princeton, New Jersey, January 1, 1914, immediately following the adjournment of the Society on that day. Routine business, such as the suggestion of a ticket for the following year and the consideration of new nominations for membership, was considered then; but since this meeting all business of the Society has been arranged by correspondence. A résumé of administration for the Society's sixth year is presented in the following reports of officers.

Secretary's Report

To the Council of the Paleontological Society:

Meetings.—The proceedings of the fifth annual meeting of the Society, held at Princeton, New Jersey, December 31, 1913, and January 1, 1914, have been published in volume 25, pages 127-156, of the Bulletin of the Geological Society of America and distributed to the members in March, 1914. Besides this publication, the scientific papers of the Society printed and distributed during the year occupy all of number 3 of volume 25, Bulletin of the Geological Society of America, consisting of twelve articles, totaling 170 pages.

The Council's proposed nomination for officers and announcement that the sixth annual meeting of the Society would occur at Philadelphia, Pennsylvania, at the invitation of the local members, were forwarded to the members on March 10, 1914.

Membership.—During the year the Society has lost by death two of its members—Dr. Theodore M. Gill, of the Smithsonian Institution, who, although interested in paleontology, was best known for his researches on recent animals, particularly fish, and Dr. J. C. Hawver, educator and scientist, of Auburn, California, whose name will always be associated with the celebrated Hawver Cave of El Dorado County, California.

One resignation has occurred during the year and two members have been dropped for non-payment of dues. The 11 candidates elected at the fifth annual meeting have been placed on the rolls, making the present enrolment 158. Ten candidates are under consideration for election to membership at the present meeting, so that the steady growth of the Society is being maintained.

At this year's election for Fellows of the Geological Society of America, Messrs. E. C. Jeffrey and T. Poole Maynard, of the Paleontological Society, were elected to Fellowship.

Pacific Coast Section.—The fifth annual meeting of the Pacific Coast Section of the Society was held at Stanford University, commencing Friday, April 24, 1914. Fifteen papers, dealing mainly with Vertebrate Paleontology of the West Coast, were read at this meeting. The minutes of the section are printed, pages — to — of this Bulletin.

Respectfully submitted, R. S. BASSLER,
Secretary.

WASHINGTON, D. C., *December* 28, 1914.

TREASURER'S REPORT

To the Council of the Paleontological Society:

The Treasurer begs to submit the following report of the finances of the Society for the fiscal year ending December 24, 1914:

RECEIPTS

Cash on hand December 24, 1913		$227.83	
Dues from 64 members		192.10	
			$419.93

EXPENDITURES

Treasurer's office:			
Postage	$3.66		
Printing and stationery	.34		
		$4.00	
Secretary's office:			
Secretary's allowance	$50.00		
Expenses	39.05		
		89.05	
Geological Society of America:			
Share of expenses, Princeton meeting	$10.10		
Separates	38.60		
		48.70	
Pacific Coast Section:			
Secretary's expenses	$18.20	18.20	
			$159.95
Balance on hand December 24, 1914			259.98
			$419.93

Net increase in funds $32.15
Outstanding dues 51.00

Respectfully submitted, RICHARD SWANN LULL,
Treasurer.

NEW HAVEN, CONNECTICUT, *December* 21, 1914.

APPOINTMENT OF AUDITING COMMITTEE

The appointment of a committee to audit the Treasurer's accounts was next in order and the President selected H. F. Cleland and C. R. Eastman.

ELECTION OF OFFICERS AND MEMBERS

The results of the ballot for officers for 1915 and election of members was the next matter of business and was announced by the Secretary as follows:

OFFICERS FOR 1915

President:

EDWARD O. ULRICH, Washington, D. C.

First Vice-President:

J. C. MERRIAM, Berkeley, Cal.

Second Vice-President:

GILBERT VAN INGEN, Princeton, N. J.

Third Vice-President:

F. H. KNOWLTON, Washington, D. C.

Secretary:

R. S. BASSLER, Washington, D. C.

Treasurer:

RICHARD S. LULL, New Haven, Conn.

Editor:

CHARLES R. EASTMAN, New York City

MEMBERS

JUNIUS HENDERSON, University of Colorado, Boulder, Colo.
CHARLES C. MOOK, American Museum of Natural History, New York City.
CHARLES E. RESSER, U. S. National Museum, Washington, D. C.
MERTON Y. WILLIAMS, Geological Survey of Canada, Ottawa, Canada.
ALICE E. WILSON, Victoria Memorial Museum, Ottawa, Canada.

ELECTION OF NEW MEMBERS

The President then called the attention of the Society to five nominations for membership which had been received and indorsed by the Council too late to be placed on this year's printed ballots. The names and a brief statement regarding these proposed members follow.

Albert L. Barrows (M. S., University of California, 1912), Instructor in Department of Zoology, University of California, Berkeley, Cal. Engaged in invertebrate paleontology. Proposed by J. C. Merriam and F. M. Anderson.

John A. Guintyllo, Assistant in paleontology, University of California. Proposed by J. C. Merriam and F. M. Anderson.

Winthrop P. Haynes (Ph. D., Harvard, 1914), Instructor in Geology, Wellesley College, Wellesley, Massachusetts. Engaged in stratigraphic paleontology. Proposed by P. E. Raymond and H. W. Shimer.

Clarence L. Moody, Student of paleontology, University of California. Engaged in invertebrate paleontology. Proposed by J. C. Merriam and F. M. Anderson.

Jorgen O. Nomland (B. S., University of North Dakota, 1910), Graduate Student, University of California. Engaged in invertebrate paleontology. Proposed by J. C. Merriam and F. M. Anderson.

In the discussion that followed the motion to suspend the by-laws in order to elect these members at the present meeting, John M. Clarke asked that the name of Winifred Goldring (M. A., Wellesley College, 1912), assistant in paleontology, New York State Museum, proposed by John M. Clarke and A. W. Grabau, be added to the list. On motion, it was then voted by all members present that these six nominees be elected to membership in the Society.

CHAPTER ON PALEONTOLOGY OF MAN

At the fifth annual meeting the proposition to organize a chapter dealing with the paleontology of man was discussed, but action was deferred and the matter was referred back to the Council. After further consideration, the Council reports that it seems inadvisable to organize such a chapter, because papers dealing with this subject are of general interest to all of the members and should be presented before the Society in general session.

NEW BUSINESS AND ANNOUNCEMENTS

President Osborn then read a communication from J. C. Merriam, who, by previous vote of the Council, had been placed in charge of arrangements for the meeting of the Paleontological Society to be held in Cali fornia in August, 1915. Professor Merriam reported that this meeting had been arranged for the first week in August, and that the sessions would occur as follows: The first session will be at the University of California on August 3, the second at Stanford University on August 4, and the remaining sessions at the University of California. Feeling that the most important features of the program should relate to matters of mutual interest to the members of the East and of the extreme West, and considering further that material of the Pacific area might be of especial interest to those visiting California, the Pacific Coast members have arranged for a series of papers on correlation between the paleontologic record of the far West and the standard records of the better known portions of the earth's surface. This series will include a general discussion of paleontologic criteria used in determining time relations between stratigraphic units and several symposia on correlation between the West and other parts of the world.

After some general announcements by the President as to arrangements for the several sectional meetings, and there being no further matters of business, the Society proceeded to the reading of papers of general interest.

PRESENTATION OF GENERAL PAPERS

The first paper of this section, which was presented by the author and illustrated with lantern slides and specimens, brought forth a general discussion of the problem, in which C. A. Davis, Charles Schuchert, E. O. Ulrich, G. R. Wieland, and the author took a prominent part: 15 minutes.

OCCURRENCE OF ALGAL AND BACTERIAL DEPOSITS IN THE ALGONKIAN MOUNTAINS OF MONTANA

BY CHARLES D. WALCOTT

Another paper on fossil algæ was selected for presentation next and was illustrated by the author with lantern slides: 30 minutes.

FOSSIL ALGÆ OF THE ORDOVICIAN IRON ORES OF WABANA, NEWFOUNDLAND

BY GILBERT VAN INGEN

Two papers on the paleontology of man were next in order. The first was presented by the author and was illustrated by lantern slides; 15 minutes.

MIGRATION AND SUCCESSION OF HUMAN TYPES OF THE OLD STONE AGE OF EUROPE

BY HENRY FAIRFIELD OSBORN

Following President Osborn's paper and supplementing it was a demonstration of models of ancient man, which was further illustrated with lantern slides; 15 minutes.

RESTORATIONS OF PITHECANTHROPUS AND PILTDOWN AND NEANDERTHAL MAN

BY J. H. MC GREGOR

The above two papers brought forth a discussion in which J. M. Clarke and the two authors took part.

There was next read from manuscript by the author and illustrated with lantern slides and panoramic views a paper of general interest on account of its bearing on Upper Cretaceous stratigraphy.

EVIDENCE PROVING THAT THE BELLY RIVER BEDS OF ALBERTA ARE EQUIVALENT TO THE JUDITH RIVER BEDS OF DOG CREEK AND COW ISLAND, MONTANA

BY CHARLES H. STERNBERG

(*Abstract*)

This paper will be illustrated with lantern slides and several photographs, including a panoramic view of Dog Creek, showing the three distinct horizons of the Eagle sandstone, Clagett shales, and Judith River beds. The slides show the Bear Paw shales on top of the Judith River beds at the head of an eastern branch of Dog Creek called Taffy Creek. In the Bear Paw shales were secured Fort Pierre Ammonites, Baculites, a new Clidastes, and bones of plesiosaurs. Immediately below, in the Judith River beds, we found a typical locality for the vertebrates and made a large collection of Dinosaur, Myledaphus teeth, and vertebræ of Campsosaurus and the footed ischium of Lambe's Stephanosaurus and other Belly River vertebrates. We found Myledaphus teeth in the Eagle sandstones, leaves belonging to Belly River types, as well as numerous shells from the same horizon. We followed the strata down to Cow Island and found the stratigraphy simple, but for the uplift of the strata, everywhere. My work there substantiated Hatcher and Stanton in every particular, as noted in their bulletin of the U. S. Geological Survey.

At 5 o'clock the Society adjourned for the day. In the evening the members assembled to hear the address of the retiring President of the Geological Society of America, and attended the complimentary smoker following this address.

Session of Wednesday, December 30

Wednesday morning, at 9.30, the Society was called to order by President Osborn, who asked for the report of the Auditing Committee as the first matter of business. The committee reported that the accounts of the Treasurer were found to be correct; whereupon it was voted that their report be accepted. The chairman next announced that as the symposium, in joint session with the Geological Society of America, would commence at 10.30, the intervening time would be devoted to papers of general interest.

COMPLETION OF PAPERS OF GENERAL INTEREST

The first paper of the morning was then presented by the author and illustrated by lantern slides; 15 minutes. Discussed by J. M. Clarke, A. W. Grabau, and C. J. Sarle, with replies by the author.

SHAWANGUNK FORMATION OF MEDINA AGE

BY CHARLES SCHUCHERT

(Abstract)

The Shawangunk has furnished *Arthrophycus harlani* (*A. alleghaniense*) and eurypterids. The formation will be traced from Kingston, New York, to Lewiston, Pennsylvania.

The next paper was transferred to the Paleontological Society from the program of the Geological Society of America and was illustrated by the author with a large drawing showing this splendid section in the colors of the rocks themselves; 10 minutes. Discussed by Charles Schuchert.

PIC D'AURORE SECTION

BY JOHN M. CLARKE

Announcement of an interesting discussion of vertebrate remains in the Pleistocene of New York was then made by the senior author under the following title:

PECCARIES OF THE PLEISTOCENE OF NEW YORK

BY JOHN M. CLARKE AND W. D. MATTHEW

The hour for the symposium having arrived, the Society adjourned to the general lecture hall of the Philadelphia Academy of Sciences, meeting in joint session with the Geological Society of America. The speakers and titles of their special subjects in the symposium are as follows:

SYMPOSIUM ON THE PASSAGE FROM THE JURASSIC TO THE CRETACEOUS

INTRODUCTION

BY HENRY FAIRFIELD OSBORN

THE MORRISON: AN INITIAL CRETACEOUS FORMATION

BY WILLIS T. LEE

GEOLOGIC EXPOSURES OF THE MORRISON

BY CHARLES C. MOOK

SAUROPODA AND STEGOSAURIA OF THE MORRISON COMPARED WITH THAT OF SOUTH AMERICA, ENGLAND, AND EASTERN AFRICA

BY RICHARD S. LULL

THE PALEOBOTANIC EVIDENCE

BY EDWARD W. BERRY

THE INVERTEBRATE FAUNA OF THE MORRISON

BY T. W. STANTON

With the completion of the symposium, at 1 p. m., the Society adjourned for luncheon, meeting again in general session at 2.30 in the library. There was then presented the presidential address of the retiring President, on the subject,

THE ADDITION AND EVOLUTION OF "CHARACTERS" IN PALEONTOLOGIC PHYLA

BY HENRY FAIRFIELD OSBORN

Following this address, which was illustrated by lantern slides, President Osborn announced that the Society would then meet in two sections for the rest of the program, a vertebrate section to occupy an adjoining room and a section of invertebrate, paleobotanic, and general paleontology to remain in session in the library. The minutes of the first section follow.

SECTION OF VERTEBRATE PALEONTOLOGY

The section was called to order by President Osborn, chairman, at 3.35, Wednesday afternoon, for the reading of sectional papers. W. D.

Matthew was requested by the chair to act as secretary. The following papers were submitted:

MEGALOCNUS AND OTHER CUBAN GROUND-SLOTHS

BY CARLOS DE LA TORRE AND W. D. MATTHEW

(*Abstract*)

Four genera of ground-sloths are represented in the Cuban Pleistocene collections made by La Torre, Brown, and Moreno. The largest and most abundant is *Megalocnus* Leidy, of which the complete skeleton has been articulated and mounted. The other genera, *Mesocnus. Miocnus*, and *Microcnus*, are smaller animals, the last no larger than a woodchuck. Although well distinguished, they form a related group, their nearest continental allies being *Megalonyx* of Pleistocene North America and *Euchotocops* of Miocene South America. Affinities to the modern tree-sloth *Cholœpus* are not to be excluded for the smaller genera.

AFFINITIES OF HYOPSODUS

BY W. D. MATTHEW

(*Abstract*)

Jaws of Hyopsodus are very common in the Eocene, but skulls and skeleton parts are rare. The zoological position of this small mammal has been much questioned. It has been referred by different authors to the Suillines, to the Primates, to the Insectivora. Evidence is now brought forward for its reference to the order Condylarthra.

NEW EVIDENCE OF THE AFFINITIES OF THE MULTITUBERCULATA

BY WALTER GRANGER

(*Abstract*)

These Mesozoic and early Tertiary mammals have been regarded by some authorities as Marsupials, by others as Monotremes. Additional and more complete skeleton material from the Paleocene of New Mexico indicates that they are not nearly related to either, but are probably entitled to rank as a distinct primary division of the Mammalia, equivalent in evolutionary stage to the Marsupials, but not closely related, and more remote from either Monotremes or Placentals.

The paper was discussed by Messrs. Gidley, Gregory, Osborn, and Matthew.

The meeting then adjourned.

The section reconvened at 9.10 a. m., Thursday, January 31, and the program of sectional papers was continued as follows:

HEADS AND TAILS; A FEW NOTES RELATING TO SAUROPOD DINOSAURS

BY W. J. HOLLAND

(*Abstract*)

The author announced the discovery of many dinosaur skeletons, some remarkably complete, in the quarries worked by the Carnegie Museum in the Morrison formation of Uinta County, Utah. He presented the evidence for associating with the skeleton of *Brontosaurus* a skull unlike that arbitrarily referred to this genus by Professor Marsh, and much more nearly resembling the skull of *Diplodocus*. The tail of *Brontosaurus* is extended in a long, slender whiplash, as in *Diplodocus*.

The paper was discussed by Messrs. Osborn, Lull, Granger, and Matthew.

Mr. Granger's paper, submitted at the preceding session, was then brought up for further discussion by Professor Osborn, Doctor Matthew, and Mr. Granger.

The next two papers read were:

OBSERVATIONS ON ADAPIDÆ AND OTHER LEMUROIDEA

BY W. K. GREGORY

OBSERVATIONS ON THE PHYLOGENY OF THE HIGHER PRIMATES

BY W. K. GREGORY

(*Abstract*)

The author presented certain conclusions from recent researches on living and extinct primates, with the aid of more complete materials than had hitherto been available. The importance of the basicranial characters and their interpretation were discussed and present conclusions stated as to the affinities of the several living and extinct groups.

The papers were discussed by Professor Osborn and Doctor Matthew.

RECONSTRUCTION OF THE SKELETON OF BRACHIOSAURUS

BY W. D. MATTHEW

(*Abstract*)

The author presented a sketch reconstruction of the skeleton of this genus, the largest known Dinosaur, based on the skeletons in the Field Museum, Chicago, described by E. S. Riggs, and partial descriptions by Professors Branca and Janensch of the skeleton from German East Africa in the Berlin Museum.

FISH FAUNA OF THE CONODONT BED (BASAL GENESEE) AT EIGHTEEN-MILE CREEK, NEW YORK

BY L. HUSSAKOF AND W. L. BRYANT

(Abstract)

The conodont bed is a thin layer of impure limestone at the base of the Genesee at Eighteen-mile Creek, New York. It has a maximum thickness of four or five inches, thins out in either direction, and in some sections is absent altogether. It thus seems to occur in lenticular patches. Conodonts are extremely abundant in it, to which circumstance is due its name.

Until a few years ago no vertebrate remains were known to occur in this bed; but an extensive and very remarkable fish fauna has since been obtained. This includes sharks, Arthrodires, Ptyctodonts, Ichthyodorulites, Dipnoans, and Ganoids. There are four or five new genera and about a dozen new species in the materials. The remains are generally fragmental, but complete dental elements and other plates have been collected. The assemblage constitutes one of the most remarkable Devonic fish faunas known. It will be described and fully illustrated by the authors in a catalogue of the fossil fishes in the Museum of the Buffalo Society of Natural Science, now nearly ready for press.

Discussion by Messrs. Wieland and Burnett Smith.

STRATIGRAPHIC RELATIONS OF THE FOSSIL VERTEBRATE LOCALITIES OF FLORIDA

BY E. H. SELLARDS

(Abstract)

Two principal faunal horizons were considered, the Alachua clays and the Peace Creek beds. The latter have been thought to be intercalated between marine Pliocene strata, but the evidence for this is inconclusive, and there appears to be no reason against regarding the fauna as Pleistocene. The Alachua clays are probably Upper Miocene.

The paper was discussed by Messrs. Osborn, Gidley, and Matthew.

SCALED AMBHIBIA OF THE COAL MEASURES

BY ROY L. MOODIE

The paper was presented and briefly discussed by Doctor Gregory.

This being the last paper on the program, the section then adjourned.

SECTION OF INVERTEBRATE, PALEOBOTANIC, AND GENERAL PALEONTOLOGY

This section was called to order for its first session at 3.30, Wednesday afternoon, with Vice-President Van Ingen presiding. The chairman announced that, on account of a conflict in the program, the papers of Group B of the Geological Society of America had been transferred to the Paleontological Society for reading.

The first paper of Group B was presented by the author and illustrated by lantern slides; 10 minutes. Discussed by E. O. Ulrich and A. W. Grabau, with replies by the author.

ALEXANDRIAN ROCKS OF NORTHEASTERN ILLINOIS AND EASTERN WISCONSIN

BY T. E. SAVAGE

There was next presented by the author, illustrated by diagrams and lantern slides, a paper transferred from Group A of the Geological Society of America to the Paleontological Society in order that all papers bearing on the black shale problem should be read in succession. The discussion on this paper was postponed until all of those dealing with the subject had been read.

DIASTROPHIC IMPORTANCE OF THE UNCONFORMITY AT THE BASE OF THE BEREA SANDSTONE IN OHIO

BY H. P. CUSHING

The second paper in the black shale discussion was read by the author and illustrated by drawings; 30 minutes.

KINDERHOOKIAN AGE OF THE CHATTANOOGAN SERIES

BY E. O. ULRICH

At 5.30 the Society adjourned for the day. Wednesday evening the members attended the annual dinner with the Fellows of the Geological Society of America at the Hotel Walton.

SESSION OF THURSDAY, DECEMBER 31

Thursday morning the section met at 9, with the completion of the black shale and related papers first on the program. Vice-President Van Ingen presided.

The first paper was presented by the senior author and was illustrated by drawings; 10 minutes.

DEVONIAN OF CENTRAL MISSOURI

BY E. B. BRANSON AND D. K. GREGOR

Next was presented by the author, illustrated by diagram, the following paper of the Paleontological Society's program: 30 minutes.

OLENTANGY SHALE OF CENTRAL OHIO AND ITS STRATIGRAPHIC SIGNIFICANCE

BY A. W. GRABAU

(*Abstract*)

In its typical localities the Olentangy shale is intimately associated with the Huron shale, this latter representing merely a change in facies, without interruption of stratigraphic continuity. The Olentangy clearly belongs to the Upper Devonic, resting disconformably on limestones of Lower Hamilton age. The shales and limestones now classed as Olentangy in northern Ohio are, however, early Hamilton, and considerably older than the Olentangy. This name should therefore not be used for strata of Hamilton age, but instead the name Prout series is proposed for the northern Ohio deposits of Hamilton age.

This concluded the series of black shale papers and a general discussion followed, in which Messrs. Branson, Cushing, Foerste, Grabau, Kindle, Prosser, Savage, Schuchert, David White, I. C. White, and M. Y. Williams took part.

There was then presented by the author a stratigraphic paper, illustrated by lantern slides and diagrams; 30 minutes. Discussed by Charles Schuchert and Gilbert Van Ingen.

GEOLOGICAL RECONNAISSANCE OF PORTO RICO

BY CHARLES P. BERKEY

The last paper of Group B was presented by the author and illustrated by lantern slides; 15 minutes.

RELATIONS OF CRETACEOUS FORMATIONS TO THE ROCKY MOUNTAINS IN COLORADO AND NEW MEXICO

BY WILLIS T. LEE

By previous arrangement the two sections of the Society met in general session at 12.30, when matters of business relating to the next meeting place, etcetera, were discussed.

In closing the session, the splendid arrangements to make the Society's Philadelphia meeting a pleasant one were also discussed, and the Secretary was authorized to convey the Society's appreciation to the members of the local committee.

At 1 o'clock the Society adjourned for luncheon, to meet again at 2 p. m. in two sections.

The first paper in the afternoon session of the section of invertebrate, paleobotanic, and general paleontology was presented by the author and illustrated by drawings; 15 minutes.

EVOLUTION OF THE ANTHOZOA AND THE SYSTEMATIC POSITION OF PALEOZOIC CORALS

BY T. C. BROWN

(*Abstract*)

In the development of the zooids of modern Anthozoa a stage is always observed in which there are eight mesenteries present. This condition may persist throughout life, as, for example, in the subclass Alcyonaria; or it may be only transitory, as it is in the subclass Zoantharia.

To the subclass Alcyonaria probably belong those Paleozoic corals that are either without septa or in which the septa probably were not directly related to the internal mesenteric structure of the zooid—Columnaria, Favosites, Syringopora, etcetera.

In the subclass Zoantharia four distinct orders can be recognized, and these orders are distinguished by the number and arrangement of the mesenteries added beyond the primitive number eight. In the Ceriauthidea new mesenteries are added at only one point in the periphery of the zooid; in the Zoanthidea they are added at two points; in the Tetracorallidea at four points; in the Actiniidea at many points; generally some multiple of six. The first two of these orders are known only from modern forms; the third is confined to the Paleozoic; the fourth probably begins in the Mesozoic and is dominant at the present time.

The second paper of the afternoon was given by the author and illustrated by lantern slides and diagrams; 15 minutes. Discussed by Charles Schuchert, P. E. Raymond, J. M. Clarke, and A. W. Grabau.

NEW FACTS BEARING ON THE PALEOZOIC STRATIGRAPHY OF THE REGION ABOUT THREE FORKS, MONTANA

BY W. P. HAYNES

(*Abstract*)

In the various sections studied in the region about Three Forks and the adjacent country to the south, in southwestern Montana, the Jefferson limestone lies in apparent conformity on the Cambrian limestone, without any intervening formations. From Paleozoic evidence all of the Jefferson limestone is regarded as of Devonian age, and it is considered to lie disconformably on the Cambrian limestone in this region.

The presence of intervening strata of different lithological character, containing in some cases fossils of Ordovician and Silurian ages, between the Cambrian limestone and the Jefferson limestone, as noted by various writers, in sections in neighboring regions to the west and southwest, points to a stratigraphic overlap which involves a hiatus in sedimentary record for the region about Three Forks.

The Three Forks formation overlies the Jefferson limestone in this region, but differs greatly in its lithological characters from north to south. In the type region at Three Forks and to the north, along the Missouri River, it consists of seven fairly distinct shale and limestone members, the upper five of which are generally fossiliferous and contain a late Devonian faunule. In the southern sections the formation is chiefly limestone and sparsely fossiliferous. The Three Forks formation is not nearly so widely distributed as the Jefferson limestone or the overlying Madison limestone.

The next paper was given by the senior author and illustrated by lantern slides; 20 minutes. Discussed by R. S. Bassler and E. R. Cumings.

STUDIES OF THE MORPHOLOGY AND HISTOLOGY OF THE TREPOSTOMATA (MONTICULIPOROIDS)

BY E. R. CUMINGS AND J. J. GALLOWAY

(Abstract)

This paper is a minute study of wall structure, with reference to its taxonomic significance; of the exact nature and function of acanthopores in the genus *Dekayia;* of certain peculiar cystlike structures in a number of genera; of communication pores in numerous genera, and of the structure and relationships of the recent sponge genus, Merlia.

Then followed a paper presented by the author, with diagram; 20 minutes. Discussed by John M. Clarke, with reply by the author.

HAMILTON GROUP OF NEW YORK

BY A. W. GRABAU

(Abstract)

The various subdivisions originally made by the author for the Hamilton of Eighteen-mile Creek have been correlated with a similar number of subdivisions in central New York by the New York Survey. The validity of this correlation will be considered and the facts suggesting that an error has been made will be given. A new series of names for these subdivisions will be proposed. A brief comparison with the Traverse group of Michigan will be made.

The next paper was read by the author; 15 minutes. Discussed by C. J. Sarle, Charles Schuchert, J. M. Clarke, M. Y. Williams, Charles Prosser, and Henry M. Ami.

A CLASSIFICATION OF AQUEOUS HABITATS

BY MARJORIE O'CONNELL

(*Abstract*)

An attempt will be made to classify aqueous habitats on the basis of salinity. A table of salinity ranges for the various types will be given, with a discussion and restriction of the terms fresh, brackish, and marine waters. The faunal significance of these habitats will be considered and several illustrations given, with especial attention to the relation between salinity and faunas. The purpose of the study is to obtain a faunal standard for each habitat by which faunas of former periods can be judged and interpreted in terms of habitat.

The final paper of the program was given by the author, who illustrated it by drawings.

NEW SPECIES OF FICUS FROM THE INTERGLACIAL DEPOSITS OF THE KOOTENAY VALLEY, BRITISH COLUMBIA

BY ARTHUR HOLLICK

(*Abstract*)

Fossil plants, if their generic relationships to living plants can be satisfactorily determined, are generally regarded as excellent climatic indices. Remains of a species of *Ficus*, for example, in strata of any geologic age would at once be recognized as good evidence that a tropical or subtropical climate must have prevailed in the locality where the strata are, at the time when they were laid down. The generic identification of fossil leaves can not always be relied on as correct; but well preserved remains of fruit are generally very satisfactory subjects for determination, especially if the generic characters are peculiar or striking. Recently a study was made of a collection of fossil plants, stems, leaves, and fruit from interglacial deposits in the Kootenay Valley, British Columbia, sent for examination and report by the Director of the Canada Geological Survey.

At 1.30 p. m. the Society adjourned.

Register of the Philadelphia Meeting, 1914

Henry M. Ami
Paul Bartsch
Ray S. Bassler
Edward W. Berry
E. B. Branson
Barnum Brown
Thomas C. Brown
William B. Clark
John M. Clarke
Herdman F. Cleland
Will E. Crane
Edgar R. Cumings
Charles R. Eastman
August F. Foerste
J. W. Gidley
C. E. Gordon
Amadeus W. Grabau
Walter Granger
W. K. Gregory
Chris A. Hartnagel
Winthrop P. Haynes
Arthur Hollick
L. Hussakof
Edward M. Kindle
Frank H. Knowlton
Richard S. Lull
J. H. McGregor
W. D. Matthew
Charles C. Mook
Marjorie O'Connell
Henry F. Osborn
R. W. Pack
Charles S. Prosser
Percy E. Raymond
Chester A. Reeds
Thomas E. Savage
Charles Schuchert
William J. Sinclair
Burnett Smith
T. W. Stanton
L. W. Stephenson
Charles H. Sternberg
Charles K. Swartz
Mignon Talbot
E. L. Troxell
M. W. Twitchell
Edward O. Ulrich
Gilbert Van Ingen
F. M. Van Tuyl
T. Wayland Vaughan
Charles D. Walcott
David White
G. R. Wieland
Merton Y. Williams

OFFICERS, CORRESPONDENTS, AND MEMBERS OF THE PALEONTOLOGICAL SOCIETY

OFFICERS FOR 1915

President:

EDWARD O. ULRICH, Washington, D. C.

First Vice-President:

J. C. MERRIAM, Berkeley, California

Second Vice-President:

GILBERT VAN INGEN, Princeton, New Jersey

Third Vice-President:

F. H. KNOWLTON, Washington, D. C.

Secretary:

R. S. BASSLER, Washington, D. C.

Treasurer:

RICHARD S. LULL, New Haven, Connecticut

Editor:

CHARLES R. EASTMAN, New York City

MEMBERSHIP, 1915

CORRESPONDENTS

Dr. A. C. NATHORST, Royal Natural History Museum, Stockholm, Sweden.
S. S. BUCKMAN, Esq., Westfield, Thame, England.
Prof. CHARLES DÉPERET, University of Lyon, Lyon (Rhone), France.
Dr. HENRY WOODWARD, British Museum (Natural History), London, England.

MEMBERS

JOSÉ G. AGUILERA, Instituto Geologico de Mexico, City of Mexico, Mexico.
TRUMAN H. ALDRICH, care post-office, Birmingham, Ala.
HENRY M. AMI, Geological and Natural History Survey of Canada, Ottawa, Canada.
F. M. ANDERSON, 2604 Etna Street, Berkeley, Cal.
ROBERT ANDERSON, 7 Richmond Terrace, London, England.
RALPH ARNOLD, 921 Union Oil Building, Los Angeles, Cal.
RUFUS M. BAGG, JR., Lawrence College, Appleton, Wis.
CHARLES L. BAKER, 716 Southern Pacific Building, Houston, Texas.

Erwin H. Barbour, University of Nebraska, Lincoln, Nebr.
Paul Bartsch, U. S. National Museum, Washington, D. C.
Harvey Bassler, Geological Department, Johns Hopkins University, Baltimore, Md.
Ray S. Bassler, U. S. National Museum, Washington, D. C.
Joshua W. Beede, Indiana University, Bloomington, Ind.
Walter A. Bell, 8 Prospect Place, New Haven, Conn.
B. A. Bensley, University of Toronto, Toronto, Canada.
Fritz Berckhemer, Department of Paleontology, Columbia University, New York City.
Edward W. Berry, Johns Hopkins University, Baltimore, Md.
Arthur B. Bibbins, Woman's College, Baltimore, Md.
Walter R. Billings, 1250 Bank Street, Ottawa, Canada.
Thomas A. Bostwick, 43 Livingston Street, New Haven, Conn.
E. B. Branson, University of Missouri, Columbia, Mo.
Barnum Brown, American Museum of Natural History, New York City.
Thomas C. Brown, Bryn Mawr College, Bryn Mawr, Pa.
William L. Bryant, Buffalo Society of Natural History, Buffalo, N. Y.
Lancaster D. Burling, Geological Survey of Canada, Ottawa, Canada.
Charles Butts, U. S. Geological Survey, Washington, D. C.
John P. Buwalda, 2519 Ridge Road, Berkeley, Cal.
Ermine C. Case, University of Michigan, Ann Arbor, Mich.
George H. Chadwick, University of Rochester, Rochester, N. Y.
Bruce L. Clarke, University of California, Berkeley, Cal.
William B. Clark, Johns Hopkins University, Baltimore, Md.
John M. Clarke, Education Building, Albany, N. Y.
Herdman F. Cleland, Williams College, Williamstown, Mass.
Harold J. Cook, Agate, Nebr.
Will E. Crane, Swissvale post-office, Pittsburgh, Pa.
Edgar R. Cumings, Indiana University, Bloomington, Ind.
W. H. Dall, U. S. National Museum, Washington, D. C.
Bashford Dean, Columbia University, New York City.
Orville A. Derby, 80 Rua do Rio Branco, Sao Paulo, Brazil.
Roy E. Dickerson, 1320 Fifth Avenue, San Francisco, Cal.
John T. Doneghy, Jr., 963 Yale Station, New Haven, Conn.
Earl Douglass, Carnegie Museum, Pittsburgh, Pa.
Charles R. Eastman, American Museum of Natural History, New York City.
George F. Eaton, 80 Sachem Street, New Haven, Conn.
John Eyerman, "Oakhurst," Easton, Pa.
August F. Foerste, 128 Rockwood Avenue, Dayton, Ohio.
Julia A. Gardner, Department of Geology, Johns Hopkins University, Baltimore, Md.
G. S. Gester, 711 Flood Building, San Francisco, Cal.
Hugh Gibb, Peabody Museum, Yale University, New Haven, Conn.
J. W. Gidley, U. S. National Museum, Washington, D. C.
J. Z. Gilbert, Los Angeles High School, Los Angeles, Cal.
Clarence E. Gordon, Massachusetts Agricultural College, Amherst, Mass.
Charles N. Gould, 408 Terminal Building, Oklahoma City, Okla.
Amadeus W. Grabau, Columbia University, New York City.

Walter Granger, American Museum of Natural History, New York City.
F. C. Greene, U. S. Geological Survey, Washington, D. C.
W. K. Gregory, American Museum of Natural History, New York City.
Norman McD. Grier, 399 Elm Street, New Haven, Conn.
Harold Hannibal, Stanford University, Stanford, Cal.
George W. Harper, 2139 Gilbert Avenue, Cincinnati, Ohio.
Gilbert D. Harris, Cornell University, Ithaca, N. Y.
Chris. A. Hartnagel, Education Building, Albany, N. Y.
Adam Hermann, American Museum of Natural History, New York City.
William J. Holland, Carnegie Museum, Pittsburgh, Pa.
Arthur Hollick, New York Botanical Garden, Bronx Park, New York City.
George H. Hudson, 19 Broad Street, Plattsburgh, N. Y.
Louis Hussakof, American Museum of Natural History, New York City.
Jesse Hyde, School of Mines, Kingston, Ontario.
Robert T. Jackson, 195 Bay State Road, Boston, Mass.
E. C. Jeffrey, Harvard University, Cambridge, Mass.
Otto E. Jennings, Carnegie Museum, Pittsburgh, Pa.
W. S. W. Kew, 1522 Grove Street, Berkeley, Cal.
Edward M. Kindle, Geological Survey of Canada, Ottawa, Canada.
Edwin Kirk, U. S. Geological Survey, Washington, D. C.
Frank H. Knowlton, U. S. Geological Survey, Washington, D. C.
Lawrence M. Lambe, Geological Survey of Canada, Ottawa, Canada.
Frederick B. Loomis, Amherst College, Amherst, Mass.
Richard S. Lull, Yale University, New Haven, Conn.
D. D. Luther, Naples, N. Y.
Victor W. Lyon, Jeffersonville, Ind.
Thomas H. McBride, University of Iowa, Iowa City, Iowa.
J. H. McGregor, Columbia University, New York City.
Wendell C. Mansfield, U. S. Geological Survey, Washington, D. C.
Clara G. Mark, Department of Geology, Ohio State University, Columbus, O.
Bruce Martin, California Academy of Sciences, San Francisco, Cal.
George F. Matthew, 715 Germain Street, St. John, New Brunswick.
W. D. Matthew, American Museum of Natural History, New York City.
T. Poole Maynard, 321 James Building, Chattanooga, Tenn.
Maurice G. Mehl, University of Wisconsin, Madison, Wis.
John C. Merriam, University of California, Berkeley, Cal.
Rector D. Mesler, U. S. Geological Survey, Washington, D. C.
Roy L. Moodie, University of Illinois, Chicago, Ill.
Clarence L. Moody, University of California, Berkeley, Cal.
G. B. Moody, 2618 Etna Street, Berkeley, Cal.
W. O. Moody, 2618 Etna Street, Berkeley, Cal.
Robert B. Moran, 311 California Street, San Francisco, Cal.
William C. Morse, Ohio State University, Columbus, Ohio.
James E. Narraway, Department of Justice, Ottawa, Canada.
Marjorie O'Connell, Adelphi College, Brooklyn, N. Y.
Henry F. Osborn, American Museum of Natural History, New York City.
R. W. Pack, U. S. Geological Survey, Washington, D. C.
Earl L. Packard, 1522 Grove Street, Berkeley, Cal.
William A. Parks, University of Toronto, Toronto, Canada.

William Patten, Dartmouth College, Hanover, N. H.
John R. Pemberton, Hydrographic Survey, Argentina.
O. A. Peterson, Carnegie Museum, Pittsburgh, Pa.
Alexander Petrunkevitch, 266 Livingston Street, New Haven, Conn.
Charles S. Prosser, Ohio State University, Columbus, Ohio.
Percy E. Raymond, Museum of Comparative Zoology, Cambridge, Mass.
Chester A. Reeds, American Museum of Natural History, New York City.
E. S. Riggs, Field Museum of Natural History, Chicago, Ill.
Paul V. Roundy, U. S. Geological Survey, Washington, D. C.
Robert R. Rowley, Louisiana, Mo.
Rudolph Ruedemann, Education Building, Albany, N. Y.
Frederick W. Sardeson, 414 Harvard Street, Minneapolis, Minn.
Thomas D. Savage, University of Illinois, Urbana, Ill.
Charles Schuchert, Yale University, New Haven, Conn.
William B. Scott, Princeton University, Princeton, N. J.
Henry M. Seely, Middlebury College, Middlebury, Vt.
Elias H. Sellards, Tallahassee, Fla.
Henry W. Shimer, Massachusetts Institute of Technology, Boston, Mass.
William J. Sinclair, Princeton University, Princeton, N. J.
Burnett Smith, Syracuse University, Syracuse, N. Y.
Frank Springer, U. S. National Museum, Washington, D. C.
T. W. Stanton, U. S. Geological Survey, Washington, D. C.
Clinton R. Stauffer, University of Minnesota, Minneapolis, Minn.
L. W. Stephenson, U. S. Geological Survey, Washington, D. C.
Charles H. Sternberg, Victoria Memorial Museum, Ottawa, Canada.
Chester Stock, 492 Seventh Street, San Francisco, Cal.
Charles K. Swartz, Johns Hopkins University, Baltimore, Md.
Mignon Talbot, Mt. Holyoke College, South Hadley, Mass.
Edgar E. Teller, 3321 Sycamore Street, Milwaukee, Wis.
Albert Thompson, American Museum of Natural History, New York City.
Edward L. Troxell, Amherst College, Amherst, Mass.
William H. Twenhofel, University of Kansas, Lawrence, Kans.
M. W. Twitchell, Geological Survey of New Jersey, Trenton, N. J.
Edward O. Ulrich, U. S. Geological Survey, Washington, D. C.
Claude W. Unger, Pottsville, Pa.
Jacob Van Deloo, Education Building, Albany, N. Y.
Gilbert Van Ingen, Princeton University, Princeton, N. J.
Francis M. Van Tuyl, Department of Paleontology, Columbia University, New York.
T. Wayland Vaughan, U. S. Geological Survey, Washington, D. C.
Anthony W. Vogdes, 2425 First Street, San Diego, Cal.
Charles D. Walcott, Smithsonian Institution, Washington, D. C.
Clarence A. Waring, Box 162, Mayfield, Cal.
Stuart Weller, University of Chicago, Chicago, Ill.
David White, U. S. Geological Survey, Washington, D. C.
G. R. Wieland, Yale University, New Haven, Conn.
Henry S. Williams, Cornell University, Ithaca, N. Y.
Samuel W. Williston, University of Chicago, Chicago, Ill.
Herrick E. Wilson, 224 W. College Street, Oberlin, Ohio.

WILLIAM J. WILSON, Geological Survey of Canada, Ottawa, Canada.
ELVIRA WOOD, Museum of Comparative Zoology, Harvard University, Cambridge, Mass.

CORRESPONDENT DECEASED

E. KOKEN, died November 24, 1912.

MEMBERS DECEASED

SAMUEL CALVIN, died April 17, 1911.
WILLIAM M. FONTAINE, died April 30, 1913.
THEODORE M. GILL, died September 25, 1914.
ROBERT H. GORDON, died May 10, 1910.
J. C. HAWVER, died May 15, 1914.

MEMBERS-ELECT

ALBERT L. BARROWS, University of California, Berkeley, Cal.
WINIFRED GOLDRING, New York State Museum, Albany, N. Y.
JOHN A. GUINTYLLO, University of California, Berkeley, Cal.
WINTHROP P. HAYNES, Wellesley College, Wellesley, Mass.
JUNIUS HENDERSON, University of Colorado, Boulder, Colo.
CHARLES C. MOOK, American Museum of Natural History, New York City.
JORGEN O. NOMLAND, University of California, Berkeley, Cal.
CHARLES E. RESSER, U. S. National Museum, Washington, D. C.
MERTON Y. WILLIAMS, Geological Survey of Canada, Ottawa, Canada.
ALICE E. WILSON, Victoria Memorial Museum, Ottawa, Canada.

Minutes of the Fifth Annual Meeting of the Pacific Coast Section of the Paleontological Society

C. A. Waring, *Secretary*

The fifth annual meeting of the Pacific Coast Section of the Paleontological Society was held in divided session at Stanford University, California, and at Seattle, Washington. The Stanford meeting was held in the Geology Building, on Friday, April 24, 1914; the Seattle meeting was held in Science Hall of the University of Washington, on Friday, May 22, 1914. President J. C. Merriam presided at both meetings.

The relation of the paleontological series of the Pacific coast to that of the Atlantic coast and outside areas, with special reference to methods of correlation of the Triassic, Cretaceous, and Miocene, was suggested as the general topic of discussion for the meeting of the Paleontological Society to be held in San Francisco in 1915. A motion was made and carried ratifying this report as made by Doctor Merriam, chairman of the Program Committee.

Election of officers

The following officers were elected for the ensuing year:

President, Roy E. Dickerson, 114 Burnett Ave., San Francisco.
Vice-President, H. Hannibal, Stanford University.
Secretary-Treasurer, E. L. Packard, Berkeley, Cal.

It was voted to hold the next meeting at the call of the President.

Following are the programs and abstracts of the papers presented at the two divisions:

Papers of the Stanford meeting

Note on the Cretaceous Echinoderms of California

BY W. S. W. KEW

Relations of the Santa Margarita Formation in the Coalinga East Side Field

BY JOHN H. RUCKMAN

(*Abstract*)

A discussion of evidences of unconformity with the Jacalitos above and Big Blue below.

TENTATIVE CORRELATION TABLE OF THE NEOCENE OF CALIFORNIA

BY BRUCE L. CLARK

FAUNA OF THE LOWER MONTEREY OF CONTRA COSTA COUNTY, CALIFORNIA

BY BRUCE L. CLARK

EXTINCT TOAD FROM RANCHO LA BREA

BY CHARLES L. CAMP

(*Abstract*)

Amphibian bones from Rancho La Brea show the existence there of a toad closely allied to present-day forms of the Pacific coast.

RODENTS OF RANCHO LA BREA

BY LEE R. DICE

(*Abstract*)

The rodents found at Rancho La Brea are closely related to the forms living in the same region.

OCCURRENCE OF MAMMAL REMAINS IN THE ASPHALT BEDS OF MC KITTRICK, CALIFORNIA

BY NEILL C. CORNWALL

(*Abstract*)

In the asphalt deposits of McKittrick certain mammal remains have been found. These seem to indicate that the formation of the asphalt was not later than Lower Pleistocene.

OUTLINE OF THE HISTORY OF THE CASTORIDÆ

BY W. P. TAYLOR

(*Abstract*)

The beaver family was doubtless derived from Eocene Ischyromyidæ. The genera, *Paramys* (Eocene), *Sciuravus* (Eocene), and *Steneofiber* (Oligocene and Miocene), are near, if not actually, members of the phylogenetic series, of which the genus *Castor* is the latest development. There have been probably at least three beaver intercontinental migrations. The determinations of the age of the Etchegoin formation bears directly on the problem of the first appearance of the genus *Castor*.

CRETACEOUS-EOCENE CONTACT IN THE ATLANTIC AND GULF COASTAL PLAIN

BY L. W. STEPHENSON

(*Abstract*)

The paper emphasizes the fact that the Cretaceous and Eocene deposits of the Atlantic and Gulf Coastal Plain are separated by an unconformity of regional extent. Faunal evidence is offered to show that, in terms of geologic time, this unconformity represents a very great hiatus. The differences exhibited by the faunas on either side of the contact indicate changes greater than those effected through evolutionary development during the time represented by the *Exogyra ponderosa* and *Exogyra costata* zones of the Upper Cretaceous; the differences are also greater than the faunal changes effected between the lowermost Eocene and the Recent, in the same province. The unconformity marks a great diastrophic movement which involved the entire Atlantic and Gulf Coastal Plain.

IONE FORMATION OF THE SIERRA NEVADA FOOTHILLS, A LOCAL FACIES OF THE UPPER TEJON-EOCENE

BY ROY E. DICKERSON

(*Abstract*)

The Ione, in part at least, is marine and of Tejon-Eocene age. Marine fossils have been found in the upper portion of the Ione formation at Marysville Buttes, Oroville South Table Mountain, Merced Falls, and Ione. Apparently the same faunal zone, the *Siphonalia sutterensis* zone, is represented in all these places.

STRATIGRAPHIC AND FAUNAL RELATIONS OF THE LATER EOCENE OF THE PACIFIC COAST

BY HAROLD HANNIBAL

(*Abstract*)

Illustrated discussion of the stratigraphic and faunal relations of the Chehalis, Olequa, and Arago formations of Oregon and Washington, and the Tejon and Ione formations of California.

FAUNA AND RELATIONS OF THE WHITE SHALES OF THE COALINGA DISTRICT

BY JOHN H. RUCKMAN

VERTEBRATE FAUNA IN THE MARINE TERTIARY OF CALIFORNIA; THEIR SIGNIFICANCE IN DETERMINING THE AGE OF CALIFORNIA TERTIARY FORMATIONS

BY J. C. MERRIAM

GEOLOGY OF A PORTION OF THE MCKITTRICK OIL FIELD

BY G. C. GESTER

PAPERS OF THE UNIVERSITY OF WASHINGTON MEETING

STRATIGRAPHIC AND FAUNAL RELATIONS OF THE LINCOLN FORMATION IN WASHINGTON

BY CHARLES E. WEAVER

CRETACEOUS FAUNAS OF THE SANTA ANA MOUNTAINS

BY EARL L. PACKARD

(*Abstract*)

The Santa Ana Mountains afford a Chico-Cretaceous section of simple structure, yielding a rich invertebrate fauna, which is divisible into four faunal zones. The section may serve as a faunal type section to which other Chico localities may be referred.

REVIEW OF THE FAUNA OF THE RATTLESNAKE PLIOCENE OF EASTERN OREGON

BY JOHN C. MERRIAM

(*Abstract*)

The Rattlesnake formation of the John Day Valley contains a fauna which has been presumed to be of late Miocene or early Pliocene age. The material known from this formation is very fragmentary and commonly of uncertain occurrence. The paper presents a review of the fauna, with a statement as to the probable age and correlation of the formation.

EOCENE OF THE COWLITZ VALLEY

BY CHARLES E. WEAVER

FAUNA OF THE SIPHONALIA SUTTERENSIS ZONE IN THE ROSEBURG QUADRANGLE, OREGON

BY ROY E. DICKERSON

(*Abstract*)

A collection made by Mr. Bruce Martin from the Umpqua formation, on the Umpqua River, at the mouth of Little River, contains several forms, such as *Chrysodormus martini*, *Cardium marysvillensis*, *Siphonalia sutterensis*, *Cari cella stormsiana*, *Surcula davisiana*, and *Venericardia planicosta*, new variety, which are characteristic of the *Siphonalia sutterensis* zone of the Tejon group

of California. The paper presents a fauna obtained from the Umpqua formation and a tentative correlation of the beds containing the fauna with the uppermost Tejon of the California province.

EVOLUTION OF THE PACIFIC COAST MACRIDÆ

BY EARL L. PACKARD

(Abstract)

The genus *Spisula*, represented in the Horsetown beds by *Spisula ashburneri* (Gabb) became dominant in the Middle Miocene, thence gradually declining to the present day. The earliest undoubted mactroid species occurs in the Miocene, reaching its greatest development at the present time. The mulinoid forms appeared suddenly in the early Miocene, spread rapidly, and then quickly disappeared from the region north of Mexico.

CORRELATION OF THE TERTIARY FORMATIONS IN WESTERN WASHINGTON

BY CHARLES E. WEAVER

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

VOL. 26, PP. 171-204 MARCH 31, 1915

ISOSTASY AND RADIOACTIVITY[1]

PRESIDENTIAL ADDRESS BY GEORGE F. BECKER

(Read before the Society December 29, 1914)

CONTENTS

INTRODUCTORY

It is the purpose of this paper to point out some apparent discrepancies between the observations of geodesists on isostasy and the inferences which some radiologists have drawn as to the great age of certain specimens of minerals. It seems well to begin by reviewing the results of isostatic investigations, in order to estimate the degree of confidence to which they are entitled; and recent advances in radiology demand similar attention.

Correlation of these widely distinct researches is possible because it happens that the emission of heat by a globe whose excess temperature is due solely to radioactivity obeys Fourier's law exactly as does that emitted by a hot but radioinactive globe. It is thus easy to plot the distribution of temperature in a globe which at the consistentior status had a high temperature due in part to radioactivity and in part to compression, the diagram being strictly analogous to that given by Kelvin for a cooling globe.[2] By trial and error it is possible to obtain an approximate answer to the question whether in the present state of science it can be admitted that the greater part of the heat radiated by the earth is of radioactive origin and whether approximately complete isostatic compensation at such

[1] Manuscript received by the Secretary of the Society December 29, 1914.
By reason of illness, Dr. Becker was unable to present his paper in person.

[2] Nat. Phil., part 2, p. 477.

depths as are reported by the geodesists is compatible with the lapse of something like a thousand million years since the ocean was gathered together.

Geology as a science is conditioned by the state of the earth's interior and our knowledge of its constitution is now advancing. So late as the foundation of this Society, in 1889, the Cartesian doctrine of a fluid earth, inclosed in a very rigid shell, a score or two of miles in thickness, was held by most geologists. We now know that the globe is solid and, on the whole, of great rigidity, and probably divisible into at least four distinct shells, each more rigid than that overlying it;[3] that the irregularities in density and structure, which are so marked at the surface, extend only to a depth of something like a fiftieth of the earth's radius; that open cavities or cracks may exist at depths of 20 miles and very possibly down to the level of isostatic compensation. We know, too, that the earth is radioactive, but that the radioactivity is superficial, reaching only to a moderate, though uncertain, level; we also know, however, that the earth's heat is not wholly of radioactive origin. More information is certainly in store for us, for Mr. Michelson is now measuring the terrestrial tides in terms of the wave-length of light,[4] while methods have been developed by which the distribution of density above the level of isostatic compensation can be studied.

Thus the future is full of hope. The rational method of attaining it is to make trial hypotheses and to devise methods of testing them.

Premonitions of Isostasy

Observations bearing on the problem of isostasy are as old as geodesy itself. During the measurement of the Peruvian arc, 1735 to 1745, Pierre Bouguer[5] observed and computed the attraction of Chimborazo.

[3] L. Geiger and B. Gutenberg, continuing investigations by Wiechert, Zoeppritz, and themselves on the intensity of longitudinal and transverse earthquake waves, find in the earth three surfaces of discontinuity at depths of 1,193, 1,712, and 2,454 kilometers. The values found for Poisson's ratio only slightly exceed one-fourth. Göttingen, Nachrichten, 1912, p. 675.

[4] The first attempts to measure bodily tides in the earth were made by George H. and Horace Darwin with the horizontal pendulum, but without satisfactory results. Better success attended the experiments by E. von Rebeur-Pashwitz with a similar instrument. O. Hecker at Potsdam, in 1907, and A. Orloff at Dorpat, in 1911, demonstrated small terrestrial tides and the high rigidity of the earth, also with the horizontal pendulum. Their results and others were discussed by W. Schweydar, Roy. Preus. Geod. Inst., 1912. To obviate certain difficulties and uncertainties attending the use of the horizontal pendulum, A. A. Michelson is experimenting with an apparatus consisting of two water-levels (acting on the principle of a spirit-level) at right angles to one another, each about 500 feet long. Astrophys. Jour., vol. 39, 1914, p. 97.

[5] La figure de la terre, 1749, p. 379. On page 391 he remarks that mountains attract much less than the greatness of their volume would promise.

From the unexpectedly small observed deflection of the vertical he inferred, just as a modern geodesist would have done, that the volcano must contain cavities. On the other hand, Charles Hutton[6] perverted the attraction of Schehallien to a determination of the density of the earth and entertained a poor opinion[7] of Cavendish's method,[8] now become the standard means of determining this constant. Hutton, however, introduced the method of dissecting a mountain mass into elements bounded by two horizontal planes, two vertical cylindrical surfaces, and two vertical planes, radiating from the station, which is still in use much as he developed it.

Laplace seems to have been the first to grasp the problem of isostasy. In 1818 he pointed out that Bouguer's pendulum experiments at Quito demonstrate that the Cordillera is of very low density, far smaller than the mean density of the earth, which, following Cavendish, he takes at 5.5. This is a distinct recognition of compensation. Between the years 1735 and 1818 a considerable number of observations in both hemispheres had been made on the length of the pendulum beating seconds, and discussion of these, together with measurements of degrees and lunar observations, led Laplace to conclusions which may be expressed as follows: The earth was once liquid and shells of equal density were approximately spherical; it solidified throughout, for the most part with very slight changes of configuration or disturbances of isostasy, and the irregularities manifest at the surface then extended and still extend to a very small depth compared with the earth's radius. The argument for the superficiality of these irregularities, as I understand it, is substantially that if Legendre's law of density (often referred to as Laplace's law) is assumed, the computed attractions agree with those observed extremely well, better than they could agree if such irregularities in the distribution of mass as are observable at the surface prevailed at great depths.[9] I find nothing like a rigorous demonstration of this probable thesis.

---

[6] Phil. Trans., London, 1778, Hutton's Abridgment, vol. 14, p. 408.

[7] Phil. Trans., London, 1821, Part I, p. 276.

[8] Phil. Trans., London, 1798, p. 469.

[9] Laplace's memoir on the figure of the earth appeared in the Mémoires de l'Académie for 1817, printed in 1819. It is reprinted in his complete works, vol. 12, 1897. It is only partially reproduced in the chapter on the figure of the earth in Book XI of the Mécanique Céleste. A summary is given in the memoir, but not in the magnum opus.

His mathematical analysis he says:

. . . "compared with pendulum determinations, with the measurements of degrees, and with lunar observations leads to these results:

"1. The density of the shells of the terrestrial spheroid increases from the surface to the center.

"2. These shells are to a close approximation symmetrical with reference to the center of gravity.

"3. The surface of this spheroid, a part of which is covered by the sea, has a figure

In 1849 Stokes[10] showed that to the first order of small quantities the relation between gravity and latitude discovered by Clairaut can be deduced from the Newtonian law of gravitation without any explicit assumption as to the form of shells of uniform density. The only express assumption made is that equipotential surfaces, external or internal, are approximately spherical. It follows that the mean figure of the earth, though not its dimensions, can be determined from pendulum observations alone, a task actually performed some time later by the famous geodesist, F. R. Helmert.[11]

---

differing but little from that which it would assume in virtue of the laws of equilibrium if, the sea ceasing to cover it, the spheroid were to become fluid.

"4. The depth of the sea is a small fraction of the difference between the two axes of the earth.

"5. The irregularities of the earth and the causes which disturb its surface extend to but a small depth.

"6. Finally, the whole earth was originally fluid.

"These results of analysis, observation, and experiment ought, it seems to me, to be set down among the few truths which geology has to offer."

Laplace in many passages refers to the earth as solid. The liquid shells, he says, "would change their shape only very slightly during solidification." Nearly a century has elapsed since these conclusions of Laplace were made known, yet it is doubtful whether they could be modified to advantage.

In this memoir Laplace is by many supposed to have extended Clairaut's theorem on the variation of gravity with latitude; but Todhunter's review in his history of the theories of attraction and the figure of the earth, vol. 1, p. 229, denies this, splendid as he considers Laplace's analysis. Clairaut did not assume, according to Todhunter, that the component shells were fluid or of the configuration corresponding to fluidity, but only that the bounding outer surface has the same form as if it were fluid, and that it is in relative equilibrium when rotating with uniform angular velocity. In the 11th edition of the Encyc. Brit. the article on the figure of the earth is by Clarke, revised by Helmert, and in it Todhunter's conclusion is accepted.

[10] Stokes published two papers on this subject: Camb. and Dublin Math. Jour., vol. 4, 1849, p. 194, and Trans. Camb. Phil. Soc., vol. 8, 1849, p. 672. Both are included in his Collected Papers.

[11] Stokes's investigation has been extended by Helmert, who has added to the expression for the variation of gravity with latitude a small negative term of the second order, which is maximum in latitude 45°, and there amounts to 7×10^{-6} times gravity at the equator. All modern geodesists accept Helmert's emendation, which is in accord with investigations by George H. Darwin and E. Wiechert, indicating a depression of sealevel in latitude 45° of some 3 meters. Besides being an essential part of the history of the subject, this correction serves to show how very nearly the geoid coincides with the ellipsoid excepting for local attractions.

For a rotating homogeneous mass without rigidity the only figure of equilibrium is an oblate ellipsoid. Strictly speaking, this figure is that of equilibrium only for the case of homogeneity. The external equipotential surface of a heterogeneous globe, in which the masses are either liquid or disposed as if they were liquid, is represented by an algebraic equation of the tenth degree, differing but little, however, from an ellipsoid. The equation of the potential, V, may be written as in Pratt's Figure of the Earth, article 122,

$$V = \frac{E}{r} + \left(\epsilon - \frac{m}{2}\right) \frac{Ea^2}{r^3} \left(\frac{1}{3} - \mu^2\right).$$

Here $\mu = z/r$ and of course $r^2 = x^2 + y^2 + z^2$.

Making $V = C$, a constant,

$$Cr^5 = Er^4 + \left(\epsilon - \frac{m}{2}\right) Ea^2 \left(\frac{r^2}{3} - z^2\right)$$

Though no explicit assumption was made by Stokes as to the distribution of density, there is none the less a very important implicit postulate. It requires no analysis to show that if there were very great irregularities in the distribution of density the level surfaces or equipotentials of the globe would not necessarily be approximately spherical, and it is essential to make some estimate of the degree of irregularity implied in Stokes's theorem.

Clairaut's theorem is expressed in terms of the flattening or ellipticity of the earth, known to be about 1/298 (though possibly it is a little larger), and is denoted by e.[12] If the mean radius of the earth is taken as unity, e is 1/298 of a radian, or $11' 32'' = 692''$. Stokes neglects all terms in e^2, and e^2 is equivalent to $2''.3$. Now if the ellipsoid of revolution whose ellipticity is e is an equipotential surface, it is easy to prove that the maximum angle between the normal to the equipotential surface and the radius vector is e. Stokes's theorem is consequently true only of an earth on which the angle between the geocentric vector and the normal to the geoid does not exceed a quantity of the same order as e. Otherwise expressed, its truth is limited to cases in which the deflection of the vertical is of the order of e^2. Now observation shows that a deflection of 23″ is, relatively speaking, very large. Mr. Hayford in his first memoir, which will presently be noticed more at length, records the observed deflection at 509 stations, and only at 7 of them does this exceed 20″, the highest approaching 30″, which is also about the maximum observed in any country. At seven-eighths of these stations the deflection is less than 10″.

Thus, closely enough, the assumption implied in Stokes's theorem may be said to be that

$$e + 23'' = e + e/30 = 1.033\, e$$

is to be regarded as of the same order of magnitude as e or, since

$$23'' = 10\, e^2,$$

substituting the value of r and squaring each side of this equation reduces it to the required algebraic form. E is the earth's mass, e the ellipticity of the meridian, a the mean radius of the earth's surface, r the geocentric radius vector, and m the ratio of centrifugal force at the equator to gravity at the equator.

The geoid is a far more complex solid, being one in which all irregularities due to local attraction are superposed upon the surface of the tenth degree. The maximum departure of the geoid from the theoretical spheroid is supposed to be about 100 meters and to occur under "the roof of the world" in central Asia.

[12] Stokes extends the application of the term ellipticity to a slightly irregular figure, such as the geoid, or sealevel surface. At a distance from the earth such as that of the moon, the attraction of the geoid would coincide with that of the mean ellipsoid: consequently the mean flattening of the geoid may be regarded as the ellipticity of the mean ellipsoidal spheroid.

that quantities as great as $10\,e^2$ may be neglected in determining the mean figure of the earth.

To illustrate in terms of geology the meaning of these figures, suppose a spherical batholith of peridotite embedded in the outer shell of a spherical earth, so as just to reach the surface at its uppermost point, and consider what must be the radius of the batholith to produce a certain maximum deflection. The problem is a very simple one and has been fully discussed.[13] Taking the earth's mean density at 5.5 and the surface density at 2.75, let the peridotite have a density of 3.25. Then if the batholith is to produce a maximum deflection of 23″, it appears that the radius of the batholith must be 4¼ miles; that it will produce this deflection at a distance of 3 miles from its point of contact with the surface, and that just above its highest point it would raise the surface of the sea or of the geoid by 2 feet 2 inches.

No geologist would be surprised at the occurrence of a batholith whose greatest dimension is 8½ miles or at the contiguity of rocks whose densities differ by 0.5. Now since Stokes's postulate applies not merely to the external equipotential surface, but also to the interior level surfaces of the globe, it would appear that such a batholith as that described represents the order of magnitude of the largest heterogeneities occurring anywhere in the globe.

Possibly this agreement might be pushed a little farther. Various phenomena show that the ellipticity of the equipotential surfaces diminishes from the exterior of the earth to its center, and so also must $e/30$ or $10\,e^2$ If this quantity measures the heterogeneity, then this must also diminish toward the center; but it would be very unsafe to conclude from

[13] It may be well to note here the formulæ for the effects produced by a spherical batholith. The proof may be found in Thomson and Tait, Nat. Phil., sections 786 and 787. Let a be the radius of the earth supposed spherical and r the radius of the batholith. Let $c\,r$ be the depth of the center of the batholith, ρ' its density, and ρ the density of the earth's surface, while σ is the earth's mean density. If ψ is the maximum deflection of the plumb-line due to the attraction of the batholith

$$\frac{r}{a} = \sqrt{\frac{3}{2}\,\frac{\sigma\, c^2}{\rho'-\rho}\,\psi}$$

The elevation of the geoid over the central point of the batholith is, say, h and

$$\frac{h}{a} = \frac{\rho'-\rho}{\sigma\, c}\,\frac{r^2}{a^2}$$

In the text results are given for the very high value for ψ, 23″. Far commoner, though still high, would be 10″ = 0.0000 4848 radians. With $\rho'-\rho = 0.5$ and $c = 1$, this gives $r/a = 0.00046$, and with $a = 4{,}000$ miles, $r = 1.84$ miles. Then h would be nearly 5 inches.

It should be observed that the internal variations in density considered in this note differ essentially from the variations in external form which lead to the larger irregularities of the geoid. The great mass of the Thibetian Mountains stands above or outside of the geoid.

such reasoning more than that conditions are quite compatible with the hypothesis of increase of homogeneity with depth.

Thus it follows from Stokes's theorem that the observed deflections of the plumb-line may be due entirely to the heterogeneity of the earth's outer shell; but it does not follow that only the outer layer is heterogeneous. If the center of the batholith I have imagined were at 8½ miles beneath the surface instead of at 4¼ miles, its mass remaining unchanged, it would cause a deflection of only a fourth of 23″ or, say, 6″. Consequently deflections alone give no direct information as to the distribution of density in depth.

If indeed it could be assumed that the primitive earth was fluid throughout, or to a great depth from its temporary surface, such irregularities as are observed at the present surface could scarcely be supposed to exist far below it. To be sure, there is seemingly no limit to thinkable viscosity; an earth can be imagined so viscous that density would not effectively control configuration. But there is enough evidence of gravitative differentiation of rocks to show that many magmas yield at a sensible rate to the stresses produced, even by very small phenocrystic crystals, and therefore with much greater velocity to bodies of batholithic dimensions. The respective velocities for highly viscous magmas are doubtless proportional to the cross-sections.

Laplace, Pratt, and Kelvin were all convinced that the earth had been fluid originally, while Stokes considered the evidence very strong, though not conclusive. Recent investigations in isostasy strengthen this evidence and seem to confirm Laplace's view as to the superficiality of the heterogeneous shell.[14]

So far as I can see, the investigations which have been passed in review lead to no definitive conclusion as to the condition of the interior of the earth, although they leave no question that the material of the globe is arranged nearly as if it had been fluid. On the other hand, they establish a presumption that irregularities in density, such as are encountered

[14] Thomson and Tait (Nat. Phil., 1883, section 821) summarize the evidence then available as follows:

"There is, as we shall see in later volumes, a great variety of convincing evidence in support of the common geological hypothesis that the upper crust was at one time all melted by heat. This would account for the general agreement of the boundary of the solid with that of fluid equilibrium, though largely disturbed by upheaval and shrinkings in the process of solidification, which has probably been going on for a few million years, but is not quite complete (witness lava flowing from still active volcanoes). The oblateness of the deeper layers of equal density which we now infer from the figure of sealevel, the observed density of the upper crust, and Cavendish's weighing of the earth as a whole, renders it highly probable that the earth has been at one time melted not merely all round its surface, but either throughout or to a great depth all round."

It is probable that the liquid portion of the earth was approximately in convective equilibrium, and that consolidation began at the center.

at the surface, are confined to a superficial shell; in other words, they lend probability to the hypothesis that a level of approximate isostatic compensation underlies an heterogeneous external shell.

Direct Investigations of Isostasy

Turning now to researches addressed more directly to elucidating the conditions existing in the earth's superficial shell, Sir John Herschel and Charles Babbage seem to have been the first to indicate a tendency to isostasy as the controlling factor in at least some recent upheavals and subsidences.[15] Babbage confined himself to effects of temperature change. Herschel relied on "the variation of the pressure, and the infinity of supports broken by weight, or softened by heat, to produce tilts." He finds in erosion and deposition the *primum mobile* of geology through the subversion of equilibrium of pressure. Neither of these authorities appears to have pursued the matter, nor was the subject resumed for many years.

Archdeacon John H. Pratt, in 1855, called attention to the fact that the attraction of the Himalayan range produces in the plains of India a deflection of the plumb-line far smaller than was to have been expected, but he then offered no satisfactory explanation.[16] Airy in the same year attempted to explain the facts by the hypothesis that the solid crust of the liquid earth, supposed only a score or two of miles in thickness, extends downward under mountain chains and is of relatively small density, while beneath the oceans it is thin, the whole crust being supported by flotation.[17] In answer Pratt pointed out that no possible law of cooling could produce such a crust as Airy described, and furthermore that W. Hopkins[18] had shown the crust to be at least 900 miles thick and probably more than 1,000 miles.[19] But in 1858 Airy's hypothesis gave Pratt an idea, namely, that although the earth is solid to a very great depth, if not throughout, there is a relative deficiency of matter under mountain ranges and relative excess of matter beneath oceanic depressions; in short, an approach to isostasy.[20] This idea, not unknown to Laplace, he elaborated in a number of papers, most authoritatively, of course, in his well known work on Laplace's Functions and the Figure of the Earth.[21]

---

[15] Babbage's paper on the Temple of Serapis was read before the Geol. Soc. Lond. in March, 1834, but published in full in the Proceedings, vol. 3, 1847, p. 186. Herschel's letters to Leyell and Murchison were printed in Proc. Geol. Soc. Lond., vol. 2, 1833-1838, pp 548 and 596.

[16] Phil. Trans., vol. 145, 1855, p. 53.

[17] Phil. Trans., vol. 155, 1855, p. 101.

[18] Phil. Trans., 1839 to 1842.

[19] Airy does not seem to have made any reply at the time, but in a popular lecture in 1878, Nature, vol. 18, 1878, p. 43, again expressed his belief in a lumpy crust.

[20] Phil. Trans., vol. 149, 1859, p. 747.

[21] The copy before me is the 4th edition, 1871.

Geodesists, I have been told, were well aware for many years that with sufficient labor it would be possible to test Pratt's theory, to which C. E. Dutton gave the name isostasy.[22] They recognized, however, that the task would be a very formidable one. As we all know, it was at last undertaken by Mr. John F. Hayford,[23] in what Mr. Helmert characterizes as a "truly magnificent investigation." The same veteran geodesist renamed the underlying idea "the Pratt-Hayford hypothesis" in recognition of the importance of Hayford's work in establishing the actuality of isostasy.

Mr. Hayford's second memoir[24] is a supplement to the first and the two should be considered together. In all they embrace and discuss 765 deflections of the vertical in the United States. In the nature of the case, isostasy can be investigated only by trial and error. Among many hypotheses, reasonable or unreasonable, as to the distribution of isostatic compensation, one is selected and all of the deflections are computed as if it were true. The results of such a discussion are called by Mr. Hayford a "solution." Those portions of the deflections which remain unexplained after each solution are known as residuals. Pretty nearly, but not exactly, a residual is the difference between the observed deflection and the computed deflection.[25] This is not an exact definition because the observed deflection involves errors of observation and instrumental errors, while the computed deflection may be inaccurate from many causes; thus the maps from which the volume of topographic features is derived are not perfectly accurate, nor is the density of the rocks accurately known, while the determination of the latitude, longitude, azimuth, zenith, etcetera, are all to some extent imperfect. The residuals include errors of all descriptions, and would reduce to zero only if ideal conditions were dealt with by infallible observers and computers. Among trial hypotheses that is the best in which the sum of the squares of the residuals is smallest.

For each observed deflection Mr. Hayford computes the deflection which would be produced by all the topography within 2,564 miles or 4,126 kilometers.[26] This so-called topographic deflection (or perhaps better orographic deflection) always differs from the observed deflection in the sense to be expected on the hypothesis of isostatic compensation.

[22] Phil. Soc. Washington, vol. ii, 1889, p. 51.

[23] The figure of the earth and isostasy from measurements in the U. S. Coast and Geod. Surv., 1909.

[24] Supplementary investigation in 1909 of the figure of the earth and isostasy. Coast and Geod. Surv., 1910.

[25] Cf. Hayford's first monograph, p. 106, and his second monograph, p. 69, footnote.

[26] Helmert considers 1,000 kilometers a sufficient radius, and disagrees with Hayford's method of dealing with the more distant masses. Sitzungsber. k. Preuss. Akad. der Wiss., 1911, p. 440.

that is, mountains attract less than would be anticipated from their volume, as if they overlay regions of relatively small density; while lakes or other depressions diminish the attraction less than would be expected if the underlying material were of average density.

Mr. Hayford has considered eight trial hypotheses as to the distribution of compensation, of which five suppose uniform distribution each to some particular depth. Of these, two represent extremes; one, solution B,[27] supposes the depth infinite, which is equivalent to assuming that there is no compensation at all, while the other solution, A, assumes that it is complete at the surface, which amounts to the assumption that topographic forms exert no effect on the direction of the vertical. Three solutions, called E, H, and G, assume uniform complete compensation at depths of 162.2 kilometers, 120.9 kilometers, and 113.7 kilometers respectively. Three other hypotheses which deal with selected representative data are (1) that compensation is confined to a layer 10 miles in thickness at a mean depth to be determined, and which turns out to be 40 miles; (2) that it diminishes uniformly from the surface; (3) that it diminishes by a law suggested by Mr. T. C. Chamberlin.

Discussion of the residuals by least squares at once throws out the hypotheses of no compensation or of compensation complete at the surface. Hence there really is compensation nearly or quite complete at a finite depth. Thus Hayford has proved Laplace's dictum that the irregularities of the earth and the causes which disturb its surface extend to but a small depth compared with the earth's radius. Of the three hypothetical depths for uniform compensation, solution H, or 120.9 kilometers, gives the smallest sum of the squares of the residuals, and this sum is less than a tenth of that found on the assumption that there is no compensation. Compared with the opposite extreme of complete surface compensation, the sum of the squares of the residuals for solution H is 53 per cent. Thus for uniform distribution the depth of complete compensation is near 120 kilometers.

As might have been anticipated from Stokes's investigation, however, the deflections of the vertical do not decide between various configurations of compensation. Within the limits of errors of observation a compensating layer 10 miles thick, at a mean depth of 40 miles, or a wedge, widest at the surface and extending to a depth of 117 miles (or having

[27] Solution B corresponds to the Bouguer reduction. Although Bouguer recognized that some mountains did not exert the attraction he expected of them, he would have been rash to assume that a mountainous conformation was in general attended by corresponding subterranean deficiencies of mass. Helmert 30 years ago found it best, as suggested by Faye, to rely on the free-air reduction, or solution A, which leads to errors in a sense opposite to those of Bouguer's reduction, but affords a closer approximation to the observed deflections. Sitzungsber. k. Preuss. Akad. der Wiss., 1912, Jan. to June, p. 308.

its center of inertia at 39 miles), will satisfy the conditions as well as a uniform compensation to a depth of 76 miles or 122 kilometers.[28]

In 1912 Hayford and Bowie published a memoir on the effect of topography and isostatic compensation on the intensity of gravitation.[29] For 105 stations they computed the effect of the topographic features of the entire earth on attraction at the station and assumed uniformly distributed compensation complete at a depth of 113.7 kilometers, corresponding to solution G of Mr. Hayford's investigations. This study was begun before Mr. Hayford had reached the conclusion that 122 kilometers is more probable than the smaller depth, but Hayford and Bowie show that the difference in the conclusions reached would be negligibly small.

While their results are confirmatory of the hypothesis of compensation, studies of the intensity of gravitation are very inferior to the deflection method for the determination of the depth of the level at which compensation is complete.

As in the former investigation, Hayford deduced residuals; so here he and Bowie obtain from comparison of observations and computations what they call new method anomalies. These consist of observed intensities less computed intensities plus a small constant systematic correction to the Helmert formula of 1901. This correction is only 0.009 dyne, and if it were applicable at the equator would reduce gravity there to 978.039 dynes.[30] Like the residual, an anomaly lumps together all sorts of errors of assumption and observation. Two of its components are of special geological importance. If compensation is supposed complete and there were no errors in maps or mean density and the like, then for a given region the new method anomaly, if positive, would indicate excess of material or of pressure, an overload. Similarly a negative anomaly would be interpreted as a deficiency of mass in the column underlying the surface area; but an anomaly might equally well be due to irregular distribution of compensation. A very moderate batholith of peridotite just below the station might be accurately compensated by deficiency of mass at a depth of 50 miles so that there would be complete

[28] Although these compensating excesses or deficiencies of matter cannot be considered, strictly speaking, as concentrated at their centers of inertia, the depths of these points are not very different; 40 miles for the thin layer, 39 for the wedge, 38 for a shell reaching the surface.

[29] The effect of topography and isostatic compensation on the intensity of gravity. Coast and Geod. Surv., 1912.

[30] Helmert's formula of 1901, on the Potsdam system, for the theoretical value of gravity at sealevel is

$$\gamma_0 = 978.030\,(1 + 0.005302 \sin^2 \phi - 0.000007 \sin^2 2\phi)$$

The corresponding formula of Hayford and Bowie on which their "new method anomalies" are based is

$$\gamma_0 = 978.039\,(1 + 0.005302 \sin^2 \phi - 0.000007 \sin^2 2\phi).$$

isostasy at 120 kilometers and yet produce a very considerable anomaly at the surface. If this batholith were $4\frac{1}{4}$ miles in radius, as in a previous example, and only just buried, it would increase the attraction by 0.094 dynes, which is almost exactly the largest anomaly detected in the United States, the mean anomaly being only 0.017 dyne.

Hayford and Bowie compare their anomalies with what they call the Bouguer and free-air anomalies. Of these the former corresponds to solution B and implies that there is no compensation, or that the earth is infinitely rigid. The free-air anomalies answer to solution A and imply that topographic forms exert no attraction. Comparison shows that the new method anomalies are only a fourth as great as the Bouguer anomalies if all stations are considered, whereas if only mountainous regions (where the Bouguer correction is of great moment) are included this is twelve times as large as the Hayford and Bowie anomaly. As has long been known, total neglect of the attraction of mountains gives better results than their consideration by Bouguer's methods; but in mountainous areas the new method anomalies are only a third as great as the free-air anomalies.

Hayford's investigations on deflection were confined to the United States. Hayford and Bowie's study of the intensity of gravity included 89 stations in the United States, besides 16 selected stations outside of that area, and scattered all over the world, seven of them being at sea and having been occupied by Mr. O. Hecker, of whose work more will be said presently. In Switzerland the method developed by Hayford and Bowie has been applied to 13 stations. This is too small a number to give strong evidence, but, so far as it has gone, the investigation indicates an isostatic condition in that country of mountains and a mean anomaly scarcely differing from that in the United States.[31] Mr. Bowie has also discussed 14 gravity stations in British India.[32] The number is again very small, but the results tend strongly to confirm those obtained in this country.

That eminent veteran in geodesy, Mr. F. R. Helmert, has not only expressed the warmest interest in the American investigations on isostasy, but has made very important contributions of his own to the subject. While Hayford determined the level of isostatic compensation from deflections of the vertical alone, Helmert devised a method of finding this level from observations on the intensity of gravity without reference to deflections, the numerical result being substantially the same. This accordance is most gratifying. A conclusion reached in only one way can

[31] Hayford and Bowie, p. 122.

[32] Jour. Wash. Acad., vol. 4, 1911, p. 245.

never be quite free from the suspicion of some hidden fallacy, while a result obtained by independent methods commands great confidence.

Mr. Helmert's method, printed as long ago as 1909,[33] is applicable only at selected stations, where a rather level coastal plain and a tolerably deep sea are connected by a fairly smooth and steep slope. The coast must also be assumed to be part of a great circle. On the hypothesis that there is a level of isostatic compensation, it is easy to prove that in such a region the intensity of gravity will reach a maximum at the shore and a minimum at the junction of the submarine slope with the level sea-bottom; and from the observations it is possible to make a choice between various assumptions as to the depth of the level of isostatic compensation. Like Hayford, Helmert prefers the hypothesis that compensation is uniformly distributed.

Mr. Helmert found on record 51 localities, widely distributed over the world, which were suitable for treatment by his method. From them he deduced for the depth of the level in question as a simple mean 118 ± 22 kilometers; but he took the superficial density of the earth at 2.73, while Hayford assumed it at 2.67. In a second paper Helmert so modified Hayford's equations as to render them suitable for the computation of the mean and probable errors and, with the superficial density 2.67, derived from them a depth of 123.5 ± 14 kilometers mean error.[34] Assuming the same superficial density of the earth, Helmert finds from his own investigation 124 ± 22 kilometers mean error. That the two results substantiate one another is evident; indeed, so close an agreement, apart from the error, must be considered accidental, and in later papers Helmert rounds off the figures to 120 kilometers. He points out that his mean error of ± 22 kilometers is larger than Hayford's and suggests that this may be due to the world-wide distribution of his stations.[35]

At Mr. Helmert's instance, Mr. O. Hecker made several voyages in the first years of the century for the purpose of determining the intensity of gravity at sea. The method employed was devised by Mr. H. Mohn, who found that the gravity correction of the quicksilver barometer on land could be determined by the help of the boiling-point thermometer.[36] This method carried out on a moving vessel is not of a high degree of

---

[33] Sitzungsber. k. Preuss. Akad. der Wiss., 1909, July to Dec., p. 1192.

[34] The probable error as derived from the theory of least squares is ± 9 kilometers. The actual errors are probably larger than the probable errors because of undetected systematic errors. As I understand it, Helmert takes the mean error in order to leave a margin for undetected errors. The difference is a mere estimate, not a conclusion from theory. The mean error is 1.4826 times the probable error.

[35] Sitzungsber. k. Preuss. Akad. der Wiss., 1911, Jan. to June, p. 10.

[36] Sitzungsber. k. Preuss. Akad. der Wiss., 1902, p. 126, and Encyc. der Math. Wiss., vols. 6, 1, 7, p. 125.

accuracy, but yet accurate enough to establish a fact of great importance, namely, that over the widely extended oceans of nearly uniform depth the intensity of gravity is substantially the same as on continental plains. Till Hecker's determinations were made, there was no assurance that this was the case. His results show that the greater volume of continents is compensated by their smaller density, and therefore that isostasy prevails under the ocean as well as on those continental areas within which it has been tested. That improved methods of determining gravity at sea will be evolved is scarcely to be doubted, but the most vital point at issue seems to me to have been settled by Mr. Hecker's observations.[37]

From his studies on deflection in the United States, Hayford got a value of the ellipticity of the meridian which depends on the depth of the level of isostatic compensation. If this is 120.9 kilometers, then the reciprocal of the ellipticity so found is 297.0 ± 0.5. One of the questions still to be solved is whether the same value of the flattening will result from similar surveys in other countries; or, in other words, whether the depth of the level of compensation will be found constant. There seems a possibility that it may vary with latitude,[38] and the data for the determination of this point already exist in the records of the geodetic surveys of northern Europe, as Mr. O. H. Tittmann informs me. Unfortunately the subject of compensation has not there been methodically investigated. This particular point is of the more interest since Mr. E. W. Brown's recent researches on the moon[39] give for the flattening of the earth very accordant values of about 1/294. Some means of reconciling so large a difference must be found, and possibly it may be discovered in a variation of the depth of compensation with latitude.

Hayford, Bowie, and Helmert all regard gravity anomalies as representing real loads, positive or negative. For this view there seem to be two good reasons: this assumption strains to the utmost the Pratt-Hayford hypothesis and it also lends itself readily to computation. Of course, they do not deny that the anomalies might be due wholly or in part to irregular distributions of density; but this explanation does not appeal to them as it does to Mr. G. K. Gilbert[40] and, as I shall explain presently, to me also. The geodesists are at least on safe ground. Messrs. Hayford and Bowie conclude that the average excess or deficiency

[37] See Helmert's luminous discussion. Sitzungsber. k. Preuss. Akad. der Wiss., 1912, Jan. to June, especially p. 309.

[38] To my thinking, it would be very strange if the depth at the pole should be the same as at the equator, for it is difficult to conceive that the physical conditions to which compensation is due can have been the same at the axis of rotation and the extreme periphery.

[39] Science, vol. 10, 1911, p. 389. Vice-presidential address, B. A. A. S.

[40] U. S. Geol. Surv. Prof. Paper, 85 C, 1913.

of matter is equivalent to that of a layer of rock about 570 feet or 174 meters in thickness with a density of 2.67.[41] As they point out, this is small as compared with a safe working load for granite—only 660 pounds per square inch against 1,200 for masonry—but the conditions are very different. In masonry the principal joints or contacts are horizontal. In nature joints are usually at an angle approaching 45° to the horizon, while a dry stone wall with courses inclined at 45° would have no sustaining power.[42]

Discussion of Isostasy

This long review has been written with a view to deciding what geological results of geodetic research we are bound to accept. That approximate isostasy is a reality when areas of sufficient size are considered seems to me to have been fully demonstrated. As for the unit area within which it may be taken for granted that isostasy is complete, opinions differ, Mr. Helmert's estimate being far larger than Mr. Hayford's. This question will be settled to all intents and purposes within a few years, at least so far as the United States is concerned; for fresh stations are being occupied each year, and before very long gravity maps will show a mosaic of intersecting lines of zero anomaly, each closed area overlying a column within which isostasy is complete.[43] At present such information as I have seems to indicate areas of from one square degree to several square degrees.

Subject to a mean error, the center of inertia of the compensation lies 38 or 40 miles below the surface. If compensation is uniformly distributed, this center lies at a depth of 38 miles, while if it diminishes linearly with depth it is 39 miles.

As yet the data are inadequate to decide between various hypotheses as to the distribution of density in the active shell overlying the level of isostatic compensation. This does not mean that the vertical distribution of density is beyond investigation. Helmert's method of finding the depth of this level is more promising in this respect than Hayford's, because it implies a determination of the vertical component of local attrac-

---

[41] This density is adopted from Harkness. Mr. Helmert prefers 2.73, which seems to me nearer the truth for the surface. For the mean density down to 120 kilometers I believe a larger figure would be preferable, perhaps 2.80.

[42] In his first paper Mr. Hayford adopted a lower estimate of the average sustaining power. The mode of inference was not satisfactory and was called in question by Mr. Helmert.

[43] It may be well to remember that two columns, in each of which the anomaly has the same sign, may stand in juxtaposition and convey the impression of a unit area larger than really subsists. Possibly some of the large areas pointed out by Helmert are thus composite.

tion as well as the horizontal component. But Helmert's method is applicable at a comparatively small number of stations. Baron Roland Eötvös's torsion balance[44] seems to afford a means of fixing the position of locally attracting masses with some accuracy, since by it the radius of curvature of the geoid is determinable; but this method is laborious in the extreme, and many years must elapse before thorough surveys with the torsion balance can be completed, even for a moderate number of small areas.

Meantime the only recourse is to general reasoning, trial hypotheses, and experiments on the properties of matter. To me it seems clear that gravity anomalies must be of two classes, which I shall take the liberty of calling real anomalies and pseudo-anomalies, the latter being due to irregular distributions of density and not affecting the real load per unit area at the level of isostatic compensation, while the real anomalies represent real differences in load at that level.

Areas of denudation and of deposition would seem to represent, at least in part, what I have called real anomalies, for the removal of matter from the outer surface of a column must reduce the pressure at its base, and vice versa. But Messrs. Hayford and Bowie find it impossible to trace any relation between the distribution of gravity anomalies and erosion or sedimentation. This suggests that the effects of this actual transfer of matter are masked by the effects of irregular distributions of density or that the real anomalies are relatively small.

As for the pseudo-anomalies, we know for a certainty that the distribution of densities in horizontal directions at the earth's surface is very variable, while the exposures in deep wells or in deep cuts, such as the Grand Canyon of the Colorado, give no evidence that heterogeneity diminishes with depth. On the contrary, the existence and abundance of dikes, sills, laccoliths, and batholiths make it highly improbable that homogeneity, or even a gradual and regular increase of density, prevails at any level above the deeper volcanic foci. Differences in density ascribable to mineral composition are not the only cause of these pseudo-anomalies. It is well known that the thermometric gradient varies greatly with the locality and in a seemingly capricious manner. Of course, this distribution of temperature also affects density. Voids, too, give rise to differences in density, and these, whether as geodes or as joints, may be sparsely scattered or closely grouped. With the assistance of Mr. A. F. Melcher, I have recently shown that the volume of a column or stratum of rock may increase through crushing by an amount the

[44] See Helmert's memoir on gravity and the mass distribution of the earth. Encyc. der Math. Wiss., vols. 6, 1, 7, article 23.

apparent maximum value of which is 6.73 per cent[45] of the original volume.

How far down voids can exist is not fully determined. Mr. Frank Adams has subjected cylinders of granite with holes drilled in them to pressures corresponding to a depth of 35 miles without completely closing the apertures; but, making allowance for time and heat, he limits his conclusion to the statement that openings may be permanent at least as far as 11 miles from the surface.[46] Mr. P. W. Bridgman[47] has subjected sealed hollow cylinders of glass to a pressure of 24,000 atmospheres without measurable permanent distortion, but he feels no confidence that a crystalline solid would behave in the same way as glass at a depth of 56 miles. He tells me that in his experiments on rock specimens provided with drilled holes these closed not by plastic flow, but by crumbling of the walls. Since Mr. Bridgman can command a pressure of 40,000 atmospheres, corresponding to a depth of over 90 miles, there is no doubt that more information is in store for us.

Pseudo-anomalies then certainly exist; indeed they seem of the order of magnitude of the observed or apparent anomalies, namely, ± 0.017; for, as was shown above, even the largest gravity anomaly observed in the United States, 0.095, could be accounted for by the presence of a batholith less than 9 miles in diameter. But the gravity anomalies when considered with regard to sign have a mean value of 0.000, just as would be the case were there only pseudo-anomalies and were isostatic compensation perfect at about 120 kilometers. It is barely possible that the real anomalies are of the same order of magnitude as the pseudo-anomalies, and that the mean value of each species with regard to sign is 0.000; but were this the case I should expect greater local apparent anomalies than Messrs. Hayford and Bowie have observed; for there is little direct connection between the pseudo-anomalies and the real ones, so that they might be expected to reinforce one another at something like one-half of the whole number of stations. But that the real anomalies and the pseudo-anomalies should each average 0.000, though conceivable, is very improbable. The only way I can see of reconciling the observations with probability is to suppose that the real anomalies, though not zero, are so small as compared with the pseudo-anomalies that their effect on the average is insensible, or, in other words, that the real anomalies are small quantities of the second order.

This conclusion, if conceded, means that the earth below the level of

---

[45] Jour. Wash. Acad. Sci., vol. 4, 1914, p. 129.
[46] Jour. Geol., vol. 20, 1912, p. 97.
[47] Phil. Mag., vol. 24, 1912, p. 63.

isostatic compensation has cooled only to a trifling extent, or that it is there nearly in a state of ease, although since it is solid and has cooled somewhat it must also be to some extent in a state of elastic strain. As a matter of course, solid flow does not supervene until a mass of matter has been strained to its elastic limit, and in spite of the flow such a mass retains the maximum strain it is capable of enduring.[48]

From the preceding discussion my main conclusion is that the real differences in load per unit area at the level of isostatic compensation are very small, not merely compared with total gravity at the equator, but small relatively to the apparent gravity anomalies at the surface, and that therefore the amount of shrinkage or cooling which has taken place below that level is also exceedingly small.

Note on Epeirogeny

That approximate isostatic compensation exists in the outer shell of the earth must be accepted as demonstrated by the geodesists. How to account for this very fundamental fact is a geological problem which is too complex for full discussion here. In another paper I have endeavored to prove that if the earth's surface had originally been a perfectly smooth equipotential surface, uniform in all properties excepting only in conductivity, the areas of low conductivity would undergo relative uplift because the material underlying them would cool more slowly and would ultimately develop into continents.[49] These would be subject to great pressure by the more rapid contraction of the surrounding areas and ultimately, for a sufficient temperature difference, to systematic fissuring.

So soon as the oceans came into existence and erosion began, the super-

[48] This strain, however, is probably smaller than is indicated by ordinary, brief experiments on the strength of materials. After-effects appear to be small quantities of the second order.

[49] Areas of low conductivity will also be areas of low diffusivity, provided that either is the only constant subject to variation. The superficial temperature gradient for a globe of very large radius, $(dv/dx)_0$, may be expressed thus:

$$\left(\frac{dv}{dx}\right)_0 = \frac{V}{\sqrt{\pi \kappa t}} + \gamma$$

where V is the initial surface temperature, γ the initial temperature gradient, and κ the diffusivity, or k/c, the conductivity divided by the thermal capacity. Now the heat emitted is

$$k\left(\frac{dv}{dx}\right)_0 = \frac{V}{\sqrt{\pi t}} c \sqrt{\kappa} + c \kappa \gamma$$

so that if the diffusivity is constant the emission is simply proportional to the conductivity, while if the thermal capacity is constant the emission increases with the diffusivity. The values of c are more nearly constant than those of k or of κ. See Proc. Nat. Acad. Sci., vol. i, 1915, p. 81. In preparing this the paper cited, I misplaced the decimal point in the coefficient of expansion of typical rock; an error affecting some of the conclusions though not the main thesis. These will be corrected in the Proceedings.

ficial transfer of material combined with a deep-seated solid flow in the nature of an undertow would establish a system analogous to incipient convective circulation in a mass of hyperviscous liquid. Such an unequally heated globe reduces to a species of heat engine. The outer layer down to about the level of isostatic compensation takes in heat energy of very high temperature, discharging it at little above zero, while a part of the energy thus rendered available is converted into the mechanical work implied in uplift (partly balanced by erosion) rupture and plication of the continents. The prominence of the continents above sea-bottom indicates that the mean density of the subcontinental columns of rock down to the level of compensation is lower than the density of the suboceanic columns. This difference might be due to a moderate excess in the proportion of voids beneath the continents (about 3 per cent), or to an excess in mean temperature (some hundreds of degrees), or to any appropriate combination of the two causes. The general features of the dynamical system resulting in isostasy thus become intelligible if the one simple postulate of non-uniform conductivity be accepted.[59]

Recent Advances in Radiology

Only a few years since one of the most remarkable features of radiology was the extreme simplicity of the known relations between the elements of the uranium-radium group. It was known that after a moderate time an equilibrium must be established between the various members of this group, since each member could decay only as fast as it was generated, and the law of decay was considered as absolutely established. This law for a single element is expressed by

$$I_t = I_o \epsilon^{-\lambda t}$$

where I_o is the initial intensity of radiation I_t the intensity at time t and λ is the radioactive constant. Many experiments had been made to ascertain whether the value of λ was modified, for instance, by high temperature or high pressure; but no evidence of variability was discovered then and, for that matter, none has been detected up to the present time. So confident have radiologists been of the constancy of λ that they have not hesitated to extrapolate the law of decay, verified for a year or two, over millions or thousands of millions of years.

When the law of decay had been established and the α particles had been identified with helium, it became practicable to compute the amount

[59] Kelvin discussed the restoration of mechanical energy from an unequally heated space. Phil. Mag., vol. 5, 1853, p. 102.

of helium which would escape from a system in equilibrium in a given time. Then, after it had been shown by Mr. Strutt that some minerals, notably zircon, retain at least most of the helium developed in them, the time within which this helium could be evolved could be calculated and was supposed to give an inferior limit for the age of the crystal.[51] Similarly, after Mr. Boltwood had shown it probable that lead is a stable end product of the decay of radioactive substances, he suggested that the *Pb/U* ratio would serve as a means of determining the age of plumbiferous uraninites.

These interesting and perfectly legitimate efforts, however, led to difficulties of which more hereafter.

Largely through researches in radiology, several investigators, chief among them Sir Ernest Rutherford, have developed new ideas of the structure of atoms, and indeed of the nature of the chemical elements.

It is well known that the Periodic Table of Mendeléef, arranged in the order of the atomic weights of the elements, has been of great service to chemistry and led in the hands of its inventor to the prediction of new elements, which were duly discovered; yet the table was empirical and exhibited puzzling irregularities. In recent years it has been given a new and more satisfactory interpretation, originating with Mr. A. van den Broek,[52] who arranges the elements according to the number of positive electric charges on the nucleus of the atom as conceived by Rutherford. These charges advance by units from 1, the so-called "atomic number" of hydrogen, to 92, the atomic number of uranium. To each atomic number is supposed to belong an element (or possibly a group of elements), and only three or four gaps in the series now remain to be filled by discoveries.

Now comes the astounding feature of the subject. It has been definitely discovered by Mr. Soddy, Sir Ernest Rutherford, and others that a single atomic number may be borne by each of several substances which may have different atomic weights and, in the case of radioactive substances, different stabilities, but which are inseparable by ordinary chemical or physical properties. They display the same chemical reactions, the same electrochemical behavior, the same spectrum, the same volatility. It would appear, according to Rutherford, that the charge on the nucleus is the fundamental constant which determines the physical and chemical properties of the atom.[53] Soddy calls the members of a group of elements

---

[51] Joly and Rutherford have devised a means of estimating the age of rocks from the pleochroic halos in mica foils, these halos being due to radioactivity. Phil. Mag., vol. 25, 1913, p. 644.

[52] Nature, vol. 92, 1913, pp. 372 and 476.

[53] Nature, vol. 92, 1913, p. 423, and Phil. Mag., vol. 27, 1914, p. 488.

bearing a single atomic number, and occupying therefore a single place in the periodic table, "isotopes." There has not been time as yet for exhaustive investigation, but the only means which has yet been found adequate to a separation of isotopes is diffusion (neon and metaneon), while Sir J. J. Thomson's new positive ray method of gas analysis and atomic weight determinations make it possible to distinguish isotopes from one another. It is needless to say that other methods are being sought.

Among the radioactive substances, or "radiants," as Mr. Eve[54] calls them, 34 elements have been discovered; but the study of their isotopic relations reduces them to a much smaller number of groups, about 10 in all.[55] Representatives of five of these groups have long been known (U, Th, Bi, Pb, Tl), while the remainder have been discovered through radioactive researches. Lead is isotopic with Radium B, Thorium B, Actinium B, and Radium D, while Radium itself is isotopic with Mesothorium I, Thorium X, and Actinium X.[56]

Since the chemical reactions and, in great part at least, the physical properties of isotopic elements are indistinguishable, it is very evident that in nature they must be close companions. It is well known to all of us that natural minerals are, as a rule, very impure, or that even great chemical differences do not preclude inclusions in crystals or prevent the simultaneous crystallization of different substances. Hence it is to be expected that isotopic elements should be associated in radioactive minerals; for example, mesothorium I with radium. But the period of mesothorium I is several hundred times shorter than that of radium; and, according to Mr. Soddy, a preparation containing 99 per cent radium, together with 1 per cent of mesothorium I, is no less than four times as radioactive as pure radium.[57] Yet being isotopes, radium and mesothorium I are absolutely identical from a chemical point of view and can not be separated. Hence there is no practicable means of ascertaining whether or not the helium found, say, in a zircon is derived from mesothorium I or from radium.

Similarly lead or an isotope of lead may be derived from members of the radium series, the actinium series, or the thorium series. Only an atomic weight determination of the lead would indicate its origin, and

---

54 See his very readable, and of course authoritative, account of recent researches on atomic structure in Science, vol. 40, 1914, p. 115.

55 F. Soddy, the chemistry of the radio-elements, part 1, 1911, and part 2, 1914. Much of what follows is taken from these admirable monographs.

56 The atomic number of lead is 82 and that of uranium is 92. Elements of the atomic numbers 85, 87 seem not to have been found as yet. Mr. Soddy puts actinium in the place whose atomic number should be 89.

57 F. Soddy, op. cit., part 1, p. 69.

this origin is likely to be at least twofold. As Mr. Joly points out,[58] normal lead, with an atomic weight of 207, might be regarded as a mixture of uranium-derived lead, with an atomic weight of 206, and of thorium-derived lead, with an atomic weight of 208. Messrs. T. W. Richards and M. E. Lambert have made comparative atomic weight determinations of lead from five radioactive deposits and of common lead, getting from the lead of a North Carolina uraninite deposit 206.40[59] and for common lead 207.15. As they remark, "The result is amazing." The various samples were treated exactly alike; protracted purification had no effect on the atomic weight of any sample and no difference could be detected in the spectra.[60]

Isotopism seems to be established in principle. So far as I can see, it precludes age determinations in minerals, even if the radioactive constant λ has undergone no change since a given mineral crystallized. Isotopism also sufficiently explains the very wide differences in the ages indicated for different crystals.

Ever since the earliest attempts to determine the age of minerals by radiological means it has been observed that the agreement between different specimens of approximately equal geological age, or even between specimens from the same deposit, was extremely poor. In the case of helium this was explicable by the escape of a portion of the gas. Changes in the lead-uranium ratio were less easily explained, since a variety of lead compounds and uranium compounds are very insoluble. I pointed out[61] that Boltwood's method gave ages for the minerals of Barringer Hill varying from 1,671,000,000 years to 11,470,000,000 years, and more recently Mr. F. Zambonini[62] has shown that the lead-uranium ratios of minerals from the neighborhood of Christiania indicate ages varying between 41,000,000 years and 17,302,000,000 years. Because Brögger's observations showed that galena in many cases crystallizes during "the principal phase of pneumatolitic minerals," I inferred that lead minerals were occluded in the uraninite.

Similar variations occur in the helium-uranium ratio and possibly also for a similar reason. Helium received its name because it is a prominent constituent of the sun, and it is difficult to suppose that it was not also one of the original constituents of the earth. Mr. Strutt found that

---

[58] Science Progress, July, 1914, p. 52.

[59] The 1914 atomic weights are $U = 238.5$, $He = 3.99$; so that $U - 8He = 206.6$, corresponding almost precisely to Richards's 206.4.

[60] Jour. Amer. Chem. Soc., vol. 36, 1914, p. 87. It is well to note that similar investigations have been made in the Harvard Laboratory on other elements—notably copper, silver, iron, sodium, and chlorine—which gave constant atomic weights, irrespective of their source. One of the irons was from a meteorite.

[61] Bull. Geol. Soc. Am., vol. 19, 1908, p. 134.

[62] Atti. Accad. Lincei, vol. 20, part 2, 1911, p. 131.

it exists in some beryls from which radium is absent. More recently Mr. A. Piutti[63] has examined 26 glucinum minerals which were not radioactive, though they contained helium. The amount of this gas varied in the same locality and appeared to bear no relation to the age of the crystals. Helium also occurs in large quantities in mineral springs. Messrs. Charles Moureu and A. Lepape found that the Carnot spring at Santenay (Cote-d'Or) gives out no less than 17,845 liters of helium annually.[64] Now, according to Rutherford,[65] 1 gram of radium in radioactive equilibrium yields 158 cubic millimeters of helium annually. It follows that if the helium of this spring is set free by radium there must be present no less than 113,000 kilograms of radium. The César spring at Névis (Allier) yields far more helium—33,990 liters a year. The French physicists conclude with ample reason that this helium is "fossil," or that it has been stored up for an indefinite time and is not a nascent product of radioactivity.

All attempts to determine age by radiological methods assume that the radioactive constant, λ, is truly constant and finite; but, although no one has yet succeeded in proving its variability, there are very serious doubts about the matter. From the dawn of science philosophical investigators have had in mind something corresponding to Roger Bacon's protyl or Kant's Urstoff. Lavoisier was well aware of the existence of organic radicles, groups of atoms known to be composite, but behaving like elements. Ammonium and cyanogen are familiar inorganic examples of complex bodies which take the place of supposedly elemental substances, while if complex substances may behave as elements, substances supposedly elemental may be complex. The protylic idea underlay Prout's hypothesis and Mendeléef's periodic table; Dumas also boldly asserted his belief in the transmutability of the so-called elements. Astronomical observations indicate an increasing complexity in composition during the evolution of stars. John Herschel thought that atoms bore the unmistakable stamp of a "manufactured article." In 1873 Mr. F. W. Clarke suggested the evolution of one element from another. In 1904 Sir J. J. Thomson asserted that as the universe gets older elements of higher and higher atomic weight may be expected to appear. Finally, by showing that many elements may be made to evolve helium and all elements identical corpuscles or electrons, the radiologists have prepared the way for a greatly simplified conception of matter.

Now, if there are any circumstances in which a radioactive substance is stable, λ must become zero; and if we could reproduce such circum-

---

[63] Atti. Accad. Lincei, vol. 22, part 1, 1913, p. 140.
[64] Comptes Rendus, Paris, vol. 155, 1912, p. 197.
[65] Rad. substances and their radiations, 1913, p. 560.

stances, it would be possible to manufacture synthetic radioactive substances. This has not been accomplished, but I venture to say that it is an achievement which would cause little surprise, though much admiration. Suppose that ammonium had recently been discovered and proved to consist of hydrogen and nitrogen; would any one doubt that the synthesis of ammonium would eventually be effected?

Mr. Barrel prior to 1906 suggested to Sir Ernest Rutherford that the gradual building up of the heavy and more complex atoms of matter may be slowly taking place in the interior of the earth.[66] In 1908 I pointed out that the bounds of legitimate hypothesis are not transgressed by supposing that at the consistentior status the surplus energy of aqueo-igneous fusion was potentialized by the formation of uranium. In 1909 Mr. Arrhenius expressed his opinion[67] that at higher temperatures the process of the evolution of heat by radium must take place in the inverse direction under consumption of this inconceivable amount of energy. Mr. Joly regards the mode of origin of uranium and thorium as questionable.[68] Mr. F. C. S. Schiller,[69] Mr. Leigh Fermor,[70] and Mr. Arthur Holmes[71] all consider it doubtful whether radioactive transformations can take place at very high temperatures and pressures.

Thus the constancy of λ or the uniformity of the disintegration of radioactive substances is contrary to analogy and by no means generally conceded. These substances are more endothermic than any others known, and if their synthesis is possible it must be under extreme conditions of temperature and pressure, such as have not yet been realized in laboratories.[72]

---

[66] Radioactive transformations, 1906, p. 194.

[67] The life of the universe, vol. 2, 1909, p. 236. This is a translation. I do not know the date of the original.

[68] Science Progress, July, 1914, p. 51.

[69] Nature, vol. 91, 1913, p. 424.

[70] Ibid., p. 476.

[71] Science Progress, July, 1914.

[72] The sun is not known to contain uranium. Rowland found none. In 1908 Mr. P. G. Nutting was good enough to compare for me Exner and Haschek's table of the spectrum of uranium with a 30-foot reproduction of the solar spectrum, but found no evidence of its existence. In 1911 Mr. B. Hasselberg made a very elaborate investigation of the spectrum of uranium and failed to identify any of its lines in the solar spectrum. Kgl. Soc. Vetensk. Akad. Handl., vol. 45, 1911, No. 45. Mr. F. W. Dyson has discussed six lines in the chromosphere which might be due to radium but coincide with lines of other elements. The identification seems to me unsatisfactory. Astr. Nachr., vol. 192, 1912, No. 4589. Mr. H. Giebeler has apparently identified radium, uranium, and radium emanation in Nova Geminorum 2. His conclusion is indorsed by Mr. F. Küstner. Astr. Nachr., vol. 191, 1912, No. 4582. Like the earth, the sun can not owe all of the heat it radiates to radioactivity, and Sir E. Rutherford states that "if the sun consisted entirely of uranium in equilibrium with its products, the generation of heat due to active matter would only be about one-fourth of the total heat lost by radiation." He suggests that some of it may be due to the atomic disintegration of ordinary elements at the high solar temperature. Op. cit., p. 656.

In the present state of knowledge, estimates of the age of minerals founded on radioactivity can not command confidence. But since the time element enters in a most pronounced manner into all radiological processes, this science may eventually develop methods of age determination which will be a boon to geologists.

On the Earth's Radiation

During the past few years many determinations of the radioactivity of rocks and meteorites have been made by various analysts and the activity of thorium minerals has been determined. New determinations have also been made of the caloritic effect of radium and of thorium. Some six years ago, while I was preparing a paper for this Society on the relations of radioactivity to geology, the best available average content in radium of surface rock was 1.4×10^{-12} grams radium per gram of rock as determined by Mr. Strutt, and the heating effect of radium was believed to be about 100 gram calories per gram of radium per hour, this value having been found by Madame Curie.

In 1913 Rutherford concluded that the amount of radium per gram of surface rock was about 2×10^{-12}, and that it is accompanied by 1.2×10^{-5} grams of thorium. The heating effect of radium as determined by St. Meyer and Hess and adopted by Rutherford is 132 gram calories per gram per hour, while Pegram and Webb find that one gram of thorium in equilibrium with its products gives 2.4×10^{-5} calories per hour. With these data and taking the average density of surface rocks at 2.7, Rutherford from the equilibrium theory[73] finds the heating effect of the uranium present in 1 c. c. of rock 11×10^{-6} calories per annum and of the thorium 8×10^{-6} calories per annum.[74] The sum is 19×10^{-6}. The origin and relations of actinium are still undetermined, and it is possible but not certain that a further addition should be made for the heating effect of this substance.

Still more recent determinations by Mr. Arthur Holmes[75] indicate that

---

[73] A somewhat puzzling anomaly in the behavior of certain radioactive minerals has just been explained by Messrs. S. C. Lind and C. F. Whittimore in a suggestive manner. It has been known for some years that autunite and some other secondary uranium minerals gave U/Ra ratios which did not accord with the theory of radioactive equilibrium. Lind and Whittimore found that specimens of carnotite showed a similar abnormal behavior when the samples tested were small, but that when the samples represented large lots of ore the U/Ra ratios were normal. They infer that radium is in some cases transposed within a deposit giving rise to local inequalities which are equalized by mixing large quantities of ore. It is thus apparent that the equilibrium theory has withstood successfully a very severe test. The possibility of local inequalities even in the radium content of rocks should be borne in mind. Jour. Amer. Chem. Soc., vol. 36, 1914, p. 2066.

[74] Radioactive substances and their radiation, 1913, p. 650.

[75] Science Progress, July, 1914, p. 15.

Rutherford's estimate for the amount of radium in rocks is somewhat too low. Holmes finds for the radium in acid rocks no less than 2.8×10^{-12}, but the selection of the best average value is complicated by the fact that the radium content of acid or persilicic rocks is a maximum. For mediosilicic, subsilicic, and ultra-subsilicic rocks respectively Holmes gets 2.45, 0.85, and 0.51 all multiplied by 10^{-12}. It is almost certain that radioactivity is confined to a superficial shell of the earth only a few miles in thickness,[76] and in such a shell persilicic and mediosilicic rocks preponderate, so that with his data 2.5×10^{-12} would be nearer the truth than 2×10^{-12}.

I shall adopt the lower value for a reason which at first sight seems strange. On the hypothesis that all of the heat emitted by the earth is due to radioactivity, the higher the surface value of radioactivity the smaller will be the earth's internal temperature.[77]

Suppose the highly artificial case of a globe of uniform ordinary temperature, say 10°, provided suddenly with a uniform layer of radioactive material just sufficient to supply the amount of heat now escaping. Then assuming (as indicated by the half value period of uranium) that the supply of heat is substantially undiminished for a couple of thousand million years, it is easy to compute the distribution of temperature for any epoch. Rutherford's[78] estimate, given above, of the heat developed by radioactivity in surface rocks, when expressed in c. g. s. units, is equivalent to 6×10^{-13} calories per cubic centimeter per second. I shall call this constant q. The conductivity,[79] k, Rutherford puts at .004, while for the observed gradient at the surface he adopts 1° C. for each 32 meters, or .00031° C. per centimeter. If this gradient is denoted by $(dv/dx)_0$ and if s is the thickness of the layer of uniform radioactive matter which will maintain the gradient

$$\left(\frac{dv}{dx}\right)_0 = \frac{q}{k}\, s.$$

Substituting the numerical data cited in c. g. s. units gives

$$s = 20.7 \times 10^5 \text{ cm.} = 20.7 \text{ kilom.}$$

[76] That all of the heat emitted by the earth might be due to a relative thin layer of surface rock seems to have been suggested independently by C. Liebenow, Phys. Zeitsch., vol. 5, 1904, p. 625, and by Rutherford, Radio-activity, 2d ed., 1905, p. 644.

[77] See the value of v_m below.

[78] Radioactive substances and their radiations, 1913, p. 650.

[79] Mr. H. H. Poole concludes from experiments on granite and basalt "that for temperatures up to 500° or 600° C. the conductivity of the earth's crust may be taken at about 0.004 without risk of serious error unless the conductivity is sensibly affected by the large pressures involved." Phil. Mag., vol. 27, 1914, p. 58.

With s given the excess of temperature, v, at any distance x from the surface is[80]

$$v = \frac{qx}{k}\left(s - \frac{x}{2}\right)$$

so that at the bottom of the radioactive stratum; that is, for $x = s$; the maximum temperature is

$$v_m = \frac{qs^2}{2k} = 321° = \frac{q^2 s^2}{k^2} \cdot \frac{k}{2q} = \left(\frac{dv}{dx}\right)_0^2 \cdot \frac{k}{2q}.$$

But for the elevation of melting point by pressure, therefore, the maximum temperature developed by radioactivity in the hypothetical earth would about suffice to melt lead. Observe that for a given gradient v_m is inversely proportional to q.

The hot stratum would somewhat gradually warm up the underlying mass, and it is worth the while to ascertain its effect at Mr. Hayford's level of isostatic compensation, which lies at a depth of 121 kilometers. If u is the distance of this level below the radioactive layer, about 99 kilometers, the temperature excess, v, in accordance with Fourier's law, is given by

$$v = v_m \frac{2}{\sqrt{\pi}} \int_0^{u/2\sqrt{\kappa t}} e^{-z^2} dz.$$

Here κ is the diffusivity of the rock or the ratio of the conductivity to the thermal capacity. For the Calton Hill trap this is .00786 in c. g. s. units, or per year and square meter $\kappa = 24.8037$. If $v = v_m/2$, or 161°, so that Hayford's level acquires half the temperature excess of the radioactive shell, then

$$\frac{u}{2\sqrt{\kappa t}} = .4769 \text{ or } t = 434 \times 10^6 \text{ years.}$$

Thus it appears that heat traverses a layer of rock a hundred kilometers in thickness with extreme slowness.

It does not seem to me that on such an earth as that just considered there would be any geology. No evident source of energy is available to bring about upheaval, subsidence, or vulcanism, and therefore baseleveling would obliterate the continents.

On the other hand, as is pointed out above, a superficial shell of a cooling earth, extending from the surface down to the level of isostatic com-

[80] Proof of this equation, established independently by Messrs. R. J. Strutt and Johann Koenigsberger, may be found in Bull. Geol. Soc. Am., vol. 19, 1908, p. 137.

pensation, may be considered as a heat engine. In such an earth there is abundant energy available for geological processes, only a portion of which is dependent on the sun.

Sir Ernest Rutherford, after giving the maximum temperature due to a layer of uniform radioactive matter at, in round numbers, 300° C., continues: "This maximum temperature seems too small to fit in with the facts, for there is reason to believe that a temperature of about 1,300° exists some distance below the surface."[81] He goes on to show that by a logarithmic distribution of the radioactive matter an internal temperature excess just double that due to a homogeneous layer may be attained, though only at a great depth; but even in that case there remain at least 600° or 700° of temperature unaccounted for. It is clear that if the earth at some distance below the surface is hotter than it would be if all the emission were due to radioactivity, a part of the gradient at the surface must be due to some distinct cause, which can hardly be other than an initial excess of temperature, and consequently the shell of radioactive matter must be thinner than 21 kilometers.

Since the conduction of heat out of the earth complies with Fourier's law, no matter what the origin of that heat may be, the superficial temperature gradient is the sum of the gradients due to several causes. Of these there appear to be three only, namely, an initial high temperature of the exterior shell, an original temperature gradient due to the rise with pressure of the temperature of consolidation,[82] and exothermic transformations, including radioactivity. The evidence that the external portion of the globe has been liquid to a considerable depth is well known and Kelvin's summary of it has already been cited. Now, the initial surface temperature was determined by the nature of the rocks composing the original outer shell, and these must have been rhyolites, trachytes, and andesites, in the main of holocrystalline texture. The temperature gradient must also have been influenced by the composition of the rocks. At the surface the temperature in question can not have differed much from 1,300°, which is only about a hundred degrees higher than the melting point of the more fusible basalt or diabase. The initial gradient must have been less than the gradient of Mr. Barus's diabase melting-point curve, and I have given reasons elsewhere, based on the law of density proposed by Legendre and adopted by Laplace, for believing that it intersected his line at about 40 miles from the surface.[83] These rela-

---

[81] Op. cit., p. 652.

[82] This gradient answers to the hypothesis that the fluid portion of the earth was in convective equilibrium.

[83] Smithsonian Misc. Coll., vol. 56, 1910, No. 6, p. 17.

tions are unaffected by any hypothesis as to the origin of the heat; for even if all the heat had been due to atomic disintegration, the rocks could not solidify until the temperature sank to their melting points at the prevailing pressure.

Let V be the initial surface temperature (1,300°) and let c be the initial gradient, 300/63,710 degrees per meter.[84] Then the present superficial gradient is

$$\left(\frac{dv}{dx}\right)_0 = \frac{V}{\sqrt{\pi \kappa t}} + c + \frac{qs}{k}$$

$$s = \frac{k}{q}\left\{\left(\frac{dv}{dx}\right)_0 - c - \frac{V}{\sqrt{\pi \kappa}} \cdot \frac{1}{\sqrt{t}}\right\}$$

so that if t is assumed s can be found, or vice versa. Rutherford gives q at 19 gram calories per annum, and the conductivity k I shall take as that of the Calton Hill trap, .00115 in c. g. s. units, or per meter per year, 13.096×10^6. For the present surface gradient my preference is 1° C. in 38 meters. Rutherford's $1°/32^m$ is a fair average of observed values, but there are reasons[85] for selecting as normal the gradients in undecomposed massive rocks in relatively level country rather than a mere average of observations. Many influences tend to raise the gradient abnormally, while none, excepting the neighborhood of large bodies of cold water and the escape of gas, are known to lower it.

With $t = \infty$ and $c = o$ the data I have chosen would give a maximum value of the uniform radioactive shell, say, $s_m = 18.14$ kilometers, and all of the emission would be due to radioactivity. For any other case—that is, if only a part of the heat lost by the earth is of radioactive origin—the thickness of the radioactive layer would be in kilometers

$$s = 14.893 - 101509/\sqrt{t}.$$

In a little table below will be found values of s for t ranging from 68×10^6 years to $1,311 \times 10^6$ years. This latter portentous age is chosen because it would seemingly satisfy even the requirements of the uranium-lead ratios and because it gives $s/s_m = 2/3$, meaning that just 2/3 of the heat emitted is of radioactive origin. If this age is regarded as a superior limit, then at least one-third of the surface gradient is due to initial heat, and the maximum temperature due to the radioactivity of

[84] In other words, the initial temperature excess is taken as 300° at a depth equal to 1 per cent of the earth's radius, or 63,710 meters.

[85] Smithsonian Misc. Coll., vol. 56, 1910, No. 6, p. 26.

a uniform shell[86] is 106°. To be sure, the limit of s/s_m chosen is an arbitrary one, but it will answer the purpose in view. Were three-fourths of the heat emitted due to radioactivity, the age would be over $6{,}200 \times 10^6$ years. Even so, initial heat would play an important part in the earth's heat emission. Thus it appears that thermal equilibrium can not have been attained by the earth as yet, and that however important radioactivity may be, the earth must be considered as a cooling globe. While these results are dependent on the choice of constants, those selected can not be very erroneous, and it seems impossible to avoid the conclusion that, even if the earth is 1,300,000,000 years old, something like a third of the surface gradient, and therefore also approximately one-third of the earth's emission, is due to initial heat, while the contribution of radioactivity to the earth's internal temperature is hardly great enough to account for hot springs.

That depth at which the excess of temperature curve most nearly approaches the diabase melting-point curve I have called the eutectic level, because a smaller heat increment will bring about fusion at this level than at any other. For any age equal to or greater than 68×10^6 years the eutectic level lies 70 miles or more below the radioactive layer, and the temperature gradient at this level will be independent of q. It can readily be proved[87] that if x_1 is the distance of the eutectic level from the surface the conditions stated above are satisfied by

$$\sqrt{\pi \kappa t} \cdot \frac{V - b}{.01\, r} \cdot \frac{1}{V} = \epsilon^{\frac{-x_1^2}{4 \kappa t}}$$

r being the earth's radius and b the melting point of diabase at the surface, or 1,170°, according to Barus. The values of x_1 for each of the ages is given in the table. For $t = 68 \times 10^6$, $x_1 = 121$ kilometers, and for $t = 1{,}314 \times 10^6$, $x_1 = 300$ kilometers.

---

[86] If the radioactivity were to diminish linearly with depth, the total amount remaining the same as in the uniform shell, activity would vanish at a depth, say, $\sigma = 2s$, and at this depth the temperature would be four-thirds of that computed for the bottom of the uniform shell. Thus redistribution in this sense would increase the value 106° to 141°. Bull. Geol. Soc. Am., vol. 19, 1908, p. 144. On the other hand if, following Holmes, I had taken the Ra– content of surface rock at 2.5×10^{-12}, the temperature of 106° would sink to 91°.

[87] Smithsonian Misc. Coll., vol. 56, 1910, No. 6, p. 24.

Age.	s in kilom.	s/s_m.	x_1 in kilom.
68 × 10⁶ y.	2.58	0.1425	121
100 "	4.74	.26	140
200 "	7.72	.43	180
300 "	9.03	.50	206
600 "	10.75	.59	254
1,000 "	11.68	.64	286
1,314 "	12.09	.6667	300

The second column gives the thickness of the active shell, the activity being supposed constant, and the third column states the proportion of the emitted heat which is due to radioactivity.

Mr. Hayford's level of isostatic compensation lies at a depth of 120,900 meters, or, not to be meticulous, at 121 kilometers.[88] Such compensation at an eutectic level seems natural and comprehensible; but under that interpretation the age of the earth, with the data now available, is only 68×10^6 years, and it does not seem possible that any corrections in the values of the constants should increase the age thus determined to more than 100×10^6 years.[89] On the other hand, if the eutectic level is at

[88] Supplementary investigation of the figure of the earth and isostasy. Coast and Geod. Surv., 1910.

[89] To avoid a possible misinterpretation, it may be expedient to refer to a difference of opinion which has arisen between Mr. Joly and myself. In discussing the age of the earth from the accumulation of sodium in the ocean, as first suggested in modern times by Mr. Joly, I made allowance for the continual diminution of the exposed area of Archean and igneous rocks from which the sodium is ultimately derived. The computed age came out about 70×10^6 years. (Smithsonian Misc. Coll., vol. 56, 1910, No. 6.) In Science Progress for July, 1911, p. 45, Mr. Joly expresses his dissent from my view, maintaining the uniformity of the sodium supply and referring to his paper of 1899 in the Trans. R. Dublin Soc. for reasons. In that paper he stated that the possible diminution in the area of feldspathic rocks "should undoubtedly lead us to widen the margin we allow for error in our estimate of geological time:" and he drew attention to the fact that such analyses of ancient slates and modern silts as were at his command tended to show a decrease with increasing age of the content in alkalies. He nevertheless adhered to the hypothesis of uniformity seemingly because old sediments freshly eroded give up a fresh portion of their sodium content. This, of course, is true. Sodium extraction is a slow, perhaps asymptotic process. But ultimately the alkali all comes from the Archean and igneous rocks, and if the source of supply were cut off it would gradually cease or approach zero. Suppose that the original feldspathic rocks had been in some way protected from decomposition or denudation once for all at the beginning of the Cambrian. Would the reworking of pre-Cambrian sediments still be yielding as much sodium as is now derived from continental areas about one-fourth of the area of which is occupied by ancient feldspathic rocks? Surely not. The supply could be kept up only if decomposition were undiminished by a superjacent detrital layer. But every member of this Society knows that at many points in the northern part of the continent a layer of compact turf, only 3 or 4 inches thick, has been sufficient to preserve intact glacial scratches and polish, while exposed areas of the same rocks in the same region have lost both. In the south a coating of saprolite a score or two of feet in thickness seems likewise a complete protection against weathering. In short, I adhere to my opinion that as the amount of sodium in the ocean increases the available continental supply of sodium decreases.

300 kilometers from the surface, isostatic compensation takes place without fusion—indeed, without any known cause; and this is not the whole mystery, for it would seem that a shell no less than 180 kilometers in thickness bounded by the eutectic level and Hayford's level must have cooled many hundreds of degrees below its melting point without disturbance of its isostatic equilibrium. I can not grasp such a situation.

It does not appear certain that on a globe so old as 1,300,000,000 years there could be much more geology than on the purely radioactive earth first discussed. In a cooling sphere the temperature at the eutectic level sinks with the progress of time more and more below the temperature of fusion. In a 68×10^6 year earth a rise in temperature of about 150° would cause fusion, while in the $1,314 \times 10^6$ year earth an additional 600° would be needed to melt the rock at the eutectic level. It would seem to me that as such a globe grew old fusion would be a more and more infrequent phenomenon, and that fusion would be more and more rarely accompanied by effusion. It is even questionable whether any eruptions could occur on a globe in which the eutectic level is 300 kilometers beneath the surface.

Conclusions

The geodetic evidence for isostasy is so manifold and so consistent as to amount to proof. Observed anomalies appear due in large measure to irreguar distributions of density, and I conclude that the variations in the load per unit area at the level of compensation are very much smaller than the surface anomalies, while beneath this level the strains are probably small quantities of the second order.

Considered physically, the only interpretation I can put upon the level of compensation is that it is the level of easiest fusion or of eutexia; and, if so, at that level the tangent of the curve showing the temperature of the earth as a function of depth is parallel to the curve representing the melting point of the rock as a function of depth. Local fusion would bring about compensation. Where, then, should we look for compensation, if not at the eutectic level?

Independently of this physical interpretation, the two curves just referred to can not be far apart at the compensation level, for otherwise a thick shell underlying this level must have cooled through a large temperature interval and must have undergone strains inconsistent with compensation.

Epeirogeny and orogeny may be explained as due to the conversion into mechanical work of a part of the heat received by the outer shell of the earth at the compensation level and emitted at a comparatively low temperature by the outer surface of the globe. To account for such a mechanism it is sufficient to assume that conductivity of certain areas, destined to be occupied by continents, was lower than that of the remaining surface of the globe.

Very early in the history of radiology—the greatest achievement of physics since the establishment of the second law of thermodynamics—means were suggested for determining the ages of minerals. They seemed plausible, but gave results agreeing very badly among themselves, and for the most part many times as great as those deduced from study of the earth as a cooling body or of the ocean as the depository of the sodium extracted from continental rocks.

Recent advances in the study of atomic structure, and especially the discovery of isotopic elements—that is, different elements occupying the same place in the periodic table but inseparable by ordinary chemical means—render the uranium-helium ratio and the uranium-lead ratio practically valueless for the determination of the age of minerals.

If it is granted that the compensation level is an eutectic level, and this seems the only intelligible theory, the age of an earth heated both by compression and by radioactivity can be computed.

Geodesists assert that the compensation level is between 110 and 140 kilometers from the surface. The smaller depth would correspond to an age so small as to be unacceptable to geologists. For a depth of 121 kilometers the age would be 68×10^6 years and one-seventh of the heat emitted would be due to radioactivity. For a depth of 140 kilometers the age would be 100×10^6 years and 26 per cent of the heat lost would be ascribable to radioactivity. Greater depths of the compensation level seem incompatible with slight strain beneath that level, and can not be accepted from the point of view of this paper, but data are given for an earth no less than $1{,}314 \times 10^6$ years old corresponding to the hypothesis that two-thirds of the heat emitted by the globe is due to radioactivity.

To some extent the results reached depend on the constants adopted, but there is strong reason for believing these so nearly correct that a large percentage change in the results is very improbable.

It appears, then, that the position of the level of compensation is incompatible with any immense age for the earth, while the discovery of isotopic elements throws us back on means not involving the uranium-helium or the uranium-lead ratios for the determination of this age. In particular the age of a radioactive earth which is also initially hot may be computed from Fourier's law of conduction as readily as if it were not radioactive. There is even a possibility that radioactive energy has been potentialized at the expense of energy of compression.[90]

It has often been asserted that the discovery of radioactivity indefinitely prolongs the probable age of the earth. To me it seems that the determination of the level of compensation limits both the age of the earth and the amount of radioactive matter in its outer shell.

---

[90] Ascription of the heat of stellar bodies to compression originated with Kant in 1785, not with Helmholtz in 1854. Cf. Bull. Geol. Soc. Am., vol. 19, 1908, p. 130.

BULLETIN

OF THE

Geological Society of America

VOLUME 26 NUMBER 2

JUNE, 1915

JOSEPH STANLEY-BROWN, EDITOR

PUBLISHED BY THE SOCIETY

MARCH, JUNE, SEPTEMBER, AND DECEMBER

CONTENTS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

Subscription, $10 per year; with discount of 25 per cent to institutions and libraries and to individuals residing elsewhere than in North America. Postage to foreign countries in the postal union, forty (40) cents extra.

Communications should be addressed to The Geological Society of America, care of 420 11th Street N. W., Washington, D. C., or 77th Street and Central Park, West, New York City.

NOTICE.—In accordance with the rules established by Council, claims for non-receipt of the preceding part of the Bulletin must be sent to the Secretary of the Society within three months of the date of the receipt of this number in order to be filled gratis.

Entered as second-class matter in the Post-Office at Washington, D. C., under the Act of Congress of July 16, 1894

PRESS OF JUDD & DETWEILER, INC., WASHINGTON, D. C.

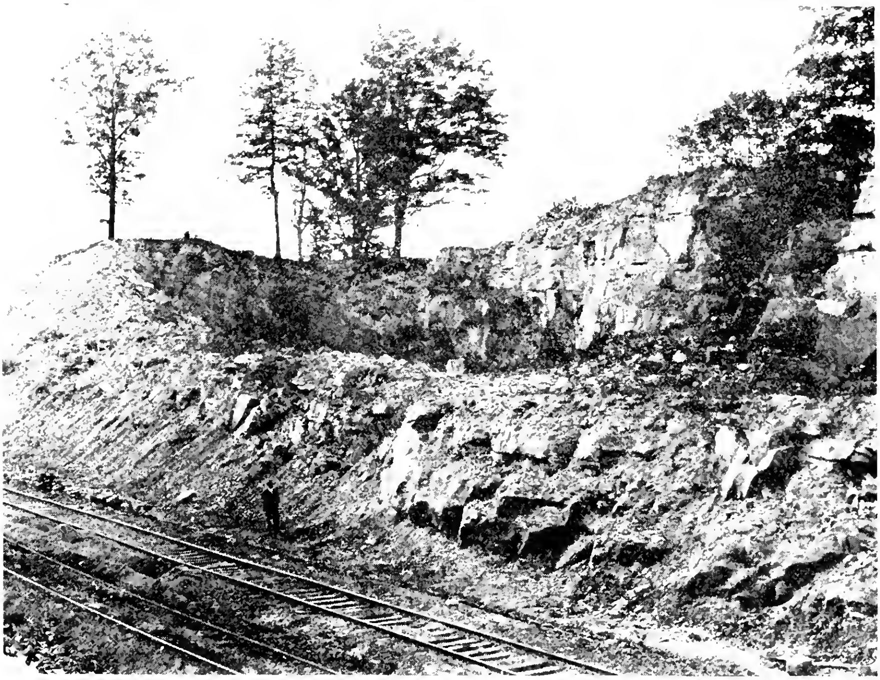


FIGURE 1.—WEST WALL OF BROOKLYN CHANNEL

The view is on the north side of the cut. On the right is sandstone at the track level. On the left is Bedford shale, reaching 10 feet above the track level

FIGURE 2.—EAST WALL OF BROOKLYN CHANNEL

On south side of cut is shown steeply inclined contact of shale and sandstone in center of view. Sandstone at track level on right and 30 feet of Bedford shale on left

EAST AND WEST WALLS OF BROOKLYN CHANNEL

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 205-216, PL. 8 JUNE 15, 1915

DIASTROPHIC IMPORTANCE OF THE UNCONFORMITY AT THE BASE OF THE BEREA GRIT IN OHIO [1]

BY H. P. CUSHING

(*Presented before the Society December 30, 1914*)

CONTENTS

INTRODUCTION

In 1874 J. S. Newberry made the following statements in the Ohio reports:

"In most localities where the Bedford shale is exposed the upper surface is very irregular, and it is evident that the formation has been extensively eroded by the agency which transported the beds of sand, now consolidated into the Berea grit." [2]

"The best exposures of the entire thickness of the Bedford shale are on the Black River below Elyria. . . . It will also be noticed here that the upper surface of the shale is very irregular, showing that the currents of water which transported the sand—now the Berea sandstone—cut away the shale, then a red clay, in broad and deep channels. As these were filled with sand, the under surface of the sandstone is very uneven and its thickness variable." [3]

This unconformity, noted so long ago by Newberry, is wide-spread, and has attracted the attention of all the more recent workers in the State.

---

[1] Manuscript received by the Secretary of the Geological Society February 8, 1915.
[2] Geol. Surv. Ohio, Geol., vol. 2, p. 91.
[3] Ibid., p. 212, Geology of Lorain County.

Orton mentions it, and seems to have attributed no more importance to it than did Newberry. Burroughs has described some phases of it in Lorain County. Prosser has treated of it in the central and northern parts of the State, and the writer has been familiar with it for many years, and has long had a description of it as it occurs in Cuyahoga County in a manuscript whose publication has been greatly delayed.[4] It is an extremely obvious discordance, is at once noted in any good section, and for several reasons the present seems an auspicious time to discuss its significance.

Description

Unquestionably this unconformity is most prominent in the district described by Burrows in Lorain County and westward, where the most northwesterly outcrops of the formation in the State occur and where the strike swerves from an east-west to a north-south direction along the east side of the Cincinnati anticline. Here its type is of deep, sand-filled channels cut out in the underlying shales. These reach an extreme depth of from 150 to 175 feet, are fairly steep-sided, and have apparently a width of but a few hundred feet, only from three to five times the depth.

East and south from this northwest angle the unconformity rapidly loses this prominent character. Considerable channels are present in Cuyahoga County, next east of Lorain, though much smaller than the Lorain examples; but the general character of the contact is that of rather slight irregularity, the surface of the shale being etched with small, shallow channels which are filled with sand. In general a thickness of less than 10 feet is involved, and usually much less. The instances described by Prosser from central Ohio seem all of this type.

The Brooklyn Channel

Perhaps the best exposure yet seen in illustration of the unconformity is one on the southwest edge of Cleveland, first studied by the writer in 1907, soon after it had been developed by a deep cut made in construction of the Belt Line Railroad. A glance at the accompanying map, figure 1, which is a reproduction of a small portion of the western margin of the Cleveland topographic sheet, will show the 840-foot contour projecting northward in a long, narrow promontory, reaching out three-fourths of a mile beyond its normal line. It forms a prominent cusp which, as seen from the north, constitutes a bold and striking feature of

[4] Jour. Geol., vol. xix, pp. 655-659; vol. xx, pp. 585-604; vol. xxii, pp. 766-771; Bull. 15, Geol. Surv. Ohio, 4th series.

the topography. The Belt Line makes a deep cut from west to east squarely across this promontory, with the track level at about 800 feet altitude. The section shown in the cut is sketched in figure 2. Midway is a filled channel of Berea sandstone, whose deeper central portion is

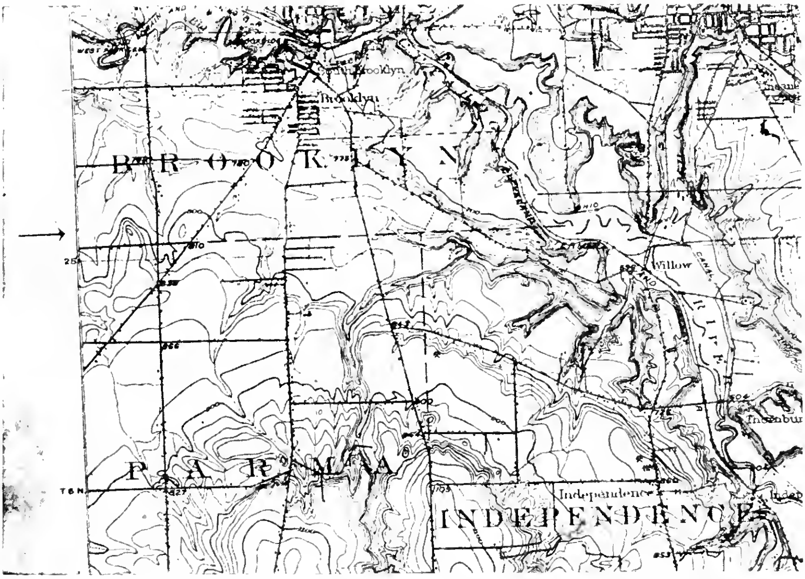


FIGURE 1.—*Portion of Cleveland Quadrangle, showing Location of Brooklyn Channel*

below the level of the road-bed, hence unexposed. The walls of the channel are of red Bedford shale. The east wall is steep, the inclination being about 35 degrees, with the Bedford shale rising rapidly above the base of the cut until it attains a height of 30 feet above the level of the

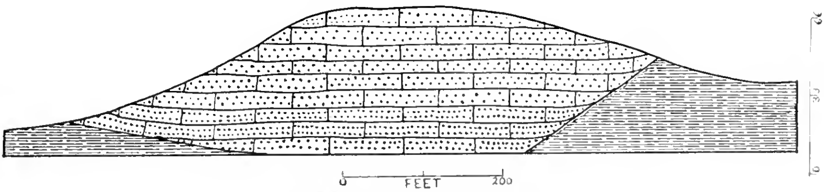


FIGURE 2.—*Section of the Belt Line Railroad Cut*

This cut is across the Brooklyn Channel of Berea sandstone cut in Bedford shale

road-bed. The west wall has a much more gentle inclination, only about 10 degrees; the Bedford rises much less rapidly from beneath and attains a height of only 10 feet above the track at the west end of the cut. The two reproduced photographs which form plate 8 show these two contacts.

the cut being altogether too long to be compressed into a single view. The Berea is below the track level for a distance of about one hundred yards and likely attains there an additional thickness of from 15 to 20 feet: but as the exposures stand they show a channel, probably a stream channel, cut into the shales to a depth of certainly over 30 feet, probably 50 feet, and with a width of some one hundred yards at the level of the road-bed. The greater steepness of the east side indicates that the current was cutting against that bank. The sandstone in the channel is very unevenly bedded and the adjacent shale is disturbed, chiefly by a bending down parallel to the slopes of the channel sides.

So far as known to me, this is the most easterly of the channels of good size that has been discovered. While by no means so large as some of those farther west, it is of the same type and the excellent exposures justify its lengthy description. Unfortunately today the showing is by no means as good as it formerly was. The Bedford shale, especially in its upper red portion, is an extraordinarily weak formation, crumbling with great rapidity and becoming covered with vegetation in a single season; but the base of the Berea still shows as sharply as in 1908, when photographed.

Elsewhere in the Cleveland vicinity the contact shows only minor irregularities. The shale surface is repeatedly channeled, but the channels are small and shallow, and this is the general character of the contact all across northern Ohio.

The underlying Formations

Beneath the Berea is a thickness of many hundreds of feet of shales. Directly beneath lies the Bedford shale, with a thickness of from 75 to 100 feet where fully developed. For the most part it is an exceedingly weak, clay shale. In the western sections, those containing the channels, the formation is mostly a red shale of this type which, when freshly exposed, breaks down to a sticky, red clay in a very few days. In the basal portions are some thin, harder bands of shale and an occasional thin band of sandstone. In the Cleveland district the formation carries a 20-foot sandstone lentil, the Euclid bluestone, in its basal portion; but I know of no channel which has cut down to the bluestone horizon. The bluestone has an interest from the standpoint of this paper, since it shows at its base irregularity of the channel type, quite like that at the base of the Berea, though on a much smaller scale. In the quarry floors of some of the quarries at Euclid excellent illustrations of this are shown. It is an interformational irregularity and due to contemporaneous erosion, with the change of conditions from mud to sand deposit; but it seems to me of distinctly the same type as the channeling at the base of the Berea.

In central Ohio there are some sandy beds near the summit of the Berea, so much so that there have been differences of opinion as to where to place the line between the two. Prosser thinks these sandy beds have been eroded away over areas of considerable extent prior to Berea deposition, and argues a time interval of considerable extent between the two to account for this erosion. The writer is unfamiliar with those sections, but in conversation with other geologists, who do know the region, expressed interpretations of the phenomena did not correspond with Prosser's interpretation.

Below the Bedford lies the Cleveland shale, a black, slaty shale, which today is a much more resistant formation than the Bedford; but it breaks down rapidly on exposure to the weather, when exposed in banks, and certainly is not a formation of any particular resistance to erosion as compared with ordinary sandstones and limestones. In the post-glacial valleys of the small streams in northern Ohio an excellent idea of the erosional resistance of this formation can be obtained. It comes into the problem at all only because the deep channels of the northwest district cut into it.

Beneath the Cleveland in the eastern sections lies the gray Chagrin shale. It is weak, but the Berea erosion nowhere reaches it. West of Cleveland a blackish shale, with occasional blue bands, lies beneath and is a weaker rock than the typical Cleveland shale. The bottoms of the deeper western channels are in this rock.

Extent of the Berea Sandstone

The Berea extends out of Ohio into Michigan on the north, Kentucky on the south, and Pennsylvania on the east. In Michigan it is known only on the east side of the Carboniferous basin and does not show in outcrop. Lane, from study of the drill records, reports it as varying in thickness from 40 to over 300 feet, as being thickest and coarsest on the west, and then suddenly disappearing.[5] In all probability this means also the occurrence of channels similar to those on the northwest in Ohio, perhaps somewhat deeper, since the greatest known thickness in Ohio does not much exceed 200 feet. Lane states that the Michigan Berea forms a deposit along a shore facing east and running nearly north-south, and this corresponds well to the Ohio conditions.

[5] Jour. Geol., vol. 18, p. 418.

Southward in Kentucky the Berea rapidly thins, becomes indistinguishable from the underlying Bedford, which also thins, and both disappear before central Kentucky is reached, according to Foerste and Morse.[6] Either the Berea was not deposited so far south or else the deposits swerve to the east of the present erosion surface, so that their western edge is still under cover.

Traced into western Pennsylvania, the Berea is found to be the equivalent of I. C. White's Corry sandstone, at least in part. Whether it includes more than that and comprises the Cussewago sandstone and shale also, as urged by Prosser, is quite likely.[7]

Now the Corry sandstone in western Pennsylvania, notably at Corry, carries a marine fauna, as White long ago showed. Recently Girty has published a faunal list from this formation.[8] Evidently the Berea here is, at least in its upper portion, a marine formation.

Ohio Berea a non-marine Formation

In outcrop in Ohio certainly the entire Berea must be classed as nonmarine. It holds occasional fossil fishes, notably at Chagrin Falls, and contains plant fragments in abundance in certain layers at many localities, but practically no other fossils. The plant fragments are in general converted into coal, and layers with abundant plants often carry clay lumps in the sand. The formation must be regarded as a continental one, probably a delta deposit.

Uplift following the Bedford

The foregoing account enables us to picture the events which closed Bedford and inaugurated Berea deposition. The Bedford is a marine deposit, with the possible exception of its extreme upper portion. At its close the land which lay to the north of the Bedford basin was given increased altitude above sealevel, streams were invigorated and brought down a plentiful sand supply in place of the fine muds of the Bedford. The northwestern district was sufficiently far inland and of sufficient altitude to enable the currents to channel deeply and efficiently. East and south the sand was spread broadly over the low delta region, with much minor channeling of the underlying surface, but no deep channels. The sealevel was slowly rising, so that ultimately delta conditions pre-

[6] Ohio Naturalist, vol. 9, p. 516.

[7] Bull. 15, Geol. Surv. Ohio, pp. 375-377, 390-404.

[8] Annals N. Y. Acad. Sci., vol. 22, p. 303.

vailed over the channeled district, while marine conditions were brought about in western Pennsylvania.

Importance of the Unconformity

Unlike many unconformities in horizontal rocks, that between the Bedford and Berea is exceedingly plain. Evidence for it fails in few good sections. But how much of a time gap is indicated by it?

The answer to this question is somewhat affected by two considerations, for which there is little obtainable evidence one way or the other. Had the underlying rocks become indurated during the interval between their deposition and the beginning of Berea time, and if so how thoroughly? Did perhaps a long time gap intervene between the close of the Bedford and the beginning of the Berea, a time during which the land lay quiet at low altitude, experiencing neither erosion nor deposit?

Even with the present degree of induration the rocks which underlie the Berea across Ohio are for the most part so weak that they afford little resistance to currents of even weak erosive power. Many of the shale banks along the stream courses even show rain-gulleying. This is especially true in the western district where the prominent channels occur. They are chiefly cut out in soft red and blue shales, which are even less resistant than a heavy clay soil would be, since they crumble on exposure. The black shales beneath, those in which the bottoms of the deep channels are cut, are not greatly more resistant. They are weak rocks today. The occasional thin sandstones which are cut out present a greater obstacle on the supposition that they had so quickly attained their present degree of induration, and it is on their evidence that Prosser chiefly bases his conception of the importance of the unconformity. But if the time gap was small, as we conceive it, it is certainly not illogical to hold that it is unlikely that these sands had so quickly attained their present compactness. The quotations from Newberry, with which this paper begins, shows this to have been his view. When one considers the general condition in which many rocks of Tertiary age are found today, in districts unaffected by orogenic or igneous activity, the supposition seems not unreasonable. But we may grant that the rocks had attained their present degree of induration before Berea deposition began and yet not materially affect our argument. We regard it as probable that induration was not far advanced, because all other features of the break speak for a very short time gap. But the present degree of induration may be admitted and still not materially affect the force of the argument.

The minor channeling in the eastern region is likely the result of scour and fill action on a delta floodplain. The more prominent channels on the northwest seem more like definite stream channels, yet their depth, their varying direction (they trend all the way from north-south to east-west), and the evidence of rapid filling suggest that they may be scour channels also. But definiteness here is not necessary to the point which we wish to make, namely, that on either view the erosion stage indicated is a very juvenile one and points to a very short time gap between the two formations. If the process was one of scour and fill in soft muds, currents adequate to the transportation of quantities of coarse sand and of complete removal of all finer material from it as it was deposited were competent to do the work in a very short time. If the westerly channels were cut by individual streams and the rocks had their present degree of induration, the time required would be longer, several times longer; but even then the character of the channels is indicative of a very immature erosion stage. They are cut in weak rocks, mostly very weak. They are not broad; in fact, when the nature of the banks is considered, they may all be said to be very narrow. Their tops are all at the same geologic horizon and their bottoms at quite different horizons, even in the same restricted district. There is not even an approximation to gradation in the channel beds when compared with one another. Between channels there was no removal of material at all. The whole physiography bespeaks immaturity of erosion stage. And it was, no doubt, this phase of the subject which impressed Newberry so forcibly that he made no point whatever of the break when he built up his Ohio section. In these weak materials wide-spread baseleveling would have resulted from a long erosion interval, and the stream beds at least would have been thoroughly graded in a shorter interval; but there is no approximation, even to the latter.

Precisely the same phenomena on a smaller scale are shown at the base of the Euclid sandstone lentil in the basal Bedford shale. The sandstone is argillaceous and of finer grain than the Berea; and though a shore deposit, it is a marine one, even though the appearance of the sand badly discouraged the marine fauna of the Bedford; yet the soft, underlying shale is channeled in moderate fashion, and at the westerly margin of the lens, in west Cleveland, sand-filled channels several feet in depth occur, with great disturbance of the underlying black muds. No one calls this anything but contemporaneous erosion.

The Berea rests always on the Bedford. To us the most obvious and most conclusive evidence in support of our view of the trifling character of the Bedford-Berea break is the fact that all across Ohio, along a measured length of outcrop of about 300 miles, from the Ohio River north to the lake and then eastward to the Pennsylvania line, the Berea rests on the Bedford shale. The Bedford is both a thin and a weak formation, susceptible of easy and rapid erosion. It seldom exceeds 100 feet in thickness and seldom falls below 50 feet, except along the channel bottoms in the northwest corner, in the deeper of which it is entirely cut out. To believe in a considerable time gap between the two formations, one is forced to believe that along this entire long line oscillation took place, with *no warping whatever.* The land was either so low that no erosion took place, and the channels seem to negative that, or else it was so evenly uplifted that the same amount of erosion took place everywhere. There is nowhere, so far as known to us, an oscillation involving so long a line without some local warping being involved. We have had occasion in the past ten years to study many of the unconformities within the Paleozoic series in New York. Without exception, they are characterized by the fact that the formation which follows the break rests on underlying beds which vary in horizon from place to place. The oscillation has been always accompanied by gentle, very gentle, warping, and the upwarped beds have been truncated by erosion before renewed deposit took place. This is the one feature which they all have in common, and the one feature unexplainable on any other theory than that of a protracted erosion interval between the two sets of deposits. It is wholly lacking at the Berea base in Ohio. We are personally unable to conceive of the possibility of an oscillation of the type, involving such a long line, without the appearance of some warping, with ensuing truncation should an erosion interval follow.

Comparison with the Pottsville Unconformity

The break at the base of the Pottsville in Ohio furnishes an excellent illustration of this ordinary type. It is a real break. It rests on the gently truncated edges of several of the Waverly formations, as it is followed across Ohio. In the Chagrin Valley, east of Cleveland, the Pottsville base is only 100 feet above the Berea summit and rests on the Orangeville. Eastward other beds come in, and when the Pennsylvania line is reached the Pottsville is some 350 feet above the Berea, the thickness being added, bed by bed, in passing east. West from the Chagrin Valley the same thing takes place, and somewhat more rapidly than in the other direction. Over most of northern Ohio the Pottsville rests on various beds of the Royalton formation. West of the Cuyahoga the Potts-ville-Berea interval is from 300 to 400 feet. By the time central Ohio is reached the entire Black Hand and Logan formations have come in and the interval expanded to something like 1,000 feet.

At the base of the Berea we utterly miss this sort of evidence. The underlying horizon is unvarying. To be sure, when we pass out of Ohio the Berea is found resting on the Chagrin formation, in the counties of western Pennsylvania. To Ulrich and myself the Bedford absence there seems a case of overlap. It is absent because it was never deposited there, the district lying without its basin. Prosser does not accept this view, but holds, if I understand him correctly, that the Bedford disappears by lateral gradation into beds which carry a Chemung fauna. The sections are scattered and poor and the evidence incomplete either way; but to the writer it seems a clear case of overlap. Along the Ohio-Pennsylvania line there seems to have been a barrier formed between two separate troughs of deposit. On the Pennsylvania side the Knapp and Conewango formations were laid down on the Chemung, but did not get into Ohio to any extent. On the Ohio side the Bedford was deposited, but failed to pass over into Pennsylvania. Along the barrier both substantially fail and the Berea lies on the Chagrin. It so lies not because of erosion of the other formations, but because they were never deposited there.

It is frankly admitted that the above interpretation does not meet the views of many geologists. It seems to us, however, that we may also waive this and not greatly affect the force of our contention that the uniform resting of the Berea on the thin and weak Bedford formation all across Ohio makes it exceedingly improbable that their contact can mark a time interval of any particular importance.

Prosser has described a Berea-Bedford contact at Warner Hollow, Ashtabula County, where the upper Bedford has been slightly crumpled and also slightly faulted before Berea deposition began.[9] He emphasizes the locality as of exceptional importance in demonstrating a disconformity between the two formations. We can not see it in the same light. The disturbance is exceedingly local and exceedingly small in amount. The locality is not many miles west of the meridian along which the Bedford disappears, hence near what we regard as its eastern shoreline. Very trifling local causes could produce disturbances of this character in unconsolidated muds and sands. It seems to us to have no weight whatever in comparison with the great general fact that the Berea base practically does not change horizon all across Ohio, but rests everywhere on the thin Bedford shale.

In Kentucky the Berea disappears by overlap. It may also be noted that the Bedford is a partner in this transaction, the two both thinning and pinching out together, letting the Sunbury black shale down on the

---

[9] Bull. 15, Geol. Surv. Ohio, pp. 312-315.

Cleveland shale as contributing elements to the Chattanooga shale. This does not seem to us indicative of any particular time gap between the Berea and Bedford.

At the base of the Pottsville in northern Ohio precisely the same sort of channeling of the underlying surface is observable as at the Berea base. This seems to us a feature produced entirely subsequent to the general long period of erosion which truncated the gently warped surface of the Mississippian rocks before Pottsville deposition began. After the base-leveling was complete the surface was channeled by the currents, which transported the gravel and sand which constitute the basal Pottsville. The channeling does not of itself suggest a time gap; it is the previous warping and the truncation of the warped beds by long erosion, so that the rock just under the Pottsville varies much in horizon across the State, which demonstrates the unconformity and proclaims its importance. It is just this sort of evidence which absolutely fails in the case of the Berea base.

Conclusion

The matter is here discussed and this view emphasized because of the present tendency on the part of several geologists to draw the line between the Devonian and Mississippian at this Bedford-Berea horizon and to quote the unconformity as evidence justifying the procedure. If this were a mere local question affecting only Ohio and Michigan, I should not have discussed it. I readily admit that, in so far as considerable parts of these two States are concerned, this is perhaps the most convenient and easily recognizable horizon at which to draw this line. I also willingly admit that it is a better place to draw it than at the base of the Bedford shale, where it was placed by Orton and where there is no break at all, so far as I can discover. But it would seem that this convenient line in Ohio is located at the expense of the geologists of Kentucky, New York, and Pennsylvania, in which States it is far less easy of recognition or else not recognizable at all. But this is a long and involved question, with many phases, and my purpose is simply to emphasize one of these.

In many districts the line between the Devonian and Mississippian is a confessedly difficult one to draw. Nowhere is this more true than in Ohio, where difference of opinion concerning its proper location has long prevailed and still prevails. Unless we are totally at fault in our attempted locations of this boundary, we must conclude that either in many localities the Devonian passed into the Mississippian without any considerable break or else that the break is a peculiarly elusive one, hidden in weak and poorly exposed shales in such wise that it is very difficult to detect. If it be true that in the northern Appalachian basin the Devonian passed into the Mississippian without diastrophic oscillation and sea withdrawal, then the trifling character of the break at the base of the Berea would have no significance: but if this be not true, if diastrophism be periodic and is to be used as the basis of geologic classification, it is not out of place to urge that this break is of too minor a sort to be successfully used as an argument for drawing the line between two geologic systems at its horizon. The immature stage of erosion represented by the channels and the fact that the Berea base rests on the same thin underlying formation all across the State seem to us cogent arguments against the break being other than a most trifling one.

FIGURE 1. NODULAR PART OF POPO AGIE BEDS

Oolitic, sandy shale without bedding planes

FIGURE 2. CROSS-BEDDED SANDSTONE

The sandstone is supposed to be of Æolian origin
Photograph by Arnold Leonard

RED BEDS OF WESTERN WYOMING

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

VOL. 26, PP. 217-230, PL. 9 JUNE 28, 1915

ORIGIN OF THE RED BEDS OF WESTERN WYOMING[1]

BY E. B. BRANSON

(Presented before the Society December 29, 1914)

CONTENTS

INTRODUCTION

After working on the Red Beds (Chugwater formation) of western Wyoming for four summers, the writer is convinced that some recent investigators are assigning their origin too largely to subaerial forces. He has found proof of such origin in one member about 60 feet in thickness, evidence of æolian origin in another member of about the same thickness, and abundant indications of subaqueous origin for all of the rest.

The writer's investigations were made during the summers of 1904 and 1905, when he worked on the Red Beds from about 20 miles south to

[1] Manuscript received by the Secretary of the Geological Society February 8, 1915.

about 35 miles northwest of Lander and examined the exposures about 15 miles north of Rawlins, and in the summers of 1911 and 1913, when the studies were continued from about 25 miles south of Lander to near Dubois, a distance of about 100 miles; but the investigations on the Red Beds were incidental to other work. In the main the discussion in this paper is confined to the western outcrops.

Historical

Darton says of the Red Beds in Wyoming:

"In the latter part of the Carboniferous time, and probably during the Permian also, there was a widespread emergence, resulting in shallow basins with very wide mud-flats which occupied a large portion of the Rocky Mountain province. In these regions were laid down the last deposits of the Pennsylvanian division and the great mass of red clay and sands constituting the Chugwater formation. These beds probably were deposited by saline water under arid climate conditions and accumulated in a thickness of 1,000 feet or more. The waters were shallow much of the time, and there were wide, bare, wash-slopes and mud-flats, as is indicated by the frequent mud cracks, ripple-marks, and impressions of various kinds on many of the layers throughout the formation." [2]

With this the writer agrees, but in western Wyoming the mud-flats appeared only two or three times.

Schuchert says:[3] "The marine Triassic of California, Oregon, and Nevada early in this period extended into Idaho and as continental deposits continued thence into eastern Wyoming." Referring to the Wyoming Triassic, he says: "Farther to the east all the Triassic appears to be devoid of marine strata." Schuchert's maps in his Paleogeography of North America show all of the Wyoming Triassic as of continental origin, but in continuous connection with the marine formations of Idaho, Nevada, and California.

Description of Red Beds of western Wyoming

For about 60 miles along the eastern slope of the Wind River Mountains the outcrops of the Red Beds are almost continuous and the beds reappear in a small anticline 10 to 15 miles east of the main outcrops, though they are never exposed to the bottom in the anticline. Darton's map[4] shows their distribution in a general way.

The Red Beds on the Little Popo Agie River, 15 miles south of Lander,

[2] Bull. Geol. Soc. Am., vol. 19, 1908, pp. 465-466.
[3] Bull. Geol. Soc. Am., vol. 20, p. 579, pls. 86 and 87.
[4] Bull. Geol. Soc. Am., vol. 19, pl. 22.

are 1,421 feet thick, according to Woodruff,[5] and just south of the Big Popo Agie River stadia measurements by the writer and his party showed 1,452 feet. No complete measurements were made in other places, but the thickness seems to run about the same in the entire region studied.

The contact with the overlying formation, which in this region is the Sundance, is usually covered; but on the west side of Table Mountain, 7 miles south of Lander, the exposure is good in a small valley. The contact is one of disconformity, as evidenced by the weathered surface of the Red Beds on which the sandstone of the Sundance was deposited. The same phenomenon appears in the anticline near the Dallas oil wells, but no other evidence was found at any place.

The contact with the underlying formation is rarely seen, but on Bull Lake Creek, 40 miles northwest of Lander, the exposure is excellent. The beds at the bottom are of red shale, containing much pyrite; the change to the underlying Embar is merely change of color from red to green, and sedimentation appears to have been continuous from the older formation into the younger. Near Ed Young's house, on the Little Popo Agie River, 16 miles south of Lander, a massive conglomerate up to 20 feet in thickness occurs at the contact in at least two places. In neither place was the red rock found immediately overlying the conglomerate, but the situation was such as to leave no doubt concerning the relationships of the conglomerate, and evidently a slight disconformity occurs between the Embar and the Red Beds.

The lower 800 feet of the Red Beds in the region near Lander is largely dark red, shaly sandstone, extensively ripple-marked and becoming more and more calcareous toward the top. Some of the beds stand out as though made of thick-bedded sandstone, uniform in texture, color, and thickness for long distances; but on weathering these appear shaly. At about 800 feet from the bottom the increasing amount of lime in the water terminated with a deposit of from 1 to 6 feet of limestone, which thickens away from the mountains. The limestone was not seen in the region north of Rawlins, though it may have been present; but in the next outcrops, about 25 miles southeast of Lander, it appears and extends northwestward for at least 50 miles. The stone is magnesian, fine grained and compact, and is locally designated as marble. The writer has never found a fossil in it. Woodruff says: "Locally this bed is thin-bedded and irregular, as if deposited from hot springs."[6]

As it has very little pore space and is in the main non-crystalline, it can not be secondary in origin. It shows no sign of being clastic. It is

[5] Bull. 452, U. S. Geol. Surv., p. 15.
[6] Bull. 452, U. S. Geol. Surv., p. 15.

not made up of shells of animals. Woodruff's theory could apply for only very small areas, where the beds are irregular in thickness. All evidences seem to indicate an origin from chemical precipitation, and the absence of fossils is not peculiar with the waters so highly charged with mineral matter.

Red sandstone continues for 80 to 90 feet above the limestone and is then succeeded by a heterogeneous member called by Williston[7] the Popo Agie beds. As the lower contact is always covered, the exact thickness of these beds has not been determined, but seems to vary from less than 20 feet to more than 60 feet. For the most part the member consists of sandy shales and mudstones. At the top a mudstone that shows no sign of bedding ranges up to 15 feet in thickness and consists of nodules of purplish, argillaceous sandstone. The mud seems to have been cracked by the sun and the cracks filled in by wind-blown or flood-washed materials and the bedding destroyed, as described by Barrell.[8] Much of the formation contains rounded white spherules, usually about 0.6 millimeter in diameter, that appear like grains of oolite and that have concentric structure.

In color the Popo Agie beds are usually red to yellow, but range through various shades of green, brown, purple, and orange, with occasionally white beds and now and then carbonaceous bands. Not infrequently included fossil bones are black, owing to carbonization.

Here and there a conglomerate, varying in composition from pebbles of various kinds of rocks to pieces of bone and teeth of reptiles and amphibians, occurs among the other rocks, and this thickens and thins remarkably in short distances. Beds of sandstone or shale 20 feet thick may give way to something entirely different within a few feet. The colors change abruptly and in a way that gives striking effects. The top was eroded before the deposition of the overlying formation, giving rise to a slight unconformity, that may be observed at most places where the contact is well exposed.

Fragments of bone and teeth are common near the upper part of the member, but articulated bones are extremely rare. Nearly all of the bones have been worn by being washed about, but the writer and his party found one nearly complete crocodile skeleton and two or three others more or less complete, and Mr. N. H. Brown collected two almost complete amphibian skulls. These remains showed no signs of having been transported and were probably fossilized where the animals died.

Plant remains are common and most of them consist of lanceolate

---

[7] Jour. Geol., vol. 12, 1904, p. 688.

[8] Bull. Geol. Soc. Am., vol. 23, 1912, p. 426.

leaves, though some trunks up to 4 or 5 inches in diameter occur. Fresh-water pelecypod shells occur in a few places.

Above the Popo Agie beds there is about 20 feet of reddish, thin-bedded, much ripple-marked sandstone that is uniform in thickness and color over large areas. One peculiarity of this member is uniformity of jointing, running almost at right angles, vertical, and usually 2 to 4 feet apart. With the weathering away of the softer beds beneath these beds are left standing with vertical faces, which are determined by the joint planes. The joints are shown at the left in figure 1, where they appear in striking contrast with the irregular jointing of the nodular beds below.

Sandstones succeed for about 180 feet, but are interrupted four or five times by beds of chocolate-colored sandy shale, 6 inches to 4 feet in thickness, that maintain the same thickness for long distances and are regular in texture and color.

These sandstones are followed by some 50 feet of a very strikingly cross-bedded sandstone of lighter red color than the other sandstones. The bedding is of a type that originates from wind action,[9] which the figures of plate 9 show better than it can be described. The false beds dip in various directions, differing from the type developed by stream work, in which the false beds dip rather uniformly in one direction.[10] This sandstone decreases in thickness to the east and may entirely disappear within a few miles, though some of it appears in the small anticlines some 10 miles east of the outcrops along the mountains. It was probably subaerial in origin; but if so, waters soon overspread the region again and thick beds of gypsum were deposited not far above it. The gypsum is almost pure from top to bottom, though the beds may thin rapidly from 40 feet to 0.

If the cross-bedded sandstone is wind-blown, as according to my interpretation, there is only slight change in color to separate marine from non-marine. But great change in color is scarcely to be expected. If the climate is arid, oxidation has no large effect on the wind-blown sand, and the seas covering thin beds of such sand place them under almost exactly the same chemical conditions as though they had been deposited under the sea. If the coloring matter is due to some impurity deposited with the sands, the wind-blown sand is likely to be less highly colored, as it will have a smaller amount of such impurities than the subaqueous deposits. The cross-bedded sandstone of the Red Beds is lighter colored than the other sandstone.

---

[9] Bull. Geol. Soc. Am., vol. 24, pp. 403 and 404.

[10] J. Barrell: Criteria for the recognition of ancient delta deposits. Bull. Geol. Soc. Am., vol. 23, p. 452.

Almost all the Red Bed sandstones are ripple-marked on plane surfaces and the beds are uniform in thickness and texture for long distances. Beds that occur 15 miles south of Lander may be traced along the outcrops almost continuously to Bull Lake Creek, a distance of some 60 miles, with slight variations in thickness and texture—variations so small that only detailed measurements could detect them if they are present. This is true for all the beds noted by the writer excepting the gypsum, Popo Agie beds, cross-bedded sandstone, and the limestone. Such regularity is found only in deposits made in bodies of standing water. Barrell says: "It appears, therefore, that typical water-made ripple-marks associated with regularity of bedding in sandstones is especially associated with the subaqueous plain of deltas and the bottoms of shallow seas." [11]

The cross-bedded sandstone is succeeded by red sandstone, and gypsum beds occur only a few feet above it. In the Lander region the gypsum ranges from a few inches to 40 feet, but maintains a thickness of a few feet for long distances along the outcrop. The thick deposits are limited in extent, rarely running for more than a mile, and seem to be fillings of depressions in the main basin floor when the deposition took place. The gypsum is remarkably pure and deposits 10 feet in thickness contain only a few thin partings.

It is the writer's opinion that the gypsum beds are strong evidence of the subaqueous origin of the Red Beds, but Mr. Schuchert maps the Red Beds as subaerial in his paleogeographic maps, and an eminent stratigrapher wrote me, after reading the first draught of this paper: "Note the extreme variability of your gypsum deposits. Translate this into topography and you get a series of pools. . . . I would rather you test out the idea that these are fresh-water deposits under an arid climate such as the Triassic was in this region."

It seemed worth while to give this hypothesis a quantitative test and the results are outlined below.

Conditions of the upper Red Bed Gypsum Deposits

1. The gypsum outcrops in places over an area of at least 20,000 square miles.

2. Probably half of the 20,000 square miles is underlain by gypsum averaging 1 foot thick and one-tenth of the area by beds 10 feet thick or more.

3. It thickens and thins remarkably in short distances, ranging from a few inches to 40 feet.

[11] Bull. Geol. Soc. Am., vol. 23, p. 429.

4. The beds are often discontinuous.

5. The beds occur at many horizons, but in western Wyoming are mainly near the top, and some are near the top in most of the areas of outcrop.

6. The gypsum is remarkably pure and salt has never been reported in association with it.

Hypothesis for Origin of Gypsum Deposits

STATEMENT OF THE HYPOTHESIS

The gypsum deposits of the upper Red Beds originated from concentration of fresh water under arid climatic conditions.

In order to test this, the topography of the area, drainage conditions, content of stream waters, and rate of evaporation were studied.

TOPOGRAPHY OF DRAINAGE AREA SUPPLYING WATER FOR THE DEPOSITS

The topography of the region surrounding the Red Beds basin in which the gypsum was deposited is conjectural, but the topography of the area of the basin itself may be postulated with tolerable certainty. No unconformity that is detectable has been seen in the upper beds, and if the red sandstone was exposed for many thousands of years, it must have been very low and flat to avoid leaving traces of erosion. The Red Beds occur over most of eastern Wyoming, with an area of some 40,000 square miles, and the sand-covered plain must have been of about that extent. The source of the red sands is uncertain, but the uniformity in thickness and continuity of the Red Beds indicates that the places investigated are not near the margin of the area of sedimentation, and thinning to the eastward indicates that the highlands were to the west.

RELATION OF RUN-OFF TO PRECIPITATION

Streams with low gradients flowing through arid regions are likely to carry only a small amount of the rainfall of their drainage basins. At Uva, Wyoming, the run-off carried by the Laramie River is usually less than 10 per cent of the rainfall of its basin, with an area of 3,179 square miles.[12] In 1896, 1897, and 1898 the run-off of the Arkansas River at Hutchinson, Kansas, with a fall of 5.6 feet per mile, was less than .3 of 1 per cent of the rainfall of its basin; at Cañon City, Colorado, 124 miles from the head of the Arkansas, and above which the fall ranges from 20 to 63 feet per mile, the run-off is 20 to 30 per cent of the rainfall; at Granite, Colorado, 24 miles from the head of the Arkansas, and

[12] Twentieth Annual Report of U. S. Geological Survey, vol. iv, p. 54.

above which the fall is 55 to 63 feet per mile, the run-off measured in 1897 was 70 per cent of the rainfall.[13] Relations of like character hold for nearly every river that leaves the mountains and flows across the more arid plains. A run-off of 30 to 70 per cent is to be expected of streams emerging from mountain regions and of 1 to 20 per cent for streams that have run for some distance through arid plains.[14]

MATERIALS IN SOLUTION IN RIVER WATERS

When waters from the upper reaches of rivers are analyzed they generally have only a small amount of mineral matter in solution and show more and more concentration as arid plains are crossed and the water taken by evaporation is replaced from underground sources, but salinity may decrease or increase if the stream continues to flow through arid plains.

The Arkansas River has a salinity of 148 parts per million at Cañon City, Colorado, where the run-off is 20 to 30 per cent: 2,134 parts per million at Rocky Ford, Colorado, and an average of 630 parts per million at Little Rock, Arkansas.[15]

In streams flowing over sedimentary rocks in arid regions the sulphates frequently become more abundant than the carbonates. Clarke says:[16] "In arid regions sulphates and chlorides prevail." But on an average the sulphates are only slightly in excess of the carbonates.

The region postulated consisted of horizontal sandstone, probably poorly consolidated, with an area of some 40,000 square miles and with slight relief. No stream analyses from such a region are available, but it is probable that stream data from the leveler parts of Wyoming, where the rocks are sedimentary, will answer as well as any to be found.

Slosson[17] gives six analyses of waters from the Popo Agie River, Laramie River, and Little Goose Creek, streams that occur in the region under discussion and are typical of it. The Popo Agie analysis is of waters emerging from the mountains into the plains and the Laramie and Goose Creek analyses are of waters that have run for some distance through arid plains.

In stating the analyses in hypothetical combinations, Slosson gives calcium sulphate in the Laramie River only, and three out of five analyses from it show none. Recalculation of three of Slosson's analyses of waters

---

[13] Ibid., pp. 56-57.

[14] Water Supply Paper 306 of the U. S. Geological Survey contains maps, plates 1 and 2, showing relationship of run-off to precipitation.

[15] Clarke: Bull. U. S. Geol. Surv., 491, p. 76.

[16] Ibid., p. 81.

[17] Wyoming Experiment Station, Bull. 24.

of the Laramie, using all of the SO_4 in $CaSO_4$, gives 33.8 parts $CaSO_4$ per million. Recalculation of an analysis of water taken 70 miles below that given above and "more or less contaminated by seepage from the canals," using all of the Ca and 36/37 of the SO_4, gives $CaSO_4$ about 220 parts per million.[18] Recalculation of the Popo Agie analyses, using all of the SO_4 in $CaSO_4$, gives 8.67 parts per million.[19] Recalculation of the mean of 29 composites of the North Platte, at North Platte,[20] Nebraska, using all of the SO_4 in $CaSO_4$, gives a calcium sulphate content of about 198 per million.[21] (The North Platte analyses are used because the river flows almost entirely on sedimentary beds across Wyoming and Nebraska.)

All of these waters are high in calcium carbonate, and in only one analysis is there more than enough calcium to unite with the CO_3, but in most cases this union takes place early in the process of concentration and limestone is precipitated. Most of the sulphuric ions would probably unite with sodium and magnesium, as they have done in the precipitates formed in the alkaline lakes of Wyoming, where sodium sulphate and magnesium sulphate make up most of the deposits and calcium sulphate is present in small amounts.[22] The calculated amount of $CaSo_4$ is then much too high, as all of the sulphuric ions should not be used with calcium. From the data available it seems that 50 parts of calcium sulphate per million is more than would precipitate from waters that have run some distance, at low grade, through arid regions, and that the amount furnished by streams as they emerge from regions of high relief would be less than 10 parts per million.

Analyses of six streams tributary to Great Salt Lake show an average calcium sulphate content of 120 parts per million, if all of the sulphuric ions are used with calcium; but in all but one of these analyses there is not enough calcium to combine with all of the CO_3 ions. All of the calcium has been precipitated from the lake, much of it as calcium carbonate. As with the Wyoming rivers, it seems probable that 50 parts per million calcium sulphate in the water is more than would be precipitated on evaporation.

ASSUMPTIONS MADE IN WORKING OUT HYPOTHESIS

Assumptions for origin of 1-foot bed of gypsum over 10,000 square miles, but with the deposition in many, more or less isolated, lakes:

[18] Run off about 10 per cent.
[19] The run off probably 50 to 70 per cent, but reliable data is not available.
[20] Run-off less than 10 per cent. Data not satisfactory.
[21] Clarke: U. S. Geological Survey, Bull. 491, p. 74.
[22] Wyoming Experiment Station, Bull. 49, pp. 110-121.

1. Lakes must have depths of hundreds of feet to prevent concentration to point of precipitation for salt.

2. Conditions of drainage basin, part 1: (*a*) Relatively flat sandstone area 30,000 square miles in extent; (*b*) rainfall, 10 inches; (*c*) run-off, 10 per cent; (*d*) 50 parts per million calcium sulphate in the run-off waters. Enough calcium sulphate brought in each year to make a layer .000075 inch thick.

3. Conditions of drainage basin, part 2: (*a*) Highlands area of 43,000 square miles; (*b*) rainfall, 15 inches per year; (*c*) run-off, 10 inches per year; (*d*) 10 parts calcium sulphate per million in inflowing waters. Enough calcium sulphate brought in each year to make a layer .000224 of an inch thick over the receiving basin.

Total calcium sulphate brought in each year about .0003 of an inch, and about 40,000 years required to bring in 1 foot. Evaporation required over the receiving basin, 58 inches per year.

Assumptions for 10-foot gypsum deposits over 2,000 square miles:

1. Basins must have a depth of hundreds of feet to prevent dry seasons from bringing water to point of saturation for salt.

2. Conditions for drainage basin, part 1: (*a*) Relatively flat sandstone area 38,000 square miles in extent; (*b*) rainfall, 10 inches per year; (*c*) run-off, 10 per cent; (*d*) 50 parts calcium sulphate brought in each year to make a deposit .000475 inch thick over the 2,000 square mile basin.

3. Conditions for drainage basin, part 2: (*a*) Highlands of 43,000 square miles; (*b*) rainfall, 15 inches; (*c*) run-off, 10 per cent; (*d*) 50 parts per million calcium sulphate. (A lower run-off and higher calcium sulphate content assumed because the mountain streams now flow for some distance over the arid plains.)

Enough calcium sulphate brought in each year to make a deposit .0008 inch thick over the 2,000 square mile basin.

Total of .001275 inch of gypsum per year. About 85,000 years required to get 9 feet of gypsum.

Sixty-one inches of water per year over the entire surface of the basins must be evaporated on the above assumptions.

Conditions not explained by the Hypothesis

WHAT BECAME OF THE CALCIUM CARBONATE?

As previously stated, the carbonates are nearly as abundant in the stream waters as the sulphates. Calcium carbonate would be in practically the same amount as calcium sulphate, and if the concentration took place from fresh water in inclosed basins, limestone of practically the same thickness as the gypsum should be present with the gypsum. But limestone is rarely associated with the gypsum and is never interbedded with it, as would necessarily be the case unless the gypsum and lime were deposited together and the resulting rock were a mixture.

In the waters of Great Salt Lake, Sevier Lake, and other lakes of high concentration little or no calcium and CO_3 are present. Clarke says that "all of the waters tributary to Great Salt Lake, so far as they have been examined, contain notable quantities of carbonates, which are absent from the lake itself. These salts have evidently been precipitated from solution, and evidence of this process is found in beds of oolitic sand, composed mainly of calcium carbonate, which exist at various points along the lake shore."[23]

Lake Lahontan, with waters of a silinity one-fifth to one-tenth as high as the Great Salt Lake, has already had most of the lime salt thrown down as tufa, while the SO_4 content remains high. Lake Lahontan represents concentration of fresh waters, but as its drainage basin is largely composed of igneous rocks, the sulphates would probably be lower than in the fresh-water pools postulated.

WHAT BECAME OF THE SODIUM CHLORIDE AND OTHER SALTS?

Deposits of salt are not mentioned in connection with the upper Red Beds, but it is frequently equal in amount to gypsum in streams in arid regions and probably averages one-half to one-fourth as abundant. As no salt beds occur, the solutions must have remained considerably above saturation, and 50 to 100 feet of water must have been left in each pool to contain the salt; but it seems almost certain that some pools would have dried up and the more soluble salts have been precipitated. Some salt may have been deposited and redissolved, but there are no evidences of this in the rocks, and waters from wells penetrating the beds do not carry unusual quantities of salt. If some of the pools had dried up, a series of alternating beds of various salts would have been formed; but such deposits are never found in the Red Beds. The waters could not escape from the region without reuniting, and if they reunited and were drained by land warping, a large part of the region must have been submerged and subaqueous deposits must have been formed over the gypsum.

[23] U. S. Geol. Surv. Bull. 191, p. 146.

Sodium sulphate and magnesium are not associated with the gypsum, but are very abundant in most waters of arid regions, and the concentration could not have reached the place where they would be deposited.

TIME, EROSION, AND PURITY

The time necessary for the deposits from fresh water seems prohibitive when it is considered that there is no sign of erosion laterally from the gypsum beds before the next beds were laid down. More or less unconsolidated sand would erode rapidly and it seems necessary that the erosion time be short. The purity of the beds seems to preclude great length of time. Some sediments must have been brought in by streams, and the winds would have brought in large amounts, but these thick beds of gypsum are in most cases relatively pure from bottom to top.

General Conclusion

It is practically impossible for thick beds of pure gypsum to form from fresh water under arid climate conditions.

Summary

The following evidences are presented as indicating marine origin for most of the Red Beds of western Wyoming and the presence of the gypsum as pointing to marine origin for the upper Red Beds of most of Wyoming:

1. Uniformity in thickness of beds over wide areas.

2. Uniformity in texture of rocks over wide areas.

3. Ripple-marking on horizontal beds through most of the formation.

4. Chemical precipitate of limestone at the 800-foot level.

5. Chemical precipitate of gypsum near the top over wide areas and at various levels in many places.

6. Absence of sun cracks and fossils of land animals excepting in the Popo Agie beds.

7. Presence of undoubted subaerial evidences in the Popo Agie beds, with textures and materials like much of the rest of the Red Beds.

Succession of Events

1. The Red Beds began under marine conditions and the sea gradually became more and more charged with calcium carbonate and magnesium carbonate until a dolomitic limestone was precipitated.

2. Above the limestone the sea gradually filled with sand until the sediments were exposed and the Popo Agie beds were formed under subaerial conditions.

3. The sea in Upper Triassic time readvanced and some 200 feet of sandstone and shales filled the western margin.

4. Subaerial deposition, mainly of wind-blown sand, succeeded and lasted while beds varying from a few feet to 60 feet in thickness were deposited.

5. The sea readvanced, but concentration of calcium sulphate had been in progress for a long time and soon resulted in wide-spread deposits of gypsum.

6. Usually some sandstone and some thin layers of limestone were deposited above the gypsum before the withdrawal of the sea at the close of the period.

Age of the Red Beds

The age of the upper Red Beds in western Wyoming deserves passing notice, though Williston[24] has recently stated the evidence. The writer and his parties have never found a fossil in the formation outside of the Popo Agie beds. From these beds Williston[25] has described four genera of reptiles, one closely related to Keuper forms of Europe and the others to South African forms. The writer has described[26] two species of amphibians similar to Keuper forms of Europe, and Mehl has described[27] a phytosaur similar to those of the Keuper of Europe and Newark of North America. To any one familiar with Triassic reptiles and amphibians the evidence of the Upper Triassic age of the Popo Agie beds is conclusive.

Below the Popo Agie beds no evidence of a break in the continuity has been seen by the writer and it is possible that the sedimentation was continuous through Upper Permian and Lower Triassic. As mentioned

[24] Jour. Geol., vol. 17, p. 396.
[25] Jour. Geol., vol. 12, pp. 688-696.
[26] Jour. Geol., vol. 13, pp. 569-589.
[27] Jour. Geol., vol. 21, pp. 186-191

before, the contact of the Popo Agie beds with the underlying sandstones is always covered and a disconformity may exist at that place. It is possible that the Red Beds below are Permian, and that the Upper Triassic rests disconformably upon them. The Red Beds above the Popo Agie beds are surely Triassic in age for some thickness, and probably to the top, though there is no positive evidence that the upper part is not Jurassic. The marine Upper Jurassic lies unconformably on the Red Beds.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP 231-242 JUNE 28, 1915

ORIGIN OF THICK GYPSUM AND SALT DEPOSITS[1]

BY E. B. BRANSON

(Read before the Society December 30, 1914)

CONTENTS

INTRODUCTION

The origin of thick deposits of gypsum without associated deposits of salt and of deposits of salt of great thickness are still open questions and no published hypothesis seems adequate to explain them. This was brought forcibly to the writer's attention by a study of the gypsum deposits of the Red Beds of Wyoming, some of which are more than 10 feet thick, and the modified bar hypothesis outlined below was gradually evolved. As the various theories have been fully explained in many places,[2] it is not necessary to restate them; but a consideration of the more important phenomena that they do not explain seems worth while.

PHENOMENA NOT EXPLAINED BY PUBLISHED HYPOTHESES

The main difficulties in explaining the origin of thick gypsum deposits are: 1. In accounting for the volume of water required to contain the calcium sulphate in solution, necessitating a depth of basin in excess of any known continental depression; 2. In explaining the rarity of other

[1] Manuscript received by the Secretary of the Society February 8, 1915.

[2] See particularly A. W. Grabau: Principles of stratigraphy, pp. 347-380.

salts in the deposits; 3. In accounting for the absence of salt deposits above the gypsum: 4. In explaining the absence of sedimentary impurities; and 5. In accounting for the absence of fossils. The difficulties in explaining thick deposits of almost pure salt are: 1. Prohibitive depth of water required to contain the salt in solution: 2. Lack of alternation of salt and gypsum in many thick deposits: 3. Thick salt deposits without gypsum below: 4. Absence of fossils in the deposits.

Some Conditions for Salt and Gypsum Deposition

Sea-water contains 1.7488 parts per thousand calcium sulphate in solution, but as salt begins to precipitate rapidly soon after 1.4 parts of gypsum have been deposited, only about 1.4 parts per thousand is available for deposition in pure gypsum beds. Usiglios' experiments[3] show gypsum beginning to deposit from sea-water after .81 of the volume has been removed by evaporation and sodium chloride beginning to precipitate after .905 has been removed in that way. The total amount of gypsum precipitated in the evaporation from .19 original volume to .095 original volume is 1.466 parts per thousand. As gypsum contains 18 parts water for every 127 parts calcium sulphate and its specific gravity is slightly above 2.3, the volume of gypsum precipitated would be about as 1 to 2 compared to the weight of calcium sulphate in solution. From 1,000 feet of normal sea-water about .7 feet of gypsum would be precipitated before the point of saturation for sodium chloride would be reached, and it would require a depth of 57,000 feet of water for 40 feet of gypsum. Thick deposits would probably result from the drying up of extensive interior seas, and with the drying up the waters would occupy smaller and smaller areas and become more and more concentrated. Gypsum would not begin to precipitate until four-fifths of the water had been evaporated, and the depth of water to contain 40 feet would need to be only about 11,500 feet; but this is still much greater than the depth of any continental depressions.

The bar theory of Ochsenius helps this out to some extent, for if a new supply of sea-water were brought in over a bar as fast as evaporation took place, not all of the water would need to be in the basin at the same time, and the minimum depth of the basin would be regulated finally by the water required to keep the sodium chloride in solution. As sodium chloride begins to deposit when sea-water has been reduced by evaporation to .095 its original volume, the evaporation of the 57,000 feet must

[3] Stated in several recent English works. See U. S. Geol. Surv. Bull. 491, Clarke: The data of geochemistry, p. 208, and Grabau: Principles of stratigraphy, p. 349.

not reach that stage, or there will be salt deposits above the gypsum. Therefore the water will have to have a depth of more than 5,400 feet when the last gypsum is deposited.

Beds of gypsum 40 to 50 feet thick occur in many places, but seem to be very limited in extent, and they often grade laterally into deposits of wide extent, 10 feet or less in thickness. The literature on gypsum places little emphasis on the small extent of the thick deposits, but a careful study of the sections given in various publications indicates the patchiness. The thick Red Bed gypsum deposits of Wyoming are rarely more than 1 square mile in extent and occupy a small area compared to the total. A rough estimate would be 100 square miles of 40 to 50 foot gypsum and about 2,000 square miles of 10-foot. If 11½ feet were deposited over the entire area, the thicker beds could originate by currents shifting gypsum along the bottom and filling up the deeper depressions. All of the thick deposits noted by the writer in the Red Beds were related to the thinner deposits, as indicated in figures 1 and 2, and this is conclusive proof that the waters were not much deeper above the thick deposits than above the thin. The extra depth of water required for 40-foot beds over that for 10-foot beds is about 9,000 feet, if the precipitation is from water five times as concentrated as normal sea-water, and it follows that if the extra thickness was from direct precipitation the beds should be depressed some 9,000 feet below the 10-foot beds. Deposits 10 feet thicker than the surrounding beds would require an extra depth of water of about 3,000 feet. These relations are shown to scale in figures 1 to 4.

If the 10-foot beds were deposited and the waters then gathered in smaller pools, the gypsum might be redissolved and carried in by streams. Streams flowing over gypsum beds carry more calcium sulphate in solution than ordinary streams, but do not carry enough to add rapidly to the inclosed waters. In Clarke's "Data of Geochemistry" the highest calcium sulphate content given for any stream water is about 1 part to 1,000 by weight (using all of the Ca in the water in forming $CaSO_4$) for the Santa Maria River, 25 miles above Santa Maria, California.[4] If such water came in fast enough to balance 5 feet of evaporation per year, 1 foot of gypsum would be supplied every 400 years; but calcium sulphate makes up only about .1 of the material in solution in this water, and a larger volume of other salts would probably be deposited than of gypsum. The sediments carried in by the streams would probably amount to several times as much as the materials carried in solution and the gypsum would make up only a small part of the total deposit. In this connection

[4] Data of geochemistry, Bull. 491, U. S. Geol. Surv., p. 79.

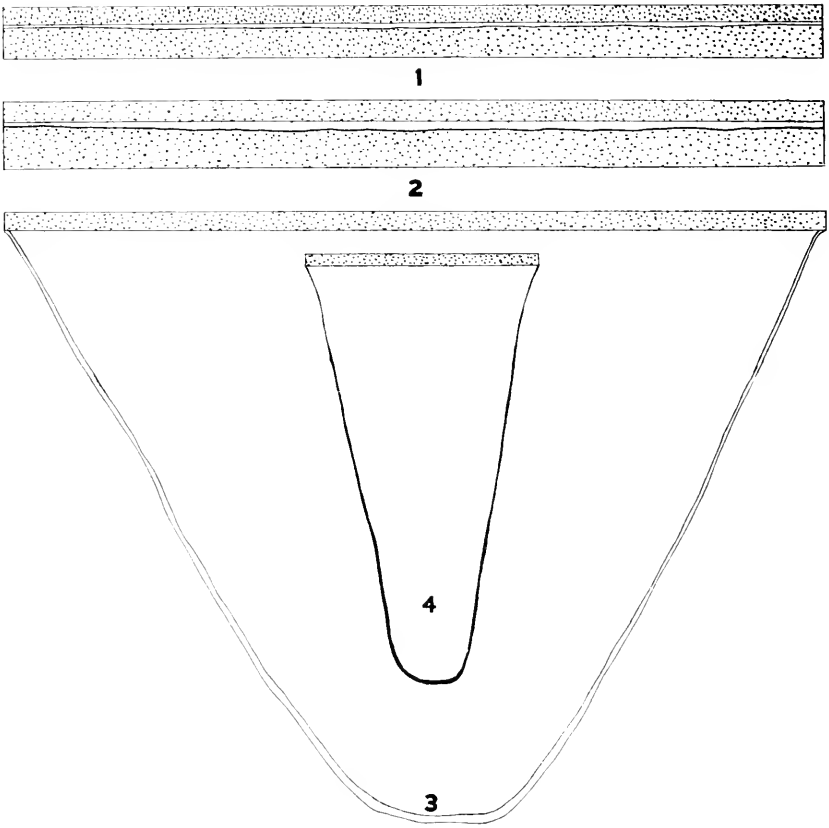


FIGURE 1.—*Idealized Section of Gypsum Beds*

To show relation of 20-foot beds of gypsum to 10-foot beds as they occur near Lander, Wyoming. Scale, 1 inch to 1,200 feet. Gypsum bed between the black lines bounding the stippled areas.

FIGURE 2.—*Idealized Section of Gypsum Beds*

To show relation of 10-foot beds of gypsum to 15-foot beds as they occur near Lander, Wyoming. Scale, 1 inch to 1,200 feet. Gypsum bed between the black lines bounding the stippled areas.

FIGURE 3.—*Idealized Section of Gypsum Beds drawn to Scale*

To show relation of 20-foot beds of gypsum to 10-foot beds if the deposits originate from direct precipitation from waters five times as concentrated as normal sea-water. Scale, 1 inch to 1,200 feet. The receiving basin would have slopes of 50° or greater. Gypsum bed between the lower lines. The 20-foot bed is at 3, about 3,000 feet below the 10-foot bed, into which it grades at the upper corners of the diagram.

FIGURE 4.—*Idealized Section of Gypsum Beds drawn to Scale*

To show relation of 40-foot beds of gypsum to 10-foot beds if the deposits originate from direct precipitation from waters five times as concentrated as normal sea-water. Scale, 1 inch to 5,000 feet. Gypsum represented by the heavy black line.

The diagrams illustrate the impossibility of thick deposits, in continuous beds with thin deposits, originating from direct precipitation without lateral shifting of the gypsum along the bottom. In diagrams 3 and 4 the space between the stippled, horizontal bed and the gypsum bed represents sandstone.

it should be borne in mind that the thick deposits are only a few square miles in extent in any basin, and that the waters would necessarily remain deep enough to keep all sodium chloride and more soluble salts of the original ocean water in solution.

With a number of deeper pools in which the thick gypsum deposits are made it seems highly improbable that none of them would evaporate to the stage where sodium chloride and the more soluble salts would be deposited. Perfect balance between inflow and evaporation would be hard to maintain in a considerable number of unconnected pools, and probably some of them would have no inflowing streams and would dry up very rapidly. But the Wyoming deposits seem never to be associated with salt beds.

A 40-foot bed of gypsum, resulting from the evaporation of 57,000 feet of normal sea-water, should have nearly 3 feet of limestone below it if the evaporation all took place in a restricted basin; but if the waters were wide-spread in the beginning, about half of the limestone might be deposited over the wider area, as more than half of the $CaCO_3$ precipitates when the volume of sea-water is reduced about 50 per cent, and the limestone below the gypsum might be less than 2 feet in thickness. The writer has not seen limestone immediately below the gypsum at any place in the Red Beds.

Grabau discusses[5] the abundance of animals that are brought into inclosed basins that have partial connection with bodies of water that supply as fast as evaporation depletes their waters, and concludes that gypsum and salt deposits, formed where normal sea-waters supply, across a bar, the waters taken by evaporation, should be highly fossiliferous. Thick gypsum and salt deposits are usually non-fossiliferous.

Grabau[6] emphasizes the agency of streams and winds in carrying efflorescent gypsum to interior basins, but it is evident that such deposits, if they are extensive, can not be pure, as the streams and winds would carry silt, sand, and other minerals with the gypsum. The gypsum of the Wyoming Red Beds is remarkably free from sediments and other minerals, and though the entire region surrounding must have been of red sands and clays, the gypsum beds are white and pure.

Modified Bar Hypothesis

A modified bar theory seems to explain the phenomena of thick gypsum and salt deposits, and the modification consists of supplying the receiving

[5] Principles of stratigraphy, p. 366.
[6] Principles of stratigraphy, p. 367.

basins with highly concentrated waters instead of normal sea-water. In the drying up of a large interior sea the waters might come to lie in separate basins if the bottom were uneven. Evaporation over the full expanse of the interior sea might be rapid enough to decrease the depth and area in spite of the inflow of some stream, but when considerable areas of bottom had become exposed the total evaporation would have become less and the inflow nearer to the amount of evaporation. Assuming that isolated basins would be formed, separated by low barriers, and that the main streams would empty into the marginal basins, the inflow might be sufficient to cause these basins to overflow and supply the inner basins, that had no direct stream connections, with highly charged waters as fast as their own waters evaporated. As beds of gypsum 10 feet in thickness are wide-spread, a depth of water great enough to contain the salt of sea-water evaporated to deposit them must be assumed, and the evaporation must not be carried beyond nine-tenths of the original amount if the salt is to remain in solution. The depth of a basin for 10 feet of gypsum would have to be at least 1,400 feet and possibly 1,500.

The concentration might have reached one-fifth the original volume of sea-water when the isolated seas were formed, and the waters containing .3 per cent of calcium sulphate would bring 1 foot of gypsum for every 333 feet of water. If the excess evaporation from the inner pools were 5 feet per year, a foot of gypsum would be brought in every 67 years. With the overflow of the outer basins the salinity would decrease and the amount of gypsum brought in would become progressively smaller; but, correcting for this, 5 feet of calcium sulphate would be brought in in less than 400 years. The waters of the basin 1,500 feet deep would contain about 5 feet of gypsum before the other waters came in, and 10 feet in thickness is thus accounted for. With this rapid deposition and freedom from stream inflow the deposits would be less likely to contain impurities of a sedimentary nature than with slower deposition and inflow from streams.

In the waters of the Caspian Sea calcium sulphate is as about 1 to 8 compared to salt, while in ocean water it is about as 1 to 17. The evaporation of water of this salinity would give gypsum deposits twice as thick as postulated.

The writer has not been able to find data on the rate and completeness of mixing of inflowing fresh waters with the saline waters already in the basins. The surface waters of the Caspian are relatively fresh near the mouths of the large inflowing rivers, but the salinity seems to be almost uniform from top to bottom at no great distance from the rivers. The fresh waters would probably flow over the top of the highly charged waters if the receiving basins were very small, but they would probably mix thoroughly with the saline waters in large basins, and the waters furnished to the secondary basins would be of the nature postulated.

In discussions of the bar theory of Ochsenius the backflow from the isolated basin has often been emphasized, but the backflow would be important only where evaporation did not keep pace with inflow. According to the postulates of this paper, evaporation kept pace with inflow and the depth of water on the bar was too shallow to allow backflow.

If connected with the open sea, across a bar, animals would come in with the inflowing water, and, perishing on account of the salinity of the waters in the basin of deposition, would make the deposits abundantly fossiliferous; but with the high concentration postulated under the hypothesis outlined above life would have ceased to exist in the supplying basins before the gypsum deposits began and no fossils would be present.

With the conditions postulated, gypsum deposition might automatically stop. The filling up of the outer basin with sediments would cause more water to flow over to the inner basin, and this fresher water might entirely stop the gypsum deposition by causing the inner basin to overflow and would prevent any salt being deposited.

Origin of thick Salt Deposits

The conditions outlined above are much more favorable for thick salt deposits than for gypsum. Suppose a sea with a depth of 1,500 feet were ten times as concentrated as sea-water and had lost most of its gypsum as explained above.

The water left above the gypsum would contain about 15 feet of salt per 100 feet, and if this were evaporated to about one-fourth its volume, or .023 the original volume of normal sea-water, about 12½ feet of salt would be deposited for every 100 feet of water, or a total of 175 feet for 1,500 feet. With this would be associated about 2½ per cent of impurities, consisting of $CaSO_4$, $MgSo_4$, $MgCl_2$, and NaBr. With 5 feet excess evaporation per year, the deposit of 175 feet of salt would be formed in 75 years.

But many times there are no thick deposits of gypsum below the salt and this is easily accounted for. Suppose that the basin is caused to overflow by inflow of fresh water and its waters flow into another depression of one-tenth its area, in which no deposits had previously been formed. If evaporation here keeps pace with inflow after the basin is partially filled, and if excess evaporation is 5 feet per year, 820 feet of salt, with about 2½ per cent impurities, as listed above, will be deposited in 1,500 years, if the basin is deep enough to receive so much.

The loss from the larger basin would be 6 inches per year and, replacing this with fresh water at the rate of 6 inches per year, its concentration would be only three-fourths as great at the end of 1,500 years, and the total amount of salt carried in by the waters would be seven-eighths as much as though the same concentration had been maintained. This correction has been applied to the computation in the preceding paragraph.

The Example of the Caspian Sea

The Caspian Sea and its Gulf of Karaboghaz furnish conditions analogous to those postulated save in the solutions. The area of the Caspian is about 169,000 square miles and of the Gulf of Karaboghaz 7,100 square miles. The gulf is separated from the main sea by a narrow sand-bar pierced by a strait, 1¼ miles long and 115 to 170 yards wide, through which a current flows continuously into the gulf at the rate of 1½ to 5 miles per hour, and there is no compensating outflow. The evaporation from the gulf is 3.2 feet per year.[7]

If the gulf were deep enough to accommodate large amounts of water and the incoming waters from the Caspian had already deposited most of their gypsum, great deposits of salt would be formed.

The Salina Salt

Schuchert's map of the Salina Sea shows it covering an area of a little more than 220,000 square miles and the salt and gypsum deposits extending over about 12,000 square miles. If this sea were 900 feet deep and evaporated to one-third the area and one-third the depth, it would leave about 73,000 square miles of inland lakes with a depth of 300 feet and a concentration nine times as great as in the original sea. For convenience in computation, it is assumed that the concentration was ten times that of the original sea-water. Assume that the drainage from the surrounding region practically all came into 60,000 square miles of the lakes and these overflowed to supply the loss from evaporation of the other 13,000 square miles of lakes. If the rate of evaporation was 5 feet per year, the rainfall over the inland seas 1 foot, the overflow four-fifths of 1 foot, and the run-off over the drainage basin 8 inches, the area of the drainage basin must have been about 360,000 square miles, in addition to the area of the lakes, to supply the necessary water. This is a little less than one-

[7] Encyclopedia Britannica, 1912.

third the area of the Mississippi basin—a little less than the area of Ontario, Michigan, Ohio, Pennsylvania, and New York. The 100 feet of salt might be brought to the settling basins in about 166 years, as explained in an earlier paragraph.

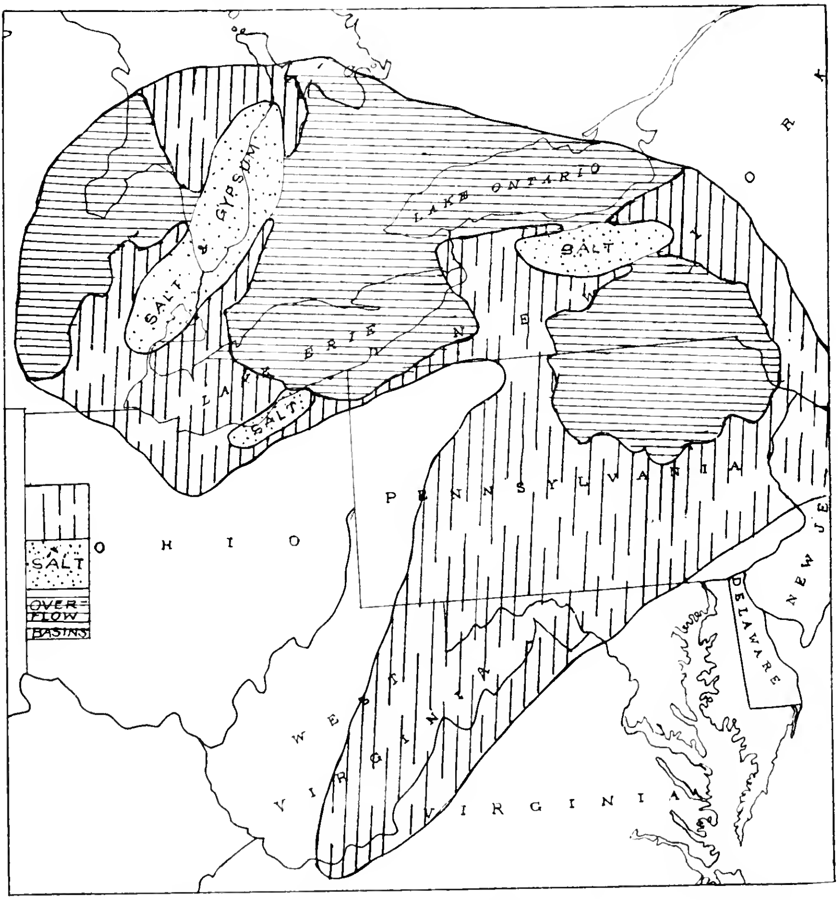


FIGURE 5. *Map showing hypothetical overflow Basins and Basins of Salt and Gypsum Deposition during Salina Time*

The outline and salt and gypsum areas are copied from Schuchert's map of the Salina Sea as given in Bulletin of the Geological Society of America, volume 20, plate 69. The map is presented to illustrate an hypothesis and no claim is made that it shows actual conditions.

Grabau says[8] that a salt bed 100 feet thick and covering 25,000 square miles is probably in excess of the area covered by thick salt beds. If the

[8] Michigan Geological and Biological Survey, Publication 2, p. 236.

salt beds had this extent the basins may have been on a larger scale, but as the beds are not all contemporaneous the basins postulated are probably larger than are required.

The same author states "that for every great salt deposit formed in the neighborhood of the sea by concentration of sea-water, there should be a corresponding fossiliferous series of normal marine type of sediments."[9] For salt and gypsum deposits formed as postulated in this paper this would be true only in part. There would be no fossils in the contemporaneous deposit, as the waters in the supplying basins were too highly concentrated to support abundant life, and as the salts were deposited with great rapidity the clastic deposits would be thin and it would be difficult, if not impossible, to correlate the salt beds with them.

The accompanying map makes no attempt to postulate the areas of the overflow basins, but is presented to illustrate the hypothesis. The outline of the sea and the areas of salt deposits are copied from Schuchert's map of the Salina Sea.

The Gypsum Deposits of the upper Red Beds of Wyoming

In as far as the writer has been able to learn from the literature and from his own observations, the gypsum of the upper Red Beds of Wyoming covers an area of some 10,000 square miles. Over about four-fifths of the area the deposits are thin, probably not averaging over 1 foot in thickness; over some 2,000 square miles they average 9 or 10 feet, and over some 200 square miles the beds are 30 to 50 feet thick in widely scattered patches. The gypsum is remarkably pure and has no salt associated with it. The following is a brief statement of the application of the modified bar hypothesis to these deposits:

1. Original area of isolated sea, 40,000 square miles.

2. The average depth of the water necessary was 1,080 feet, but basins 500 to 800 feet deeper occurred.

3. By the time 80 per cent of the water had been evaporated the area had decreased to 10,000 square miles.

4. The time necessary for this reduction, with 60 inches evaporation, 10 inches of rainfall, and 10 inches of inflow, was 260 years.

5. At the time of 3 it is assumed that the water was in isolated lakes, about four-fifths of it being near the lands to the west and one-fifth to the east, separated by low barriers from the western lakes. The eastern lakes had a depth of at least 1,400 feet.

---

[9] Principles of stratigraphy, p. 366.

6. The western lake had 5 feet of evaporation and 1 foot of overflow per year, and this was supplied by 10 inches of rainfall and 5 feet 2 inches of inflow from the drainage basin.

(NOTE.—With a 15-inch rainfall and 10 inches of run-off, about the same as the headwaters of the Missouri today, the drainage basin would have to be about 50,000 square miles in extent, or half the size of the State of Wyoming.)

7. The 1 foot of outflow per year from 8,000 square miles would supply the inner lakes, with an area of 2,000 square miles, with 4 feet of water per year; the rainfall would supply 10 inches and the water level would remain about constant, with an evaporation of 5 feet per year.

8. The concentration in the lakes was about 1 part gypsum to 300 parts water by volume at the end of 3, and 4 feet of water coming in from the overflowing lakes would add 1 foot of gypsum every 75 years to the inner basins, or 5 feet in 375 years.[10] Correcting this for the decrease in concentration of the outer basin waters, it would take about 500 years to add the 5 feet of gypsum.

9. If the inner basin was 1,500 feet deep, there was enough water in it to supply 5 feet of gypsum. Total of 10 feet of gypsum at the close of 8.

10. Time for 4, 260 years; for 8, 500 years. Total time, 760 years.

11. The thin deposits over 8,000 square miles may have originated by precipitation from shallow concentrated waters soon after 3 and the precipitation have been interrupted by inflow from rivers.

SUMMARY

The main difficulties in explaining thick deposits of gypsum were stated on the first page of this paper.

1. The volume of water for the thicknesses of gypsum greater than 10 feet is not explained by the present hypotheses, excepting by having basins deeper than 1,500 feet or by having a higher proportion of calcium sulphate to sodium chloride; but it is shown that such deposits lie in basins just enough below the surroundings to contain the extra thickness, and that the greater thickness may have resulted from currents shifting the unconsolidated gypsum along the bottom.

---

[10] If the outer lakes were 500 feet deep and there was one foot of overflow per year, their waters would be practically one half as concentrated at the end of 500 years as at the beginning, and the amount of gypsum carried to the inner basins would be three fourths as much in 500 years as if the concentration had remained the same as in the beginning.

2. The evaporation causing the precipitation of gypsum lies between .19 and .095, the original volume of sea-water, and the only other salt precipitated at that stage is $CaCO_3$, which amounts to less than 3 per cent of the whole.

3. The absence of salt is accounted for by the precipitation being interrupted before the salt stage is reached, either by freshening from the inflow from rivers, by increase in rainfall, or by the filling of the outer basins with sediments so that the overflow exceeds that necessary to balance the evaporation from the inner basins.

4. The absence of sedimentary impurities is explained by the rapid accumulation of the deposits and by their having no inflowing streams bearing sediments.

5. The absence of fossils is due to the waters being so highly concentrated that life had ceased to exist in them before gypsum began to be deposited. The percentage of salt in the water when the first precipitation of gypsum occurred was four-fifths that in the waters of the Great Salt Lake at the present time and greater than in the Great Salt Lake when the first analyses were made.

All difficulties mentioned on the second page of this article in explaining thick deposits of almost pure salt are met by the hypothesis:

1. The depth of water is ample, even in relatively shallow basins.

2 and 3. The gypsum was precipitated out before salt deposition began and when the waters occupied much wider areas, and was relatively unimportant below the salt or might be entirely lacking, as explained on page 232.

4. Fossils would be absent in the salt and in the sediments associated with it for the same reasons as with the gypsum.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 243-254 JUNE 28, 1915

LENGTH AND CHARACTER OF THE EARLIEST INTER-GLACIAL PERIOD[1]

BY A. P. COLEMAN

(Read before the Society December 30, 1913)

CONTENTS

INTRODUCTION

The earliest inter-Glacial period known in Canada is that of the Toronto formation, which has been described more than once, and is somewhat well known to Pleistocene geologists. Excavations near Toronto and elsewhere provide fresh information in regard to it from time to time and give emphasis to the conclusions already reached as to its length and the character of its climate, and special studies of the general relationships have been made by the writer in connection with the recent visit to Toronto of the Geological Congress. As there are still some prominent Pleistocene geologists who refuse to admit an inter-Glacial interval of great length and of mild climate, it is proposed to bring together here the latest evidence of the reality and importance of this inter-Glacial period.

At Toronto five well defined[1] sheets of boulder-clay are known, with four sheets of interglacial stratified sand and clay separating them. These interglacial deposits vary from 25 to 185 feet in thickness and doubtless represent very different intervals of time. In two of them fossils have been obtained; but the lowest, and therefore oldest of them

[1] Manuscript received by the Secretary of the Society April 2, 1914

is much the most important in thickness of the deposits and in the great amount of fossil materials which have been obtained from it. The lowest of the four interglacial beds only will be considered here. It is intended to show that the time interval was very much longer than post-Glacial time, and that the removal of the ice was very widespread, including a recession beyond the James Bay slope toward the north. It is probable that the Toronto inter-Glacial period is the same as the Aftonian.

The Toronto formation includes two divisions—a lower one, best shown at the Don Valley brickyard, which may be called the Don stage, and an upper one, best seen at Scarboro Heights, the Scarboro stage. There is no unconformity between the two; but the fossils of the Don indicate a warmer climate than the present, while those of Scarboro suggest a somewhat cooler climate than the present. However, the fossils of the Scarboro beds are not arctic nor subarctic, as might be supposed, but temperate forms. All of the living species represented in the beds are now inhabitants of southern Ontario. Of the larger number of extinct beetles little can be said with certainty as to climate. The change of climate within the time of deposit of the interglacial beds was distinct, but not extreme.

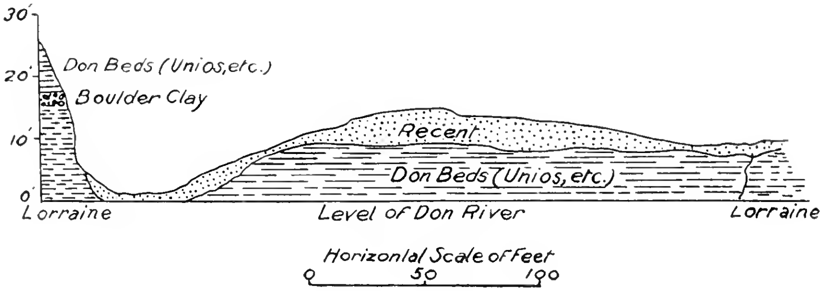
The Don beds will be taken up first.

The Don Beds

The preglacial surface at Toronto had a somewhat high relief and was made up, so far as known, of weathered Lorraine shale, more or less carved into river valleys. The oncoming ice swept off the weathered material, mixing it with solid blocks of shale and limestone, as well as the varieties of Archean rocks which occur to the north. Granites, greenstones, and green schists are common, and also well polished and striated blocks of solid Trenton limestone and smaller fragments of black Utica shale. No rocks of later formations than the Lorraine have been found, so that the ice must have advanced from the east or northeast. If it had come from the northwest or west, one should find fragments of the Red Medina sandstones or shales or of the Clinton or Niagara or Guelph limestones, all easily recognized rocks; but none have been found. There should also be blocks of the jasper conglomerate and the red quartzite of the Huronian region, which likewise have never been found, though the lowest boulder-clay has been carefully studied at more than one point. The first ice-sheet came, therefore, from the Labrador center, 700 miles away, and not from the Keewatin center, 1,400 miles away, as suggested by Professor Wright.

The lowest boulder-clay in most parts of the Don Valley rests on the Lorraine shale, with a thickness of 3 or 4 feet; but at one point, near the bend of the Don, both the boulder-clay and the shale beneath were cut away by a small interglacial river to the depth of 16 feet, over a breadth of 400 feet. The cutting into the shale, with its resistant layers of thin limestone, was as deep as that made by the Don in post-Glacial times, and probably required as long a time to accomplish.

In this old river valley a fairly swift current deposited shingly gravel made from the underlying shale mixed with leaves, wood, bark, and other vegetable material, including wood of the red cedar and pawpaw, showing that the climate was no longer glacial, but had already become warmer



Section at bend of Don

FIGURE 1.—*Cross-section of the Don Beds*

than that of Toronto at present. There are many unbroken unios, anodons, and gastropod shells in the finer beds above.

At the Don Valley brickyard wood, sometimes as tree trunks 12 or 15 feet long and still retaining branches, is found flattened into the surface of the boulder-clay, and many unios are embedded in a few inches of clay resting on the till. These shells are often in pairs and are still covered with the greenish epidermis found on living unios in the Don near by. It is evident that they lived and died on the spot where they are found.

Above the blue clay resting on the till there are well stratified beds of sand and clay, rising for about 17 feet, laid down in the shallow water of a lake. They contain many shells, especially unios, sphaeriums, and pleuroceras, seldom broken, though many are worn by the sand and fine gravel with which they were deposited. In a few of the thin beds of clay between the sand layers there are great numbers of leaves of deciduous trees, usually perfectly preserved, though hard to extract as complete leaves because of the difficulty in splitting the clay in precisely the right way to expose the whole of a leaf. Hundreds of leaves have been obtained, and most of the 35 species of trees reported from these beds have been determined from them. The leaves evidently settled to the muddy bottom in quiet water. They were not crumpled nor weathered nor torn before they were embedded, and the organic matter is still preserved as a thin brownish layer.

Above the highly fossiliferous beds there are 3 feet of blue sandy clay, with fewer shells, and 5 feet of brown sand which occasionally contains wood. The brown or yellow sand is more or less cemented with iron oxide and must have been formed in shallow water under oxidizing conditions. The whole thickness of beds at the brickyard is about 25 feet, but including the beds in the old river channel half a mile east at the bend of the Don the thickness becomes 40 or 45 feet.

Blue, finely stratified clay, resting evenly on the brown sand and rising for 23 feet at the brickyard, is considered to represent the lowest Scarboro beds.

The Don beds occur over almost the whole area of Toronto and have been found 14 miles to the north at Thornhill, where wood, a pine cone, and shells were obtained, after penetrating a great thickness of till, in stratified sand and gravel 200 or 300 feet below the surface. The warm-climate beds have been found also in a well at Scarboro Heights, 7 miles east of the Don. The known width of the beds near Lake Ontario is 13 miles, and with a length of 14 miles inland the area can hardly be less than 100 square miles and may be much greater.

The natural explanation of the facts just described is that after the earliest ice-sheet had withdrawn for a time long enough for a stream to cut a valley 16 feet into shale and to allow forest trees like those of Pennsylvania to reach the Don Valley, the outlet of the Ontario basin was slowly lifted, ponding back the waters so as to form a lake, which gradually rose to a height of 50 or 60 feet above that of Lake Ontario. Unios and other shell-fish, some of them Mississippi forms, throve on the muddy bottom; floating tree trunks got water-logged and sank into the mud, and all were buried under sand and clay brought by a great river from the north. Fresh trunks and leaves from trees that grew on the banks of the river were carried down from time to time during hundreds or thousands of years, all being quietly entombed in the beds of the growing delta, and with them were preserved bones and horns or tusks of extinct mammals like those found in the Aftonian beds. Everything went on quietly and in order, without great floods or catastrophic action of any kind, and the whole demanded a warm climate and much time.

The Scarboro Beds

Resting on the Don beds at Scarboro and elsewhere we find 95 feet of stratified clay and 55 feet of stratified sand, in which none of the warm-climate wood or leaves have been found. The mud and sand of the delta brought down from the north by the great river were spread out in the interglacial lake, which at length rose to 150 feet above the present Lake Ontario. The mud deposited by the river consisted of thoroughly weathered material from which the lime had been leached, providing clay that makes bright red brick. The boulder-clay near Toronto is highly charged with lime, and the stratified glacial clay derived from it above the interglacial beds retains so much lime as to burn to a gray or buff brick, the red color of the iron oxide being entirely masked by the lime. It is evident that the country to the north had been long exposed to the weather, and that no glacier mud was being delivered to the interglacial river or its ceras, seldom broken though many are worn by the sand and fine gravel tributaries. There was no ice lurking on this side of the northern watershed.

The fossils derived from the Scarboro beds include 72 species of beetles, of which only two still live. Doctor Scudder, who determined them, says: "Looking at them as a whole and noting the distribution of the species to which they seem most nearly related, they are plainly indigenous to the soil, but would perhaps be thought to have come from a somewhat more northerly climate than that in which they were found."

The plant remains are on the whole less satisfactory for determination than the trees of the Don beds. Among trees, *Larix americana*, *Abies balsamea*, *Picea*, *Salix*, and *Alnus* have been determined; among smaller plants, *Oxycoccus vulgaris* and *Vaccinium uliginosum* are mentioned by Doctor Macoun. A large number of seeds are found in the peaty matter, and Dr. W. L. McAtee[2] has determined from them *Scirpus fluviatilis*, *Potamogeton* sp., *Brasenia purpurea*, *Prunus*, probably *Pennsylvanica*, *Polygonum* sp., *Chenopodium* sp., and *Ceratophyllum demersum*. A number of species of mosses have been obtained also. Doctor Macoun, who determined the upper part of the list, believes that the climate was like that of the northern part of the Gulf of Saint Lawrence or southern

[2] U. S. Biological Survey, Washington, D. C.

Labrador, cool and wet; but all the plants he mentioned still live in swamps to the north of Toronto and all the trees occur at Toronto. The plants determined from the seeds indicate a climate like the present, as all of them are found here now, and most of them extend much to the south of Toronto. The later evidence just given modifies considerably the conclusion reached by Doctor Macoun, and I am told by botanists that northern forms are often found in peat-bogs or swamps far south of their usual habitat. In general, it may be said that the climate of Scarboro times was distinctly cooler than that of the Don beds and probably somewhat cooler than that of the present, but that it was far removed from arctic conditions.

Difficulties of Professor Wright's Interpretation

Prof. G. F. Wright, who has visited the sections at the Don and Scarboro, does not accept the interpretation given in the foregoing pages, and suggests another way of accounting for the facts by which the inter-Glacial interval is to be eliminated and the whole series of events is to be condensed into the briefest possible time, apparently a few thousand years. The mechanism by which he would accomplish this is not entirely evident to the present writer, but the following ideas seem to cover the essential points:

1. The lowest boulder-clay at the Don was not formed by ice from the Labrador center, but by an advance from the Keewatin center to the northwest. This has been shown to be incorrect.

2. The supposed warm-climate beds, admitted by Professor Wright to indicate a climate warmer than the present, consist of materials deposited in late Tertiary times, transported from somewhere by mysterious means and placed gently and deceptively on the lowest boulder-clay. He thinks that the specimens of warm species of plants and animals may have been "ploughed up by a readvance of the ice after a temporary recession and raised without much disturbance to the higher beds where they are now found." He supports this view by a reference to the well known but still enigmatic Moel Tryfaen deposits in Wales, where marine shells are supposed to have been lifted by the ice and afterward laid down in beds of stratified sand. He says that in a few hours several whole shells could be found, though "most of the specimens are fragmentary."

Apparently some doubts existed in his mind as to whether the innumerable whole shells, with no broken fragments, and the hundreds of perfectly preserved leaves in the Don beds could have reached their present position in this way, for he refers later to the great masses of chalk in Sweden, one of them 3 miles long, 1,000 feet wide, and 100 or 200 feet thick, shifted by the ice and now inclosed above and below by glacial materials.

Tertiary beds have not yet been found in Ontario from which the warm-climate fossils of the interglacial could be derived, and in any case it is incredible that the 100 square miles of fossiliferous deposits should not somewhere show evidence of the strange history they are supposed to have passed through. The interglacial leaves and shells, all whole and sound, could not have survived the Moel Tryfaen experience, in which the great majority of the shells were broken; and Professor Wright will hardly suggest that a sheet of sand and clay 100 square miles in area could be transported bodily for an unknown distance to be laid gently on the lower bed of boulder-clay. The immense disturbance must somewhere have left its marks.

Even if this extraordinary theory were accepted the real difficulty has not been touched, for it has been shown that the warm-climate beds are buried conformably by the later Scarboro beds. If the Don beds were shifted bodily, they could hardly be laid down so evenly that the delta clays and sands of the Scarboro stage should not show some unconformity. If it be suggested that the whole series, including both Don and Scarboro beds, was shifted together, the difficulty of transport is still further increased, since the Scarboro beds have a width of 25 miles as compared with the 13 miles of the Don beds, and the area of flat, undisturbed clay and sand to be transported is increased to probably 150 or 175 square miles.

However, it is probable that Professor Wright had no such thought in mind, since in his concluding statements he suggests that the Keewatin Glacier extended in the vicinity of Toronto into a region "occupied by some species of plants and animals which now exist only at a considerable distance to the south. At that time the lower Don beds were formed. Later the Labrador Glacier pushed outward as the Keewatin Glacier receded. . . . During this advance over the deserted Keewatin deposits in the vicinity of Toronto, the Scarboro beds, overlying the Don beds, were deposited and some of the fossil plants and animals native to the lower beds were incorporated into the lower portions of the upper beds."

How this is to be reconciled with the drainage of the interglacial waters to a depth below that of Lake Ontario, as proved by the Dutch Church Valley, at Scarboro is hard to see. This interglacial valley, a mile wide and 166 feet deep, could not have been carved while the Labrador ice-

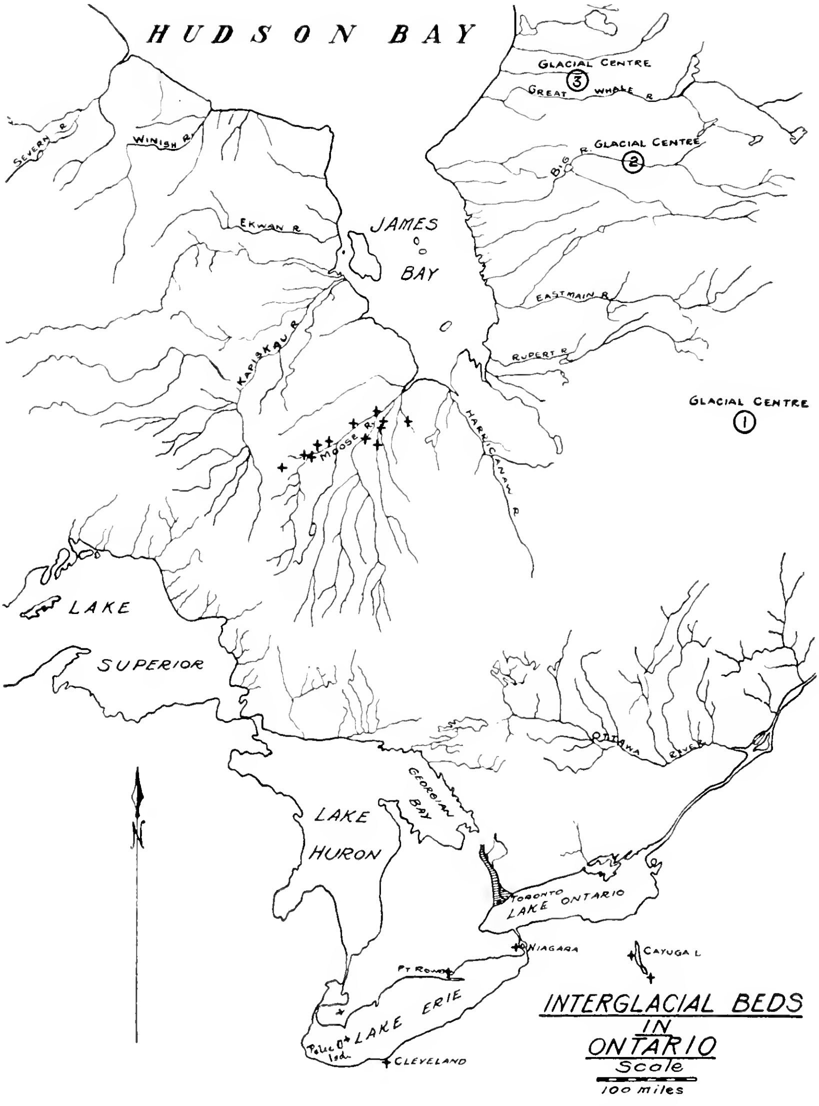


FIGURE 2.—*Map showing interglacial Beds in Ontario*

sheet blocked the Saint Lawrence. This theory ignores also the fact that later ice-advances—for instance, the Wisconsin—passed right across the interglacial beds, filled the Ontario basin, and spread out a sheet of till and a series of moraines in the States to the south.

Interglacial Deposits in other Places

The case for a great inter-Glacial period in the early Pleistocene is, however, much stronger than even the beds at the Don and Scarboro would suggest, for there is evidence to show that similar beds are much more widely distributed. Land and fresh-water shells occur in thick interglacial beds at the west end of Lake Erie,[3] and certain beetle-bearing peaty clays at Cleveland, Ohio, are precisely like those of Scarboro, and include two of the extinct species found at Scarboro, while leaves of maple and other trees have been obtained in interglacial beds north of Lake Erie near Port Rowan. Interglacial wood has been found beneath boulder-clay by Doctor Spencer near the bottom of the ancient Saint Davids Valley west of the Whirlpool at Niagara, and Miss Maury has described an interglacial bed near Cayuga Lake, New York, containing eleven of the unios, sphæriums, and other shells of the Don beds. This interglacial stage has left its mark on both sides of the two southern great lakes at points 300 miles apart.

A series of interglacial deposits 350 to 400 miles to the north of Toronto presents much the same character. The flattened trunks of trees and the peaty matter are closely like those from the Don. No less than 27 outcrops of lignite or peat of this kind are found in the river valleys of the James Bay slope, extending for 150 miles from east to west and for 50 from north to south. The climate in that northern region was mild enough for trees of large size to mature, and Professor Baker, the latest geologist to report on the region, believes that there was time enough for the vegetable matter to be buried and thoroughly carbonized before the next glaciation.[4] Either the ice retreated more than 400 miles beyond Toronto or the opponents of inter-Glacial periods have a second important inter-Glacial interval to account for. That the two sets of deposits, each demanding a great length of time, were formed contemporaneously seems most probable.

[3] Geological Survey of Canada, vol. xiv, 1901, p. 168. A summary report by Doctor Chalmers.

[4] Bureau of Mines, Ontario, vol. xx, part I, pp. 231-238. Details of authorities for previously mentioned localities may be found in "An estimate of post-Glacial and Inter-Glacial time in North America," a paper presented to the Geological Congress.

There are reasons also for thinking that the Aftonian beds of Ohio and adjacent States are of the same age. In both cases there is only one sheet of boulder-clay beneath, while there are four, separated by layers of inter-glacial materials, above. All of the genera of trees mentioned in the Aftonian occur in the Toronto formation, and probably all but one of the seven mammals found at Toronto are of the same genera as Aftonian mammals. The Ohio region has mostly been glaciated by ice-sheets coming from the Keewatin center, and if we correlate the Toronto and Aftonian formations it implies that the ice-sheets of the two centers had parallel histories, which seems highly probable.

Length of inter-Glacial Time

The total length of the earliest inter-Glacial interval must have been far greater than that of post-Glacial time. It begins, as shown in the Toronto region, with a period of river erosion comparable to that needed by the Don to cut its channel since the ice departed; is continued by the deposit of delta materials to the depth of 185 feet, requiring thousands of years, and ends with the cutting of river valleys much more mature than the postglacial valleys. Attempts have been made to estimate these different processes with the general result of tripling or quadrupling post-Glacial time. In a paper read by the present writer before the Geological Congress it has been shown from the rate of recession of Scarboro Heights through wave erosion that Lake Ontario is at least 8,000 years old. This result is corroborated by the rate of building of Toronto Island, which is formed of materials transported from Scarboro. The method of calculation is far more definite and accurate than estimates formed from the dunes of southern Lake Michigan.

The 8,000 years required by Lake Ontario to give its shores their present development must have been required also by Lake Iroquois, with shores of equal maturity. The marine episode coming between the two and certain preliminary stages of the two lakes not included in the time required to form their present shores probably demand an equal amount of time. The whole time since the ice left the Ontario basin can hardly be less than 25,000 years.

This estimate, which is based on definitely measured factors and is not merely a guess, gives a fair idea of post-Glacial time, probably under rather than over the true amount, and may be used as a measure for certain interglacial phenomena. The preliminary stages of the inter-Glacial, including the cutting of a river valley 16 feet into shale, may be estimated as equal to post-Glacial time, say 25,000 years. The deposit of the interglacial beds, checked by the counting of 672 annual layers of clay in a thickness of 19 feet 6 inches, is considered to have required not less than 4,300 years. The broad, gently sloping interglacial valley of the Dutch church at Scarboro required for its formation a time much greater than the far less mature postglacial valleys. If we say only twice as much, 50,000 years. The whole of the inter-Glacial interval must have been 75,000 or 100,000 years in length.

Even if the much too short estimate of post-Glacial time given by Professor Wright—10,000 years—is employed in computing the length of the

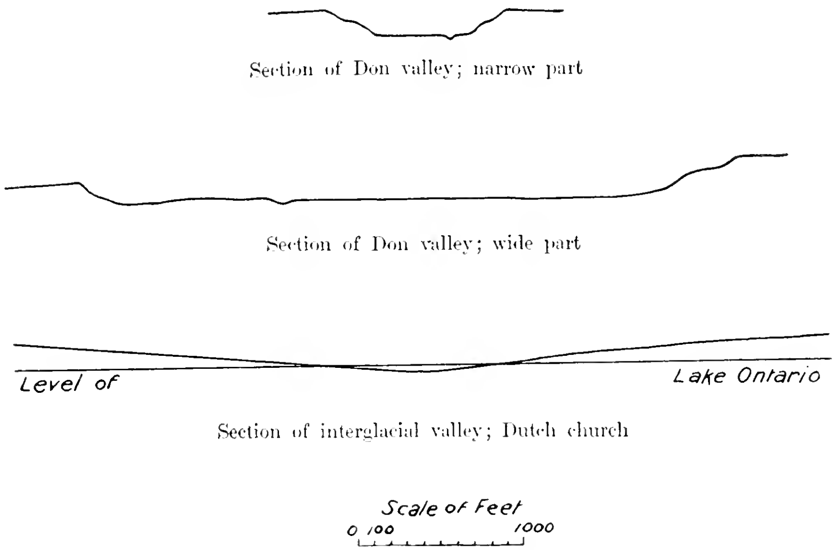


FIGURE 3. *Sections of interglacial and postglacial Valleys*

inter-Glacial period, it amounts to 34,000 years. From the evidence as to climate given above it can not be denied that as high a temperature existed both at Toronto and on the James Bay slope in inter-Glacial times as now. The Labrador ice-sheet, which centered only 300 miles northeast of the James Bay lignite deposits, does not exist now and could not exist in the equally warm or probably warmer inter-Glacial time. If the greatest of all the ice-sheets, that of Labrador, was melted in the earliest inter-Glacial period, what are the probabilities in regard to the smaller ice-sheet forest growth at least as rich as the present on the west side of James Bay? It seems highly improbable that the Keewatin ice could survive a climate like the present for more thousands of years than have elapsed since the end of the Glacial period, and we may conclude that during the earliest inter-Glacial time no ice-sheets remained in North America except alpine glaciers on the loftier mountains of the west.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 255-286 JUNE 29, 1915

OBSIDIAN FROM HRAFNTINNUHRYGGUR, ICELAND: ITS LITHOPHYSÆ AND SURFACE MARKINGS [1]

BY FRED. E. WRIGHT

(Presented in abstract before the Society December 30, 1909)

CONTENTS

HISTORICAL REVIEW

To the student of rocks the forms and relations of crystals and of crystal aggregates precipitated from a cooling magma are in large measure the expression of the physical conditions under which the magma solidified. This was thoroughly appreciated by the pioneers in petrology, who observed that as the physical conditions of freezing of such magmas varied, so also did the resulting products of crystallization, with respect both to the kinds of crystals formed (mineral composition) and to the habits and relations between the crystals (rock texture). Of the different kinds of crystals thus studied none has received more attention than the spherulites; and yet our knowledge of them is still incomplete, especially of the hollow spherulites or lithophysæ, the best examples of which have been found in the obsidian of Yellowstone National Park. These were studied many years ago by Iddings[2] in detail and with special reference to their mode of formation. At that time petrologists were not

[1] Manuscript received by the Secretary of the Society April 20, 1915.

[2] U. S. Geological Survey, Seventh Ann. Report, 1885, pp. 253-295.

in accord as to the genesis of the lithophysæ. Von Richthofen had suggested in 1860 the name Lithophysen[3] (Greek λίθος, stone, and φῦσα, bubble) for the hollow spherulites in the Hungarian rhyolites, on the assumption that their formation is due to the expansion of gas bubbles which, liberated during the crystallization of the spherulites, are unable to escape from the viscous magma and hence force out the walls of a cavity, each successive bubble carrying a thin film (bubble) or shell of the magma into the cavity, and thus producing the concentric structure. During this process chemical reactions between the gases and the crystallized material of the spherulites take place and cause solution, recrystallization, and a general rearrangement of the original material precipitated from the magma. Zirkel[4] in 1876 practically adopted von Richthofen's hypothesis of chemical alteration. S. Szabó[5] and Roth,[6] on the other hand, considered that the lithophysæ are the result of chemical and mechanical alteration of solid spherulites, the soluble portions being removed chemically, the insoluble mechanically, with the exception of silica, which constitutes the major part of the lithophysæ. This view involves transfer of material away from the cavity, while according to von Richthofen's idea there is no such transfer, only rearrangement within the cavity. Still other views were held by von Hauer[7] and Weiss,[8] who considered that lithophysæ are hollow spherulites formed about the gas bubbles which escape from the cooling magma. Cross[9] concluded from his study of lithophysæ that the minerals, topaz and garnet, which occur therein, were "produced by sublimation or crystallization from presumably heated solutions, contemporaneous or nearly so with the final consolidation of the rock. The lithophysal cavities seem plainly caused by the expansive tendency of confined gases or vapors, while the shrinkage cracks in the walls and white masses of the Nathrop rock suggest the former presence of moisture."

Iddings found "that the lithophysæ in the obsidian of Obsidian Cliff, with their contents of prismatic quartz, tridymite, adular-like and tabular soda-orthoclase, magnetite and well crystallized fayalite, are of aqueo-igneous origin, and result from the action of absorbed vapors on the molten glass from which they were liberated during the process of crystallization consequent upon cooling." An arching of the layers around

[3] Jahrb., K. K. Geol. Reichsanstalt, vol. 11, 1860, p. 181.
[4] U. S. Geol. Expl., 40th Parallel, vol. 6; Microscop. Petrography, 1876, p. 212.
[5] Jahrb., K. K. Geol. Reichsanstalt, vol. 16, 1866, p. 89.
[6] Beiträge zur Petrographie der plutonischen Gesteine, 1869, p. 168.
[7] Verhandl. K. K. Geol. Reichsanstalt, 1866, p. 98.
[8] Zeitschr. Deutsch. geol. Gesellschaft, vol. 29, 1877, p. 418.
[9] Am. Jour. Sci. (3), vol. 31, 1886, p. 432.

a lithophysa occurs frequently, and "at first sight it would seem that the expansion of a bubble of gas within the lava had occasioned the distention or displacement of its layers: but a careful study of portions of the rock which exhibit great distortion and plication of the layers makes it evident that in these cases the hollows occur beneath arches in the folds where there has been a local relief or diminution of pressure, which might allow the absorbed vapors to disengage themselves and to bring about the conditions which produce hollow lithophysæ in connection with spherulite development. In other words, the arching of the layers appears to have been the cause of the liberation of gases and the production of the cavity beneath, and not the result of expanding gases." The observed relations "leave no doubt that the spherulites and lithophysæ, in all their complexity of form and structure, are of primary crystallization out of a molten glass, which was gradually cooling and consolidating, and that, since its solidification, no alteration, chemical or mechanical, has taken place."

The work of Iddings on the Obsidian Cliff spherulites was so thorough and convincing that his conclusions have since been accepted and applied without reserve to all lithophysæ. In one particular, however, this generalization of the conclusions which hold primarily for the Obsidian Cliff rocks may not be warranted, namely, that in the formation of the cavities the expansion of the liberated gas plays no significant rôle. For the Obsidian Cliff lithophysæ the evidence probably justified the position taken by Iddings, that the cavities were formed by a kind of uniform tension in the viscous, cooling, and contracting magma (just as joints are formed in a later stage of cooling), and that at such points crystallization began and was accompanied by escape of gas into the cavity. But it is also possible that in other localities, as a result of slightly different conditions, the pressure of the escaping gas was a factor not only in enlarging the cavity, but also in its initial formation. We have thus two different hypotheses available: at the one extreme we find the total effect ascribed to hydrostatic tension or uniform pull developed by the shrinking of the magma during cooling; at the other, to the pressure of the gases set free on crystallization of the spherulites. In most cases it is probable that both factors, contraction of the cooling magma and gas pressure, have been active. The primary purpose of the present paper is to present evidence that in the case of the Icelandic lithophysæ the pressure of the liberated gas was an important factor in the development of the cavities. Incidentally the origin of certain etched surfaces of obsidian which resemble moldavitic markings will be considered.

The Hrafntinnuhryggur Obsidian

GENERAL DESCRIPTION

The obsidian specimens containing the lithophysæ were collected by the writer in 1909. Unfortunately lack of time and of transportation facilities permitted neither adequate field study of the occurrence nor the collection of a representative set of specimens. Only a few interesting random specimens were gathered to illustrate, as well as possible, the different types which occur.

The obsidian of Hrafntinnuhryggur forms a well developed, long ridge southeast of the volcano Krafla. It is not uniform in structure throughout, but ranges from dense black glass to a rock approaching pumice. Banding caused by an alternation of layers of the dense black glass with bands of semi-pumiceous or spherulitic material is characteristic of certain of the specimens. Near the west end of the ridge a small circular pond, resembling a shallow crater lake, occurs; and there the rock is apparently a breccia consisting of fragments of black obsidian glass (showing remarkable etched surfaces, which resemble those of the Bohemian moldavites and of certain desert rocks with etched surfaces) and of a white crypto-crystalline, siliceous substance.

The obsidian proper is a dense, black, brittle glass, remarkably uniform in character. Prismatic jointing was observed at several points and is of the ordinary columnar type. The obsidian glass takes a good optical polish, has a refractive index of about 1.500, and might possibly be serviceable as a source of material for making large telescope reflectors: its coefficient of expansion is probably low, in view of the high silica content. The fracture is conchoidal: in the field a single sharp blow of the hammer on a large uniform block a meter in diameter may spall off ashlars or shell-like pieces, which show most beautiful conchoidal fracture lines. The development of the two sets of lines—the one set concentric and emanating like wave-ripples from the point at which the blow was struck, the second set radiating from it in lines normal to the first—is so perfect and fascinating that the lack of transportation facilities is keenly felt by the geologist.

Under the microscope the obsidian glass is seen to be full of very minute crystallites of a colorless, prismatic mineral, not over 0.005 mm. in length and less than 0.002 mm. in width. The optical properties which could be determined on this mineral are: Refractive index, noticeably higher than that of the glass; birefringence, medium; extinction, apparently parallel to the elongation ($=\gamma'$). These properties are unfortunately not sufficient to identify the substance, but other and more precise data could not be obtained on the fine particles. Occasional minute, elongated bubbles (up to 0.05 mm. in length) were also observed.

The density (referred to water at 4° C. and to vacuum) of the obsidian is 2.387.

CHEMICAL CHARACTERISTICS

For the chemical analysis of the black obsidian I am indebted to Mr. J. B. Ferguson, of the Geophysical Laboratory, and express herewith my appreciation of his kindness. The material selected for analysis was part of specimen 88428,[10] a jet black glass free from spherulites and lithophysæ, but containing many of the minute crystallites noted above. The analysis is that of a fairly normal rhyolitic obsidian. Interesting and important is the presence of Cl and SO_3 in appreciable amounts. It will be shown later that the release of these volatile components in the magma had much to do with the formation of the lithophysæ, while the character of the physico-chemical system thus produced caused the simultaneous formation of crystals of fayalite and of tridymite at relatively low temperatures. This mineral association is not that of ordinary igneous rocks or lavas, but seems to be characteristic of lithophysæ in obsidian, notwithstanding the low content in oxides of iron (from 2 to 4 per cent). Thus in 1827 Gustav Rose discovered fayalite and tridymite in the lithophysæ of the obsidian from Cerro de las Navajas (analysis VI: $FeO + Fe_2O_3 = 2.20$ per cent); in 1885 Iddings found fayalite under similar conditions in the lithophysæ of Obsidian Cliff, Yellowstone National Park (analysis IV: $FeO + Fe_2O_3 = 1.63$ per cent).

The occurrence of an orthosilicate like olivine with tridymite is rare, if not unknown, in intrusive rocks. It is less rare in effusive rocks and indicates that physico-chemical conditions of equilibrium at the time of formation of the crystals may be very different even for magmas of the same general total chemical composition. The computed normative composition in such cases would be the same, but the actual modal composition may be totally different, thus emphasizing the difficulty of setting up a proper normative composition which even approximates the actual mineral composition of the rock.

---

[10] The specimens described in this paper have been deposited in the U. S. National Museum; the number of the specimen is, in each case, its catalogue number in the National Museum.

	1	1*a*	2	3	4	5	6	7	8	9	10
SiO_2	75.01	1.250	75.12	73.40	74.70	75.52	75.23	76.91	75.25	76.68	74.80
Al_2O_3	12.27	.120	11.34	12.90	13.72	14.11	12.36	12.18	14.60	14.49	14.32
Fe_2O_3	0.80	.005 }	3.92 (with FeO)	{ 3.70 (with FeO)	1.01	1.74	0.96	0.48	0.54	....	0.88
FeO	2.78	.039 }		....	0.62	0.08	1.24	0.92	1.60	1.09	1.00
MgO	0.08	.002	0.39	0.14	0.14	0.10	0.01	none	0.51	0.84	tr.
CaO	1.87	.033	1.73	2.35	0.78	0.78	1.00	0.92	1.06	1.53	1.26
Na_2O	3.36	.054	4.39	3.83	3.90	3.92	4.00	4.17	4.28	3.92	3.38
K_2O	2.80	.030	1.85	2.99	4.02	3.63	4.62	3.15	1.72	1.20	3.28
H_2O+	0.25	....	0.41	0.43	0.62	0.39	0.73	0.66	....	0.36	1.24
H_2O-	0.13	....	....	....	....	....	....	0.24	....	....	....
CO_2	....	....	....	....	....	....	....	....	....	....	....
TiO_2	0.33	.004	....	0.43	....	....	....	0.18	0.06	....	0.21
ZrO_2	....	....	....	....	....	....	....	....	....	....	....
P_2O_5	0.02	....	....	....	....	....	0.27	none	....	....	....
SO_3	0.07	.001	....	....	....	....	....	....	....	....	....
Cl	0.13	.004	....	....	....	....	....	....	....	....	....
F	....	....	....	....	....	....	....	....	....	....	....
S	0.02	....	....	....	....	....	....	none	....	....	....
MnO	0.06	.001	....	....	....	....	....	....	....	tr.	tr.
NiO	....	....	....	....	....	....	....	....	....	....	....
BaO	....	....	....	....	....	....	....	....	....	....	....
V_2O_3	....	....	....	....	....	....	....	....	....	....	....
MoO_3	....	....	....	....	....	....	....	....	....	....	....
FeS_2	....	....	....	....	0.40	0.11	....	....	....	....	....
	99.98	sp. g.,	100.00	100.17	99.91	100.38	100.42	99.81	99.62	100.11	100.37
	−0.02	2.387									
	99.96										

1. Obsidian. Hrafntinnuhryggur, near Krafla, Iceland. J. B. Ferguson, analyst. I. 3". 2. (3) 4.

1a. Molecular proportions of 1a.

2. Obsidian. Hrafntinnuhryggur, near Krafla, Iceland. R. Bunsen, analyst. Pogg. Annalen d. Chem. u. Physik, volume 83, 1851, page 212. 1(II). 3(4). "2. 4.

3. Obsidian. Hlitharfjall, near Myvatn, Iceland. H. Bäckström, analyst. Geol. Fören. Förhandl., volume 140, 1891, page 663. I". (3) 4. 2. 3.

4. Black obsidian. Obsidian Cliff, Yellowstone National Park. J. E. Whitfield, analyst. Described by J. P. Iddings. U. S. Geological Survey Annual Report, volume 7, 1885, page 291. I. (3)4. 1(2). 3(4).

5. Red obsidian. Obsidian Cliff, Yellowstone National Park. J. E. Whitfield, analyst. Described by J. P. Iddings. U. S. Geological Survey Annual Report, volume 7, 1885, page 291. I. 3(4). 1(2). 3(4).

6. Black obsidian. Cerro de las Navajas, Mexico. F. Baerwald, analyst. Described by C. A. Tearne. Zeitsch. Deutsch. Geol. Gesell., Berlin, volume 37, 1885, page 616. I. 4. 1". 3".

7. Pumice. Katmai Volcano, Alaska. George Steiger, analyst. G. C. Martin. Lab. Records. U. S. Geological Survey. I. 3(4). (1)2. "4.

8. Dacite obsidian. Riviere des Vieux-Habitants, Guadeloupe. A. Pisani, analyst. Described by A. Lacroix. Mount Pelée, 1904, page 588. I. 3". 2. 4.

9. Obsidian. Corinto, Nicaragua. J. Petersen, analyst. Neues Jahrb., 1898, volume 1, page 157. I. 3. 2. 4".

10. Obsidian. Kawah-manoek Volcano, Preanger District, Java. Ledeboer, analyst. Described by R. D. M. Verbeek, Jb. Mijnw., volume 37, 1908, page 93. I. 3". 2. 3 (4).

Norms computed from the above Analyses

	1	2	3	4	5	6	7	8	9	10
Q	39.90	35.52	32.7	34.9	36.7	32.34	37.80	39.78	43.92	39.48
or	16.68	11.12	17.8	23.4	21.7	27.24	18.90	10.01	7.23	19.46
ab	26.72	37.20	32.0	33.0	33.0	34.06	35.63	36.15	33.01	28.82
an	9.17	5.56	9.2	3.9	3.9	2.22	4.45	5.28	7.51	6.12
C	0.61	....	....	1.5	2.2	....	0.20	3.77	3.98	2.86
Na_2Cl_2	0.23	....	....	...	...	....	....	....	....	....
Na_2SO_4	0.14	....	....	...	...	....	....	....	....	....
di	....	2.42	2.2	...	...	0.99	....	....	....	....
hy	4.29	6.87	4.8	0.8	0.3	0.92	1.06	3.68	4.08	0.50
mt	1.16	....	....	1.4	0.2	1.39	0.70	0.70	....	1.39
il	0.61	....	....	...	...	....	0.30	0.15	....	0.46
hm	....	....	....	...	1.6	....	....	....	....	....
pyrite	....	....	....	0.4	0.11	....	....	....	....	....
ap	....	....	....	...	...	0.67	....	....	....	....

A comparison of these analyses, and especially of the norms computed from them according to the methods proposed by Cross, Iddings, Pirsson, and Washington, shows that they are all of the same general character. The Icelandic rocks contain a slightly larger amount of femic minerals than the other rocks, but the amount is not sufficient to place them in another class. It is interesting also to note that the analysis 2, by Bunsen, in 1851, agrees fairly well with the modern analysis 1 of the same rock. In the legend of the table of analyses the symbols, according to the quantitative classification of rocks proposed by Cross, Iddings, Pirsson, and Washington, are given. These symbols show that in nearly every case the rocks are located near the boundaries of the various subdivisions of the quantitative system.

If the obsidian of Hrafntinnuhryggur had crystallized under the physico-chemical conditions of a deep-seated rock, the mineral composition would probably have been: Quartz, about 40 per cent; orthoclase, about 16 per cent; oligoclase of average composition, Ab_3An_1, about 35 per cent (some of the albite substance would probably enter into solid solution with the orthoclase, but to what extent can not be predicted because of lack of information regarding these physico-chemical systems); aluminous amphibole, 6 per cent; titaniferous magnetite, 2 per cent, and a little apatite. The salts, Na_2Cl_2 and Na_2SO_4, indicated in the norm would probably be carried away in solution as part of the more soluble portion of the magma. It is, moreover, evident that the sodium would not be the only base in combination with these acid radicles as postulated in the norm. On the whole, experience has shown that in this persalane class of rocks the modal composition is not greatly different from the computed normative composition.

SPHERULITES AND LITHOPHYSÆ

Attention has been given in the preceding paragraphs to the intimate relation between spherulites and lithophysæ and to the several different hypotheses which have been offered to explain the development of lithophysæ. In the Hrafntinnuhryggur obsidian all possible gradations occur between typical, compact, lithoid spherulites and typical lithophysæ with walls lined with minute crystallites, water-clear and very fragile. Pumiceous structures are also of common occurrence, but they are usually confined to definite bands and patches which alternate with streaks of black obsidian glass containing occasional large vesicular cavities. In the case of a wide band of glass these large cavities are more abundant in the immediate vicinity of the pumiceous layers and virtually disappear within a few centimeters. The gas cavities in both the pumiceous and adjacent bands are not spherical but tubular in shape, the direction of elongation being that of the lines of flow of the lava. This indicates that the lava during the period of its final flow was sufficiently viscous to prevent the escape of the free gas bubbles which it inclosed. The restriction of the gas bubbles to definite bands and parts of the mass might be considered to indicate that during the period of its flow the lava encountered physical conditions of such nature (especially release of pressure) that certain bands became supersaturated with volatile components, which were then released and formed bubbles. These could not migrate through the lava to any great extent because of its high viscosity. It is, however, conceivable and *a priori* more probable that the appearance of a pumiceous band is not the result of direct evolution of gas from that band alone, but that either before or during the eruption of the molten obsidian there was an accumulation of gas bubbles at certain points (magma hotter and less viscous, thus allowing freer circulation and concentration of evolved gas bubbles at favorable pockets near the margin of the magma chamber), and that on final outflow of the obsidian these foamy portions of the lava were drawn out and appear now as vesicular streaks, which serve to emphasize the lines of stiff viscous flow of the lava. On this hypothesis the amount of pumice accompanying a rhyolitic flow can not be considered to be indicative of the amount of gas given off by the obsidian. Most of the gas thus liberated from the solution no doubt escaped, and that which produced the pumice represents only a small part of the total amount contained originally in the molten obsidian.

Passing now to the spherulites, we find that they occur in typical development in several of the specimens. They range in size from a few tenths of a millimeter to over 5 millimeters in diameter. In the outcrop they are not evenly distributed through the rock mass, but are confined to certain bands or layers, thus indicating that in these bands crystallization took place more rapidly than in others. In the case of finely laminated flow banding, however, the spherulites cut across the banding. In no case was a suggestion of flow banding around a spherulite observed: this would occur were the spherulites older than the banding. In one instance the wall of a hollow spherulite was serrated as the result of a difference in behavior of the different bands with respect to crystallization and to attack by the volatile components released during the crystallization of the spherulite.

The relations outlined above suggest that the determinative factors in the development of the different structures which are now found in the obsidian—pumiceous, spherulitic, and lithophysal—were the physical conditions of cooling of the different parts of the lava, together with the amount and character of the volatile components dissolved in it. In order to show this clearly, six of the specimens collected at Hrafntinnuhryggur will be briefly described.

Specimen 88428 is a black compact obsidian glass, free from spherulites, but containing fine hairlike crystallites and minute bubbles 0.05 mm. in maximal length; also dark opaque grains scattered through it. Part of this specimen served for chemical analysis I and is described in sufficient detail above.

Specimen 88429 shows clearly the passage of obsidian glass to pumice. One end of the specimen is typical pumice, with silvery luster in the direction of elongation of the vesicles; the opposite end is of massive obsidian glass, with only occasional large cavities, which trend either approximately parallel with or transverse to the general lines of flow. The transverse cavities are much larger than the others and appear to be of the nature of rupture fissures—rather than elongated gas cavities—produced during the final stages of the cooling and flow of the lava as a result of the tensional stresses thereby developed.

Specimen 88430 presents another structural type which was developed during the period of cooling of the lava. Dull gray-black lithoidal bands and irregular masses alternate with bands and patches of black obsidian glass. The lusterless parts consist of spherulites which have crystallized from the glass. Under the microscope these spherulites are seen to be of two different types:

(1) Typical radial spherulites, with fibers radiating from a central point, or more commonly from a minute central bubble. The elongation of the fibers is α'; a distinct cross is visible between crossed nicols. The refractive indices are difficult to obtain accurately, but they lie between 1.520 and 1.540. The birefringence is medium to weak. Between many of the fibers are minute irregular cavities which greatly decrease the transparency of the spherulites. The determinations indicate that these spherulites are chiefly albite, with possibly a little admixed potash feldspar and also free quartz.

(2) Adjoining the radial spherulites are usually patches of substances of a deeper brown color and of slightly stronger birefringence and less pronounced radial spherulitic development. The elongation of the fibers in this material is not pronounced, but in those cases in which an elongation was apparent its character was γ'. The development approaches that of an aggregate of overlapping crystallites and grains too fine and too intimately intergrown for satisfactory determination. The refrac-

tive index is about 1.54. It is probable that these spherulites consist chiefly of quartz intergrown with some alkali-feldspar.

Not all of the spherulites in this specimen are entirely compact and gray-black in color. Portions of many of them are porous and then usually lighter in color and coarser grained. The appearance of such spherulites leads one to infer that gas was evolved during their crystallization, and that the volatile components thus set free acted on the spherulitic material of the walls and caused its recrystallization. In other words, each little spherulite, with its portion of volatile components, which were liberated during its crystallization and were inclosed in the thick viscous hot glass, may be likened to a chemical flask filled with appropriate reagents and crystal compounds and heated to such a temperature that certain chemical reactions take place. It is evident that the physico-chemical equilibrium conditions during the partial crystallization of a melted magma, from which appreciable amounts of volatile components are being liberated, are different from the equilibrium conditions obtaining in a system of the same total composition, but at a much lower temperature and containing the volatile components chiefly as vapor phases and the other components as crystallized units. The result of this shift in distribution of the elements from a homogeneous solution (magma) crystallizing at high temperatures to a heterogeneous system consisting of solid and vapor phases held at a lower temperature is a redistribution of the constituents in the solid phases, such that the mineral association which we encounter in the normally crystallized compact spherulites or in rhyolite or in granite is different from that of the hollow spherulites or lithophysæ. This difference will appear more clearly in the descriptions below, but it is essential that the fundamental difference in behavior and in stability relations of the two cases be emphasized.

In certain bands of this specimen the aggregate volume of the gas cavities is relatively large, but they are not elongated as in specimen 88129 and have the appearance rather of a spongy structure. The cavities here are associated with the spherulites and were evidently developed *in situ*.

In one larger cavity a white coating of clear, secondary hyalite was observed. This mineral is abundant in the more altered specimens of obsidian and pumice, especially in the specimens gathered at the small circular pond mentioned above. At this place highly siliceous solutions were evidently active and not only deposited hyalite but also alunite, and corroded the black obsidian glass in a remarkable manner, so that many of the fragments resemble in outer forms the Bohemian moldavites, whose origin is still in some doubt. The formation of these surface markings is discussed in a separate section below.

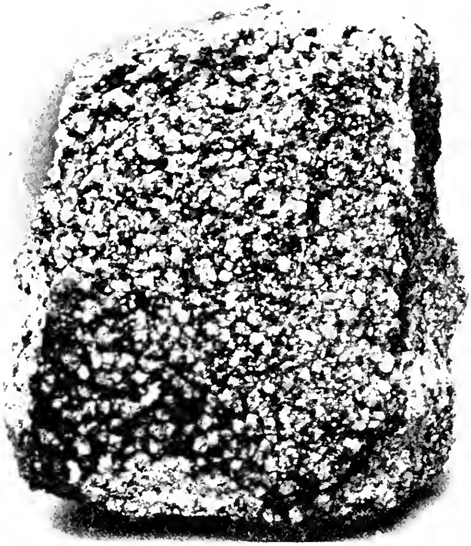


FIGURE 1.—*Obsidian containing radial Spherulites and bubble Cavities*
Specimen 88432. Two thirds natural size

Specimen 88432, as shown in figure 1, is filled with spherulites, ranging in size from mere specks to kernels half a centimeter in diameter. The radial spherulites are usually white, as a result evidently of the action of the circulating solutions which deposited the alunite and hyalite in the adjoining gas cavities. The central part of many of the radial spherulites is still dark gray and unaltered. Under the microscope the secondary alteration is seen to be of the nature of a bleaching effect rather than of complete recrystallization, although there is evidence of partial recrystallization.

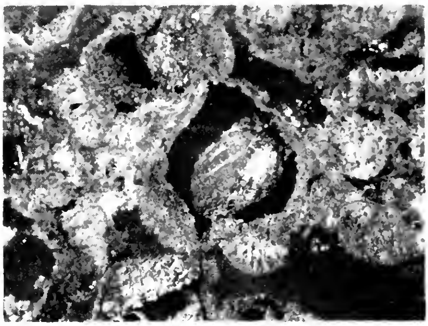


FIGURE 2.—*Lithophysa with fluted Tongue of Obsidian projecting into hollow Cavity, shown in Center of Photograph*
Specimen 88433. Magnification, 15 ×

Specimen 88433.—In this specimen there are numerous cavities (0.5 to 8 mm. in diameter) partly filled with crystal fibers which radiate from the walls toward the center. They vary in size and often in shape; but when undisturbed by adjacent cavities they are roughly spherical in outline. On breaking open the cavities, one is impressed by the fact that the crystallized material does not completely fill them (figure 2); also that the crystals in the center of the cavity are coarser than those at the margins. The radial fibers are usually water-clear, and are capped and studded with tridymite crystals in twinned groups measuring up to

0.5 mm. in diameter. The supporting needles rarely measure over 0.02 mm. in thickness (see figure 3). Their optical properties, so far as could be determined, are: γ about 1.535, α about 1.530; birefringence weak; extinction oblique with $c:\gamma'$ from 0° to 28°; elongation is usually γ', but occasionally α'. The plane of optic axes is apparently normal to the elongation. Some of the needles have the appearance, between crossed nicols, of possessing exceedingly fine polysynthetic twinning. It was thought at first that this mineral was albitic plagioclase, but several of the above optical properties do not agree with those of albite and it is not certain that the mineral is a feldspar. The composition of the obsidian itself would indicate a feldspar. The tridymite has the usual

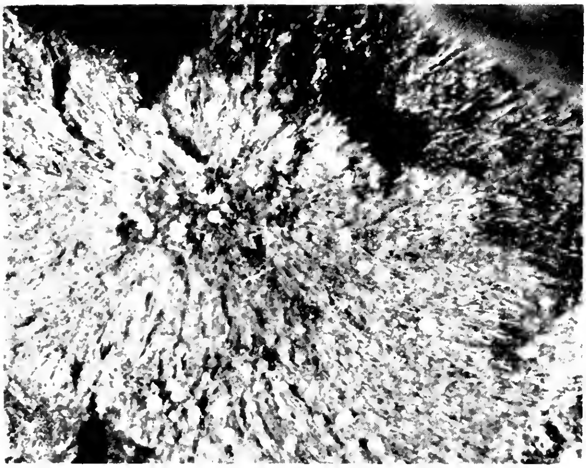


FIGURE 3. *Tridymite Crystals supported by Needles of Feldspar (?) in recrystallized Lithophysa*

Specimen 88433. Magnification, 50 ×

characteristics: Tabular plates and thick prisms hexagonal in outline; weakly birefracting in irregular fine patches; refractive index slightly less than 1.480; plates grouped in characteristic twinned aggregates.

The aspect of these lithophysal minerals and the manner of their grouping are such as to render untenable the hypothesis that they were crystallized directly from the cooling magma. A comparison of the lithophysæ of this specimen with the radial spherulites and the incipient lithophysæ of the specimens described above shows that the lithophysæ were originally spherulites with a gas cavity, but that they have been partly, and in some instances entirely, recrystallized by the action of the volatile components of the cavity at relatively high temperatures, the volatile components having been released during the initial crystallization of the spherulites. This is proved by several facts:

(*a*) The black obsidian glass can be seen at several points to have flowed into a lithophysal cavity whose walls had collapsed slightly. The inflowing obsidian was so stiff that it extended as a tongue of glass into the cavity (see center of figure 2 and figures 4 and 5). These tongues are of different shapes; they exhibit in cross-section the outline of the cracks through which they entered and are fluted longitudinally with straight grooves and lines which were impressed on them by the irregular outline of the crack shown in figure 5. They resemble the product obtained by the outflow, under great compression, of any viscous or plastic material, as iron, butter, or cheese, through an irregular orifice. The obsidian tongues on entering the cavities broke down and crushed the delicate lithophysal crystals extending from the walls. This proves that the major part of the recrystallization within the lithophysæ took place at a relatively high temperature, while the obsidian was still capable of stiff, viscous flow.

FIGURE 4. *Radial Lithophysa, in part recrystallized*

Lithophysal cavity has collapsed slightly and is pierced by tongue of black obsidian. Specimen 88433. Magnification, 15 ×.

(*b*) The tridymite crystals have the form of hexagonal plates. These plates show the irregular birefracting areas characteristic of tridymite. The temperature of formation was accordingly above the inversion temperature, 120° C. Whether or not it was above 870°, the inversion temperature of quartz-

FIGURE 5. *Sharply fluted Tongue of black Obsidian Glass projecting into lithophysal Cavity*

Specimen 88433. Magnification, 20 ×.

tridymite, can not be determined from the data available. The presence of tridymite is not decisive evidence of a temperature of formation above 870°, for Fenner[11] has shown that it may crystallize as a metastable phase at relative low temperatures, especially in the presence of fluxes.

In some of the outer cavities a later ferruginous staining has been introduced, but this does not extend into the rock for any distance, as is

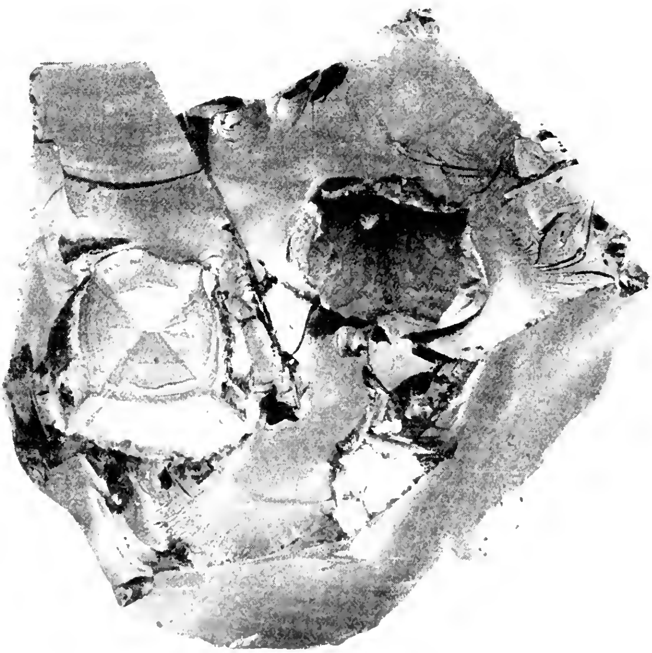


FIGURE 6. *Remarkable Lithophysa in Obsidian*
Cube-shape cavity. Specimen 88131. Two-thirds natural size

evident from the fact that the cavities on a freshly fractured surface do not show the slightest trace of such staining.

To recapitulate: Specimen 88133 proves definitely that crystallization of radial spherulites took place as a result of the action of gases at high temperatures, at which the obsidian was still soft and capable of flowing into cavities which had been sheared or had collapsed to a slight extent. The evidence of the presence of volatile components at high temperatures

[11] Am. Jour. Sci. (4), vol. 36, 1913, pp. 331-384.

is as clear in the Icelandic material as in the Yellowstone Park occurrences.

Specimen 88431.—In this specimen we encounter lithophysæ of a shape and aspect which are unique. They are so remarkable that at first sight they do not appear to be spherulites. The cavities are in the shape of a cube about 25 mm. on a side, the walls of the cube having the appearance indicated in figure 6 and in the photomicrographs, figures 7 and 8. The inner walls are not perfectly flat, but show strong diagonal ribs passing from one corner of a cube face to the opposite corner, as though each cube face had not been quite fully developed into a plane,

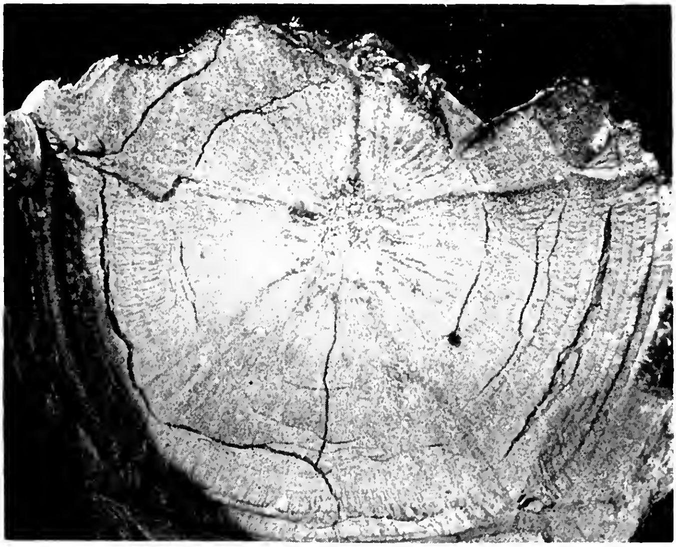


FIGURE 7.—*Lower Wall of Lithophysa on left side of Figure 6*

Shows character of crystallization. Specimen 88431. Magnification, 4 ×

but still has superimposed on it four negative triangular tetrahexahedral faces; each four-sided pyramid thus formed points toward the center of the cube and not away from the center, as in the case of natural crystal bounded by tetrahexahedral faces. Between the strong diagonal ribs hollow depressions occur. From the apex of each four-sided pyramid fibers radiate toward the sides of the cube, as shown in figure 6. In addition to these lines of growth, a second set of structural lines and ridges and cracks is present, cutting the radiating lines at right angles and emanating as encircling waves from the center (see figure 7).

On examining these cube faces still further, we find that any little irregularity on the one face is imaged in exactly the same relative position on the face immediately adjacent to it; thus in figure 6 we observe in the lithophysa on the left a sharply pointed facet on the diagonal rib in the lower left-hand corner of the vertical face; this facet appears on the horizontal face in precisely the same relative position and is shown faintly in the photograph. Much better examples of this phenomenon can be seen in the lithophysæ on the right side of figure 6, but they are not well reproduced in the photograph. The fact that any irregularity on the one face finds its counterpart on the face adjacent to it and intersecting it at the edge of the cube proves that the faces were originally together and were gradually forced apart as crystallization proceeded.

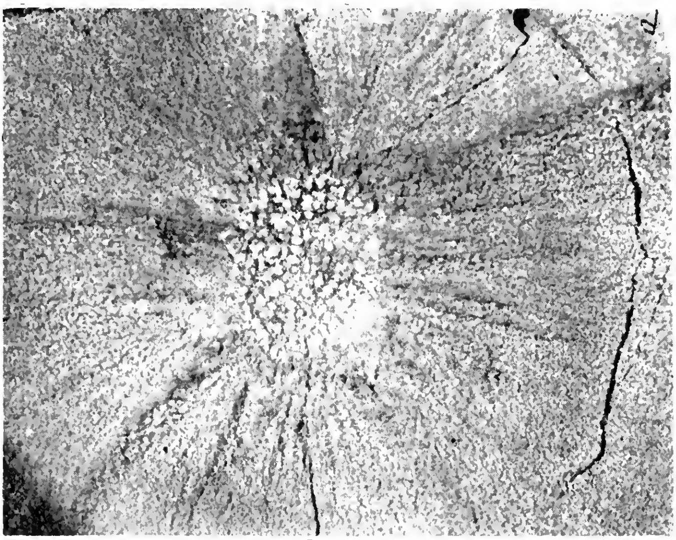


FIGURE 8.—*Enlarged central Part of Figure 7*

Shows decrease in granularity away from center. Specimen 88131. Magnification, 10×

Such pushing apart of a spherulite by the gas emitted during crystallization or by the pulling apart as a result of general hydrostatic tension is not unusual and would ordinarily be passed over unnoticed.

In the present instance the remarkable symmetry of the lithophysæ attracts attention, and the observer finds it difficult to picture the mechanism of such a process. When it is realized, however, that a cube can be considered to consist of a set of six four-sided pyramids (figure 9, negative tetrahexahedrons meeting in the center at their apices, the six cube faces being their bases), the geometry of the problem becomes clear. If, then, having started with a small spherulite and having caused it to fracture symmetrically as a result of the internal gas pressure along the lines of the pyramids of the cube, we then allow crystallization to proceed continuously with concomitant evolution of volatile components, which tend to force the rigid walls still farther apart, we obtain the present forms. Evidence that this has been the process of development is not lacking.

(1) The radius of curvature of the outer wall of the right side of the lithophysa on the right in figure 6 is variable. It is least in the center of the segment and becomes increasingly greater as the margin of the segment is approached: near the margin the curve of the outer wall shows a flexure. The edges of the lithophysal cube are very thin and only a thin film of crystallized material has been formed next to the

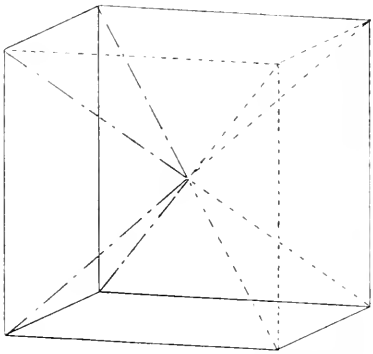


FIGURE 9.—*Diagrammatic Representation of Cube built up of six Pyramids*

The apices of the pyramids must meet at the center and their bases are the sides of the cube.

FIGURE 10.—*Ellipsoid-like lithophysal Cavity, with central Girdle of crystallized Material*

Specimen 88431. Natural size

glass, thus indicating that crystallization was active only a relatively short time at that point. The ratio of the thickness of the crystallized shell at the center of a segment to that of the crystallized film at its edge is of the order of magnitude of 50 to 1.

(2) On one side of specimen 88431 a cavity, 9 mm. in diameter, occurs, out of which the crystallized material has fallen, except for a single equatorial groove (see figure 10). In this case it appears that the spherulite was not broken into halves until it had grown to an appreciable size, and that then it was forced apart along a single plane, thus elongating the sphere into an ellipsoid-like figure with a central girdle.

(3) A difference in age between the center and the margin of the exposed faces of the lithophysa is clearly indicated by the change in granularity of the recrystallized material. Beginning at the center (fig-

ures 7 and 8), we find the original radial spherulitic material covered with a crust of geode-like crystals measuring up to 0.2 mm. in diameter. These crystals decrease in size as we pass from the center toward the margin, where they are only a few hundredths of a millimeter in diameter. The majority of these lithophysal crystals are tridymite; they form clusters and rosettes similar in every respect to the tridymites of specimen 88432. The tridymite occurs in characteristic hexagonal plates, showing weak, irregular birefringence and low refractive index, $n = 1.480$. No quartz or cristobalite was observed with certainty. Extending into the tridymite crystals and holding them together is a radial, weakly birefracting mineral of much higher refractive index. It is probably identical with the fibrous, feldspar-like mineral which occurs in larger individuals in the cavities of specimen 88432, described above.

Scattered through the mass of tridymite crystals are small (0.05 to 0.1 mm. in diameter), sharply developed crystals of a honey yellow to yellow-brown mineral of the following optical properties: Refractive index α, considerably higher than 1.78, but noticeably less than 1.857; γ, slightly greater than 1.857. Optical character negative; birefringence strong; crystal system apparently orthorhombic. On a section practically normal to the obtuse bisectrix the angle between the crystal edges was found by measurement to be about 100°. All of these properties agree with those of fayalite, which also occurs in similar association in the Yellowstone Park lithophysæ. The angle noted above is probably that between (021) and (0$\bar{2}$1), which is 99° 06′ for fayalite.

The relative abundance of the fayalite is remarkable when we recall that the total iron oxide content in the rock is less than 3 per cent. Similar relations were recorded by Iddings for the Yellowstone lithophysæ. The fayalite crystals decrease also in size from the center toward the margin of the lithophysal cube faces. The presence of fayalite and tridymite as the chief minerals formed indicates precipitation from a physico-chemical system different from that of the normal rhyolite magma; the system consisted largely, of course, of volatile components, which at the high temperatures attacked the crystals which had crystallized from the magma itself. These components were first set free on the crystallization of the spherulites, which in turn, at lower temperatures, were attacked by them, and changes were produced which resulted in new crystal phases more stable under the new conditions than the original crypto-crystalline substances of the spherulite. There is no evidence that during this recrystallization there was migration of material away from the cavity. The decrease in size of grain of the new crystals from the center to the margin indicates again that the gases acted for a much longer period at the center than at the margin: in short, the center is much older than the margin, and the gases active during the alteration were evidently those set free chiefly during the primary crystallization of the spherulites.

The evidence presented thus far proves that during the crystallization of the spherulites volatile components were active within the cavities; also that at the temperatures, at which the lava was still sufficiently molten to flow into very small cracks, the remarkable deformations described above were produced. Now the chemical analysis of this obsidian shows that it contains 0.13 Cl, 0.07 SO_3, and 0.27 H_2O—all volatile gases which would be set free, in part at least, on the crystallization of the silicates. It is not probable that either sodalite or noselite would be formed in the presence of so much quartz, and these are practically the only silicates containing NaCl or Na_2SO_4 which would be likely to be formed. We have seen, furthermore, that the escape of volatile components continued as crystallization proceeded and as the cavity was enlarged. The question arises: Did the pressure of this escaping gas force the cavity apart or was the main factor an external uniform tension developed on the shrinking of the magma?

It is evident that where gas bubbles are formed in a magma the vapor pressure of the gas has been sufficient to overcome the internal pressure of the magma: also that simple vacua of regular bubble shape in a viscous magma would be difficult to form. Field experience and laboratory practice have shown that, in such instances where the magma is inclosed between frozen walls and shrinkage occurs on cooling, cracks (joints) develop rather than bubbles disseminated evenly through the magma. Reduction of hydrostatic pressure in the liquid favors the formation of gas bubbles just as does the opening of a siphon bottle containing carbonated water. Bubbles may begin to form, moreover, when the liquid becomes supersaturated with respect to the gas. Increase of uniform pressure raises the saturation limit with respect to the dissolved gas; conversely, reduction of uniform pressure lowers the saturation limit and favors the escape of the gas. Gravity, furthermore, is a factor which would tend to close any vacuities disseminated through the magma. On cooling, it would seem, then, that a magma inclosed in a solid shell would tend to shrink away from the roof and to leave cracks rather than simple bubbles. The formation of bubbles is facilitated if there be a point of discontinuity in the liquid (differences in potential). This is given in the case of gas in the magma reaching supersaturation near some nucleus, such as a minute crystal or spherulite. It is less easy, if not impossible, to explain the formation of a vacuum bubble in a moving viscous liquid.

Another fact which bears on the present problem is the increase in solubility of gas in a liquid with falling temperature. The effect of this, if pronounced, would be, in the case of a simple bubble, a reduction in its size with lowering temperature. Opposing such reduction, however, is the hydrostatic tension which develops in the central portion of the magma on cooling and which tends to enlarge the bubbles. The ultimate effect which these opposing forces may have had on the bubbles in Iceland obsidian is not known, but the fact that the cavity was lined with crystallized material would tend to retard the magmatic resorption of the gas, and thus tend to produce larger cavities than otherwise.

To summarize the conclusion briefly: Gas escaping from the magma on crystallization was an active factor in the development of the lithophysæ in the obsidian from Hrafntinnuhryggur. It caused recrystallization and aided to a large extent in enlarging the cavity as crystallization proceeded. The amount of energy required to effect the observed recrystallization in the cavities need not have been great, because the energy necessary for the solution of the spherulite crystals first formed was probably largely offset by the energy liberated during the crystallization of the lithophysal minerals. The shrinkage of the viscous lava on cooling tended, of course, to reduce the uniform hydrostatic pressure; but the chief effect of such reduction on the size of the bubble cavities was to increase the rate of evolution of gas from the magma (reduction of solubility of gas in magma under reduced pressure). Shrinkage of the magma alone without evolution of the inclosed gas would tend to produce cracks (joints) bearing some relation to the inclosing walls. That the magma contained abundant gas, however, is proved both by the presence of pumiceous layers and by the recrystallizing action of the gas on the walls of the cavity. The conclusion seems, therefore, warranted that in the Hrafntinnuhryggur obsidian, and probably in most obsidians, the pressure of the gas set free from the magma as a result of crystallization and also of reduction of hydrostatic pressure induced by the shrinking of the central portions of the magma on cooling has been an important factor in the development of the lithophysæ. To ascribe the total effect to the uniform pull or tension developed by shrinkage of the cooling magma is not an adequate hypothesis to account for the different facts and relations which have been observed.

SECONDARY MINERALS AND ETCHING PHENOMENA PRODUCED BY HOT CIRCULATING SOLUTIONS

Although not strictly germane to the theme of this paper, it may be of interest to describe the effects produced by hot solutions on the more porous and exposed portions of the obsidian. As noted above, both hyalite and alunite were deposited from these solutions on the walls of bubble cavities. In specimen 88434 the gas bubbles adjacent to the spherulites are usually coated with minute water-clear crystals of a substance which is evidently a secondary mineral introduced by circulating solutions after the solidification of the obsidian; this mineral agrees in its optical properties with alunite. The largest crystals measure less than half a millimeter in diameter and are bounded by the basal pinacoid and by rhombohedral faces, which are triangular in shape. Basal cleavage is distinct and gives rise to a distinct semipearly luster on the basal pinacoid. As a result of this cleavage, it is an easy matter to obtain sections normal to the optical axis, on which then the uniaxial, optically positive interference figure of a mineral of medium to fairly strong birefringence is visible. Rhombohedral cleavage is also present, but is poorly developed. The refractive indices were measured by the immersion method: ω about 1.575, ϵ about 1.595; birefringence about 0.020. Hardness apparently 3 to 4. Slightly soluble in hydrochloric acid, but to a greater degree in sulphuric acid. In the HCl solution potassium was found to be present; also sulphuric acid. On heating in a closed tube, the mineral decrepitates and emits a white cloud of sulphurous fumes. This material heated on charcoal before the blow-pipe gives, after moistening with dilute cobalt nitrate solution, the characteristic blue color test for aluminum. The density was found by immersion of a clear crystal in Klein's solution to be 2.73. These properties agree with those of alunite, and the determination as such may be considered reasonably certain. The alunite appears to have been formed during the later stages of precipitation of the hyalite. Compared with hyalite, it is present in small amounts. The small geodes of alunite, when examined under high powers,[12] glisten and sparkle with the crystal faces of this mineral and are exceedingly beautiful. The same mineral occurs in the more completely crystallized rhyolite of specimen 88434, which is likewise banded and full of gas-bubble pores.

It is of interest to inquire into the character and the temperature of the solutions from which the hyalite and alunite were deposited. In this connection one feature is of special interest: The obsidian fragments and blocks which are associated with the hyalite and alunite occurrences are

[12] For the examination of extremely minute crystals in the hand specimen, the following method has been found satisfactory: Use a binocular magnifying glass (magnification, 65 ×) and view object illuminated by a strong electric light, partly inclosed in a brass holder mounted on a universal arm, which is attached to binocular stand and can be moved in any direction, thus enabling the observer to illuminate at will any particular crystal from any desired direction.

still unaltered, but their surfaces are deeply etched, pits and narrow grooves cutting into the surfaces 3 or 5 and even to 15 mm. (see figure 11, specimen 77616, and figure 12, specimen 88435). These markings vary in shape and size from semicircular grooves, which have been well characterized as lunar crater forms by G. P. Merrill,[13] to straight channels not unlike the marks left by an engraver's tools. The distribution of the various markings, both regular and irregular, follows no discernible order; and the question of the mode of formation of such remarkable etch phenomena is of interest especially because of the similarity of these

FIGURE 11. *Etched Surface of Obsidian Glass, moldavitic in Character*
Specimen 77616. Two-thirds natural size

markings to those which are found on the moldavites of Bohemia, which have been described in great detail by F. E. Suess,[14] who considers them to be of extraterrestrial origin.

In the present case the origin of the etch figures is clearly shown by the records contained in the present suite of specimens. The following facts have a direct bearing on the problem: (1) The etching is evidently the work of hot and probably alkaline solutions. This is inferred from

[13] Proc. U. S. National Museum, vol. 40, 1911, p. 485.
[14] Jahrb. d. K. K. Geologischen Reichsanstalt, vol. 50, 1900, pp. 193-382.

the obvious connection between the deposition of hyalite (specimen 88435) and the etch pits. In figure 12 a face of obsidian is shown from which a crust of hyalite was broken off. The surface shows etched grooves and markings like the lines on a turtle shell: they were obviously formed during the deposition of the hyalite. A careful study of the entire specimen under a binocular microscope leads to the conclusion that the solutions actually bored into the obsidian and continued to do so until a protecting crust of hyalite was formed. The irregular distribution of the etch channels seems to be, in part at least, the result of the irregular precipitation of hyalite from an exceedingly mobile medium, probably a

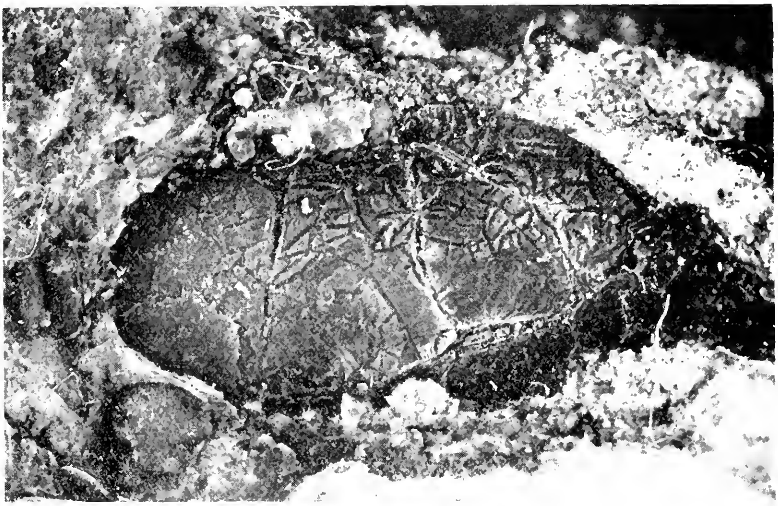


FIGURE 12. *Etched Surface of a small Obsidian Fragment*

The surface was protected in part by a coating of hyalite circulating solutions which reached the obsidian along cracks in the hyalite mantle. Specimen 88435. Magnification, 10 ×.

hot solution with admixed vapors: in short, from hot volcanic emanations which escaped from the intruded but still hot magma mass. In view of the high silica content of the obsidian, 75 per cent, it is probable that the etching solutions were alkaline and not acid. A glass bottle of the composition of obsidian should be an excellent retainer for even hot acid solutions. It is significant that the greater part of the hyalite was deposited before the alunite. This may indicate a gradual change in the composition of the volcanic emanations by the increased concentration of sulphuric acid.

(2) Experiments in etching both crystals and glasses have shown that the nature of the etched surface produced is dependent on the kind of

etching medium and on the character of the surface etched. The etching process is not unlike the abrasive action of sand-laden winds on exposed rock surfaces in deserts.[15] The attacking acid solution etches in the direction of least resistance and the material is carried away in solution. The solution currents form whirls and eddies, and thus favor unequal attack even on a perfectly homogeneous surface. Furthermore, any irregularities in the surface or material are emphasized by the solutions. An examination of the surface of the obsidian of the most uniform specimen, 88428, shows the presence of fine point irregularities, in the shape usually of minute triangular-shaped areas, as though at such points the cohesion of the obsidian was different from that of the surrounding points; this difference finds expression in the character of the surface of fracture obtained on the splitting off of the glass chips. Such points of unique cohesion are probably the minute bubble cavities which are scattered through the glass and are visible in thin obsidian splinters under the microscope. These points and cavities offer favorable points of attack for the etching solutions, which, as the dissolving action proceeds, continue to enlarge the cavities, and thus possibly to produce lunar crater forms on some of the specimens. Another explanation of these forms is that they are etched enlargements of original half-moon fracture cracks, produced by striking the glass fragment a sharp blow. The distinct wavelike lines, both radial from and concentric to the point of impact of a blow which fractures a piece of obsidian, are lines which exert a directive influence on the attacking solution, and thus give rise to certain types of the remarkable etch forms which we observe. Still another kind of crack requires mention, namely, the shrinkage rupture cracks, as shown in specimen 88429, described above. Into these fissures the solutions enter and tend to enlarge them. In the case of strain in the glass the solutions probably etch most rapidly along the lines of maximum strain, and this again tends toward irregularity of etching on the exposed surface.

In addition to these factors inherent in the etched material, any foreign substance, as a precipitate, attached to the surface serves as an obstruction to the acid streams of the solvent and forces them to flow along certain paths. Attention has been called above to the effect of precipitated hyalite in this direction. Observation proves that the pitted character of some of the slightly etched surfaces is not due to a spongy layer of original bubble cavities which have been exposed by subsequent fracturing.

[15] V. Goldschmidt and F. E. Wright: Neues Jahrb., Beilage Bd. xvii, 1903, pp. 355-390; Beilage Bd. xviii, 1904, pp. 335-376.

(3) The matter of internal strain noted above is significant for two reasons: (*a*) its directive influence on the etching solutions, and (*b*) the light which it throws on the former history of the fragment under examination. In the case of a large mass of obsidian, the internal strains set up on very slow cooling are virtually compensated at the period of their formation, so that the chilled product is a remarkably well annealed mass of glass far superior in this respect to the best optical glass.

Strain birefringence in the large fragments of the obsidian (specimen 88428) is hardly detectable even in the largest splinters, which are sufficiently transparent for observation. Around the radial spherulites (specimens 88432 and 88433) no strain birefringence could be detected in the adjacent glass in the thin section. This proves a very perfect state of annealing. On the other hand, the small etched fragments of obsidian in specimen 88435, which were found near the pond noted above and at some distance from the main obsidian mass, are in a state of severe strain. Small splinters of these fragments show gray interference colors and uneven distribution of the regions of differential compression and tension. The strain in these fragments is apparently even greater than that produced on heating a small splinter of the annealed obsidian in a Bunsen burner to a temperature of 1,000° or 1,200° C. and then quenching it in water. This proves clearly that the fragments are not simply fragments of the annealed obsidian mass which have been broken off and transported to their position and there etched, but that they were cooled very rapidly from a high temperature to relatively low temperatures. The natural inference is that they are shattered ejectamenta of the obsidian magma after the manner of the bombs of less siliceous magmas, or that they represent fragments of the outer chilled crust of the obsidian magma. The distribution of the strain phenomena indicates the first rather than the second inference. On the assumption that these fragments represent bombs, the irregular rupture shrinkage cracks are readily explained. A study of the types of volcanic bombs ejected by rhyolitic magmas and of the distribution of strain in them would be of interest in this connection. It is also important to note that on heating the obsidian in the Bunsen burner the obsidian tends to evolve gas bubbles and thus to become pumiceous. The tendency toward pumiceous development in some of the etched specimens has been noted above.

THE MOLDAVITES

In view of the great similarity between the etched surfaces of obsidian fragments at Hrafntinnuhryggur and those of the tektites, especially the moldavites of Bohemia, which have been considered to be of extraterrestrial origin, it is of interest to examine the strain phenomena in specimens of moldavites. Moldavites are fragments of a green-colored glass which occur in certain gravels in Bohemia, especially near Budweiser and Treibitsch, and are characterized by remarkable surface markings similar to those described above. The distribution of the moldavites is not unlike that of Indian arrow-heads in the Middle West. The moldavites occur here and there, but never in any manner indicative of their origin. They approximate in composition a rhyolite glass high in silica. Because of their abnormal distribution and remarkable surface markings, Suess concludes, following a suggestion of R. D. M. Verbeek,[16] that they are meteoritic in origin, derived possibly from the moon. H. S. Summers,[17] in a recent study of obsidianites, concludes that the chemical evidence also indicates that they are of meteoritic rather than of volcanic origin. G. P. Merrill,[18] on the other hand, presents evidence against the necessity for considering the moldavites to be of extraterrestrial origin because of their external surface markings. The present study tends to confirm and to strengthen the objections advanced by Merrill.

With a proper choice of solution and temperature, it should be relatively easy on rapidly chilled specimens of glass of moldavite composition to reproduce the surface markings and thus to produce artificial moldavites. This Professor Merrill has shown to be possible by simple means, namely, by suspending fragments of obsidian or glass in hydrofluoric acid vapor. The mode of occurrence of the Hrafntinnuhryggur fragments is a good example of the result of the process at work in nature on a large scale.

Two instances may be cited to prove that etching phenomena of this type can be produced on other materials: (*a*) In the course of experiments on the etching of cleavage fragments of calcite, the writer observed etch pits and channels in process of formation on the under side of the fragment immersed in a weak solution of hydrochloric acid in a beaker.[19] (*b*) On a specimen of stalactite from Luray, Virginia (U. S. National Museum specimen 88436), the surface is pitted and grooved with shallow markings across the concentric layers not unlike some of the markings on the moldavites.

Passing now to the consideration of strain phenomena exhibited by the moldavites, we may first direct our attention to the different effects which result from the various physical conditions under which strain is

[16] Jahrboek van het Mijnwesen in hederlandish Oostindie, vol. xx, 1897, p. 235. Amsterdam.

[17] Proc. Roy. Soc. Victoria, vol. 21, pt. 2, 1909, p. 428.

[18] Proc. U. S. National Museum, vol. 40, 1911, p. 485.

[19] Neues Jahrbuch, Beilage Bd. xviii, 1904, p. 310.

produced in cooling glass. These are well known in the glass industry and apply with equal force to the cooling of a silicate glass of moldavitic or rhyolitic composition, provided proper allowance be made for differences which arise because of high silica content. On the cooling of a mass of glass heated to a high temperature, the outer portions of the mass in contact with air chill most rapidly and contract, but on so doing meet with resistance from the hot interior mass. This shrinkage against strong counter-resistance produces radial compression in the marginal shell, which, because of the rapid cooling, quickly becomes so stiff that appreciable movement is no longer possible; the material thus sets under a state of permanent radial compression. The central portion contracts, in turn, on cooling and tends to draw away from the now rigid incasing shell. Tensile stresses normal to the boundary surfaces are thus set up and the material soon acquires a permanent set under tensile strain. The net result of such rapid cooling is therefore an outer zone of radial compression which decreases rapidly toward the center of the mass; it becomes zero (neutral band or band of no strain) and passes finally into a wide central region of tensile stresses.

It is obvious that the relative intensities of the strain thus set up and the relative widths of the zones of compression and of dilatation depend on the composition and size of the glass mass, on the initial temperature of heating, and on the rate and conditions of cooling. Experiments have shown that in ordinary glasses the temperature region at which the viscosity of the material becomes so great that differential strains may persist for a period of time is between 250° and 450° C. Above 500° practically all differential stresses are relieved by flow of the material, while at 250° the movement in the material is so sluggish that a very long period of annealing is required to produce an appreciable relief of stress differences. At a still lower temperature the glass is so rigid that under small loads it behaves as an elastic solid and the forces of restitution set up as a result of the strain suffice to restore the material to its initial configuration on release of the load; in short, strictly speaking, the glass is no longer viscous, according to the established definition of the term. At ordinary temperatures the glass is so rigid, or its viscosity so great, that a state of strain may persist in it for geologic ages, as tests on obsidians have shown. It is evident, therefore, that the state of strain of a glass fragment may well serve as an indicator of the conditions under which it cooled.

The strain phenomena in glass are not apparent under ordinary conditions of observation, but they can be rendered visible by simple optical methods, which in this respect function as does the developer on the photographic plate. The optical effects resulting from strain were first studied in detail by Brewster in 1814, at a time when only the simplest of optical apparatus was available and but little was known of double refraction. Notwithstanding this, Brewster deduced from a series of ingenious experiments many of the fundamental laws of the optical behavior of glass strained either mechanically by differential pressure or tension or as a result of non-uniform heating or cooling. Brewster found that a plate of glass under load is birefracting; that the optical effect produced is sensibly proportional to the intensity of the strain; that a plate of glass under differential compression behaves optically as a uniaxial negative crystal with its principal axis in the direction of the acting load, while under differential tension it acts as an optically positive uniaxial crystal; that in a glass plate cooled quickly from a high temperature a permanent strain is imparted which is at maximum intensity next to the outer surfaces (zone of compression), and which, decreasing toward the center, reaches a neutral band and passes then into a zone of tension in the central part of the plate; that compression produces retardation, while dilatation causes acceleration of the transmitted light waves.

Since Brewster's time improvements have been made in the methods of observing and measuring strain birefringence, but these refinements are not required in the present problem. To study the distribution of strain in an irregular glass fragment, the only apparatus required is two crossed nicols and a sensitive tint plate. This is easily obtained by removing condenser, objectives, and eyepiece from the microscope and observing the fragment immersed in a liquid of the same refractive index. For this purpose a small crystallizing dish or beaker is well suited as a container, and benzol, with refractive index approximately 1.50, as an immersion liquid. The purpose of the refractive liquid is to overcome the annoying surface reflections from the glass surface, which tend to disturb and to mask the interference phenomena resulting from strain.

Returning now to the moldavites, we have three possibilities to consider:

(1) The moldavites are etched fragments of a large mass of slowly cooled obsidian. In this case, as we have seen above, little, if any, strain is present. Between crossed nicols the fragment is practically isotropic.

(2) The moldavites are volcanic ejectamenta which were originally molten, but were chilled rapidly during contact with the air. In this case they should show a considerable amount of strain, with an outer zone of compression, an intermediate zone of no strain, and a central region under dilatational strain.

(3) The moldavites are meteoritic in origin. In the case of meteorites the conditions are unique. The meteor enters the earth's atmosphere as a very cold body. The frictional resistance of the atmosphere very quickly raises the temperature of the exposed surface of the meteorite to the melting region. Such melted portions are then brushed off, with the result that only a thin crust of the molten matter is left on the meteorites when they reach the earth's surface. The period of flight through the atmosphere is of such short duration that the center of the meteorite does not become appreciably heated. According to Professor Merrill, to whom the writer is indebted for a statement of the conditions which obtain during the fall of a meteorite, the only recorded instance in which a meteorite was touched immediately after it had reached the earth's surface showed that the meteorite was "stone cold." The result of such conditions of flight and local surficial heating is intense local strain analogous to the strains set up on inserting a large piece of glass into a hot Bunsen flame. The glass fragment commonly cracks into pieces, or small chips spall off analogous to exfoliation shells on rocks exposed to sudden changes in temperature. The outer forms of stony meteorites indicate that they have been subdivided in this manner.

The distribution of the strains set up under such conditions can be readily obtained by inserting the edge of a cover glass or object glass into a Bunsen burner. If care be taken to avoid fracturing, the edge of the glass plate melts, while the center and opposite edge are still cold. Examination of the plate after cooling shows the presence of a very narrow marginal band under intense compressional strain, which decreases in the direction of the center and passes through a neutral line into a zone of tensional strain, which soon reaches a maximum and then diminishes gradually and practically disappears near the center. The glass plate usually breaks asunder later near the line of maximal tensional strain.

Examination of moldavite specimens from Bohemia[20] showed a distribution of strain identical with that described above for conditions of cooling postulated under case 2, namely, those of a highly heated or molten mass of glass chilled rapidly. The small etched obsidian fragments from Hrafntinnuhryggur (specimen 88435) exhibit the same distribution of strain. In the moldavite specimens the strain is distributed in such a manner as to indicate that they are not fragments of a large mass of annealed glass (obsidian or artificial glass) or single meteorites, but rather fragments resembling in character the spatters or splashes of molten obsidian described above. It should be noted, however, that the meteoritic origin of the moldavites is not absolutely disproved, for it is

[20] The writer is indebted to Professor Merrill for the loan of these specimens.

conceivable that all of the outer zone of intense compression and part of the inter zone of dilatation have been etched away, and only the central core of the original fragment is left. It does, however, prove that the present surface markings of the moldavites are not original surface markings produced on the fragment during its flight through space. This conclusion is in agreement with the inferences which have been drawn by Professor Merrill from the etching phenomena.

It may be noted that in highly siliceous glasses the birefringence developed for a given load is less than that developed under similar conditions in ordinary, less siliceous glasses, which have much higher coefficients of expansion.

Summary

The obsidian at Hrafntinnuhryggur, near Myvatn, Iceland, is of special interest to the geologist because of the unusual opportunity it offers for the study of the effects resulting from the physico-chemical conditions of cooling. In the present paper the formation especially of spherulitic, lithophysal, and pumiceous structures is discussed; certain remarkable surface markings resembling the pits and grooves on moldavites are also described briefly. They were produced by the etching effect of hot volcanic emanations on fragments of obsidian glass.

The evidence given above indicates that in the formation of the lithophysae gases were active. These volatile components, which were released from the magma during the crystallization of the radial spherulites, attacked part of the material of the spherulites; new crystal compounds, as tridymite and fayalite, were formed which bespeak conditions of formation different from those under which the original spherulites were crystallized. The pressure of the liberated volatile components aided materially in the original formation and subsequent enlargement of the lithophysal cavities. The general hydrostatic tension (external pull) resulting from shrinkage of the central part of the cooling magma probably aided in this development, but the inclosed gas pressing against the walls of the cavity was also an important factor.

Volatile components set free during the crystallization of a spherulite may either escape along minute cracks and spaces in the spherulite to its margin and there form a bubble in the viscous magma or the viscosity of the magma may be such that the internal gas pressure forces asunder the spherulite. In the first case the presence of the gas bubble adjacent to the spherulite hinders the further growth of the spherulite at that point, with the result that the spherulites with adjacent bubble cavities are well developed, as in specimens 88430 and 88432, described above. In the second case it is important to note that the forcing apart of the cavity was a very slow process. The first rupture took place when the spherulite was small; the rigid walls of the cubical or irregularly shaped cavity thus formed were constantly forced apart, but continued to grow as crystallization advanced. The edges of the cube were thin and in contact with the magma, which, however, was probably so thick and viscous that less resistance was offered to the slow forcing apart of the walls of the spherulite than to the formation of gas bubbles adjacent to the spherulite. Examples of this phenomenon are shown by specimen 88431. It is not possible to determine from the scant evidence at hand the several quantitative factors which are essential to the formation of the type of lithophysal cavities of specimen 88431.

Evidence is also presented which shows clearly that the deeply etched surfaces on irregular fragments of the obsidian are the result of etching by hot circulating solutions from which large amounts of hyalite were deposited. Minute crystals of alunite were also deposited during a later stage of circulating solutions. The close resemblance of the surface-etching phenomena thus produced to the surfaces of moldavites and other tektites is emphasized; also the mechanics of the etching process by which such extraordinary forms are obtained. The distribution of strain within the moldavites is considered briefly. The conclusion is reached that neither the external form of the moldavites nor the distribution of strain within them can be considered to be an indication of their extraterrestrial origin, as has been stated by Suess. This conclusion is identical with that recently advanced by Merrill, and the above evidence serves to strengthen the position taken by him.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 287-294 JUNE 30, 1915

POST-ORDOVICIAN DEFORMATION IN THE SAINT LAWRENCE VALLEY, NEW YORK [1]

BY GEORGE H. CHADWICK

(Presented before the Society December 31, 1914)

CONTENTS

INTRODUCTORY

That the Paleozoic rocks of the Saint Lawrence Valley are gently undulatory is no new announcement, though it may be so regarded for the area immediately under discussion, namely, the Canton, New York, topographic quadrangle. These undulations were described on the Canadian side of the river as early as 1863 by Logan,[2] and again more recently by Cushing for the Watertown district[3] on the New York side. The present paper records their extension into the Ogdensburg-Canton quadrangles and discusses the evidence as to their origin and their relation to the belts of pre-Cambrian rocks beneath. The location of the two quadrangles is indicated on the key map, figure 1.

GENERAL STRATIGRAPHY OF THE AREA

Though the country is heavily drift-mantled, yielding few exposures, when the latter are plotted and connected up with regard to strike and to topography there results a pattern of outcrop sufficiently complicated (and likely to be found more so on removal of the drift) to denote the presence of two reticulating sets of folds here as in the Thousand Islands

[1] Manuscript received by the Secretary of the Society May 6, 1915.
With permission of the Director of the New York State Museum.

[2] Sir William E. Logan: "Geology of Canada," pp. 91, 94, 96, 114, 116, 117, etcetera.

[3] Prof. H. P. Cushing: Bull. 145, N. Y. State Museum, pp. 20, 113, 135-136.

region.[4] Nearly circular domes, with quaquaversal dips, are marked features of the good exposures along the Grass and Raquette rivers, occasioning several inliers, while bowl-shaped synclines containing outliers also occur. Though the dips are all low, seldom over five degrees, they reverse frequently or the strike veers rapidly in all the large outcrops. The general resultant is the very zigzag trace for the formation boundaries, as shown on the accompanying map, figure 2.[5]

No such zigzags are shown on the geologic maps of the State, as may be seen at once on comparison with the last State map of 1901. Their

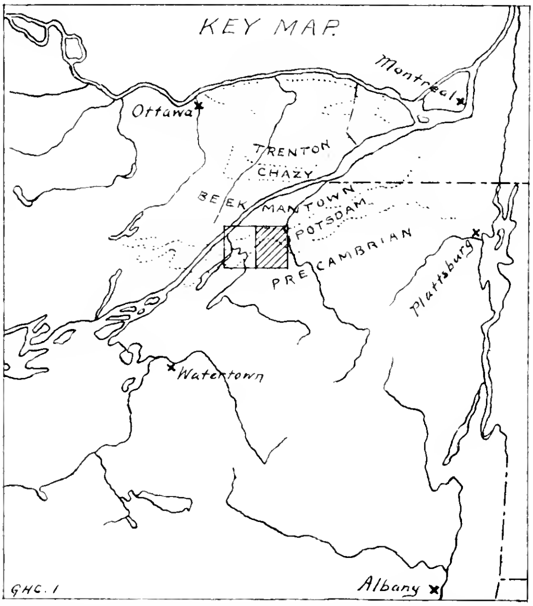


FIGURE 1.—*Map showing Location of Canton Quadrangle and Belts of Formations adjacent thereto* (after Logan and Merrill)

recognition has become possible through the refinement of the stratigraphic units in this region inaugurated by Cushing and Ulrich. In place of the old divisions, "Potsdam" and "Calciferous," we must now recognize the following formations in descending order:

[4] See Cushing, op. cit., p. 113.

[5] A word of explanation is in place here. The Ogdensburg quadrangle is being prepared by Professor Cushing, whose manuscript map has been kindly transmitted to the writer; but the generalized boundaries drawn in figure 2 had been previously worked out by the latter in a crude way. Since they form a part of the evidence material to this paper, they are here used with apologies to Professor Cushing, whose map shows the same essential fact of the larger zigzags.

A similar explanation and apology is due to Dr. J. C. Martin, who has mapped the pre-Cambrian rocks for the Canton sheet.

Upper Beekmantown (Ogdensburg) dolomite.
Unconformity.
Bucks Bridge (approximately Tribes Hill) mixed beds.
Unconformity.
Heuvelton ("Twenty-foot") white sandstone.
Theresa mixed beds (as restricted by Ulrich).
"Upper Potsdam" (Keeseville?) white sandstone.
Typical Potsdam sandstones (mostly red).

The name Heuvelton is introduced, with Professor Cushing's consent, for the heavy white sandstone, recognized independently by him and by the writer,[6] which from its resistant nature has proved the most valuable stratum on the Canton quadrangle for the solution of the stratigraphic problems injected by the obscuring drift-cover. It is characterized by

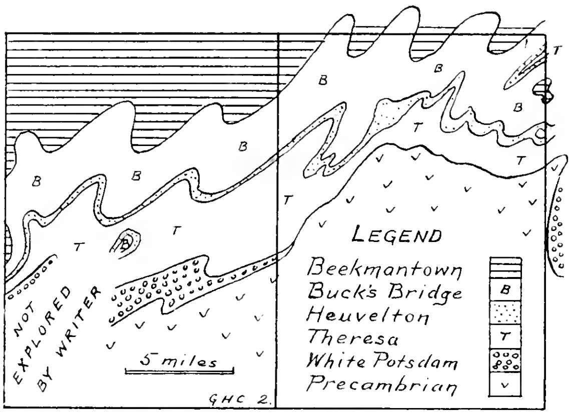


FIGURE 2.—*Folded Paleozoic Rocks on Ogdensburg and Canton Quadrangles*

Scolithus canadensis and by large gastropods suggestive of an Ordovician age, but seems conformable to the Theresa; the exact age is still in doubt. The overlying beds, totaling some 50 to 70 feet on the meridian of Canton, are characterized by *Palæophycus beverleyensis* and a lower Beekmantownian or Tribes Hill fauna; but as they differ lithologically from the beds of that formation in the Mohawk Valley and exact equivalency is not yet proved, the temporary designation Bucks Bridge is here retained. The distribution of these rocks on the Canton map is shown in figure 3.

In total absence of exposures it has been impossible to carry the Potsdam sandstones continuously across the sheet in figure 3, though present in various outliers. The upper layers may extend thinly across beneath the drift, as contended by Professor Cushing, but there seems hardly

[6] Report of Director of N. Y. State Museum for 1913, pp. 61, 64.

room for them on the Raquette River between the known Theresa and pre-Cambrian outcrops at Potsdam village,[7] and the formation presumably cuts out somewhere in the interval to reappear just east of Potsdam. There can be no question of the interruption of the lower or typical red sandstone, since the white beds are seen to rest directly on the crystallines in the more northerly outliers.

Form and Character of the Folds

Scrutiny of the map (figure 3) reveals an interesting relation between the folds there indicated and the belts of pre-Cambrian rocks that are seen disappearing beneath them. From the way in which the Paleozoics here lap around the crystallines, the area is favorably located to exhibit this relation, which became apparent to the writer while yet ignorant of Logan's and unmindful of Cushing's contributions. Here, as in their areas, the alinement of the major axes is northeast-southwest parallel with the valley. But instead of the secondary set being gridironed over these at right angles in the fulcral direction of the Frontenac axis, the minor distortions in this region are dominated by the diagonal course of the underlying pre-Cambrian belts. With less drift-mantle this would likely become even more apparent.

The question at once intrudes as to whether these very gentle undulations are not initial dips of strata laid down on the uneven surface of the much eroded crystallines or induced merely by vertical compression during consolidation. But the proofs of actual deformation are also to be found. Figure 4 shows crumpling of the limestone layers in the old quarry at Yaleville, on the west bank of the Raquette, a mile below Norwood. Figure 5 is a remarkable inverted buckle (syncline) in these same Beekmantown dolomites two miles farther down the river at Norfolk; this crosses the stream, the water of which is seen reaching up into its trough. Neither of these are conclusive, since similar structures are often ascribed to glacial or other agencies, though nothing quite like the latter instance has come to the writer's notice hitherto. But in the Potsdam outliers, in the southern half of the quadrangle, more convincing phenomena are at hand. A notable chain of these outliers has been preserved from erosion in the Grenville marble belt of Harrison Creek and Grass River (see figure 3). These occupy the middle of a pre-Potsdam Valley, on either side of which the harder granite gneisses rise from 50 to 100 feet above these Potsdam remnants. All of these patches exhibit

[7] The type locality for the Potsdam (red) is four miles farther up the Raquette in a pre-Cambrian embayment.

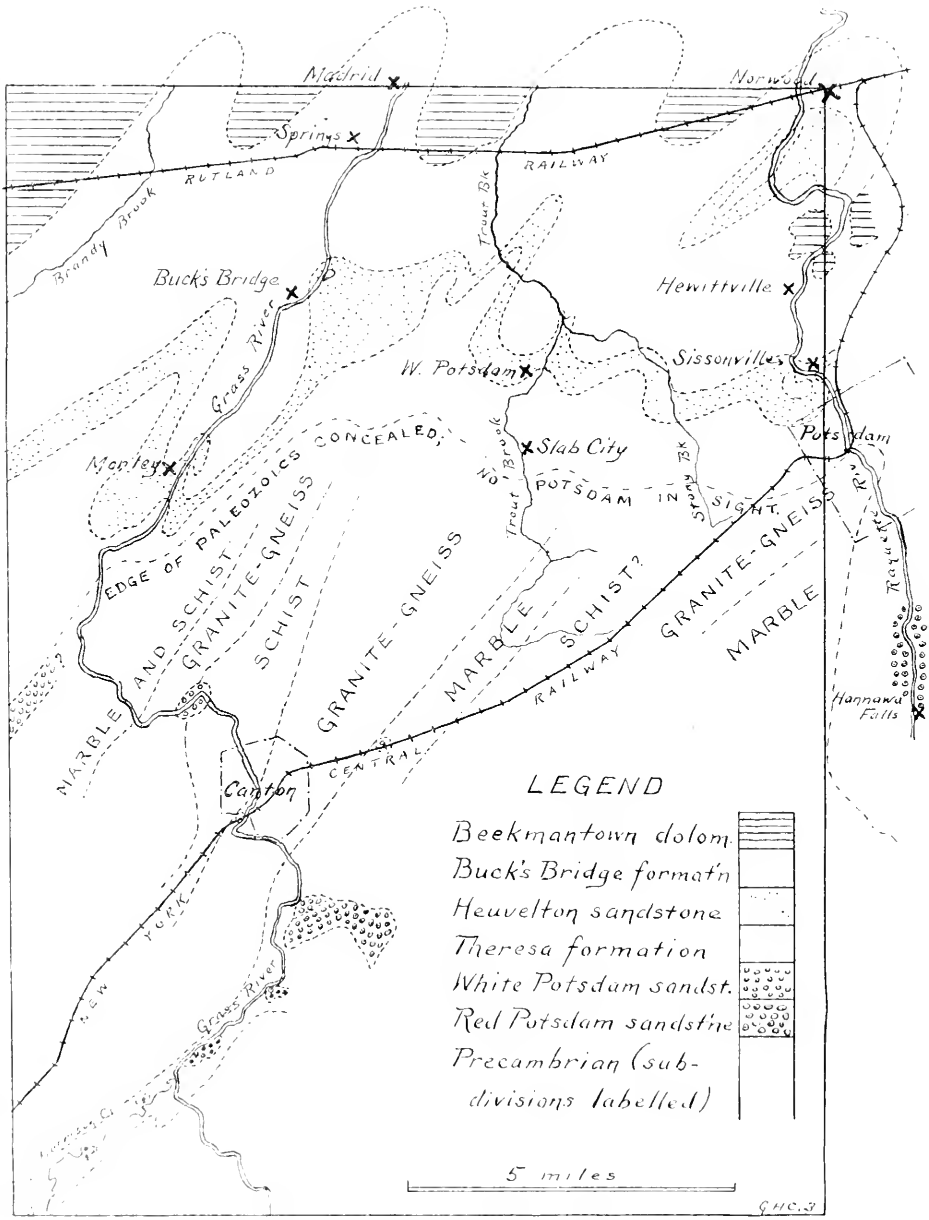


FIGURE 3. Partial geologic Map of Canton Quadrangle, showing Relation of Paleozoic Rocks to pre-Cambrian Belts

disturbance, the most noteworthy examples being at the east end of the largest, as shown in the cross-section (figure 6), and the area just below the name "Harrison Creek" of the map, of which a cross-section is given

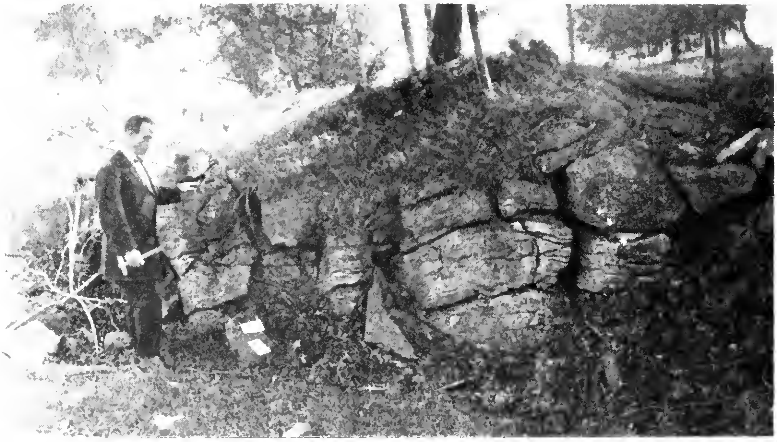


FIGURE 4. *Crumpling of Beekmantown Limestone in old Quarry at Yaleville*

FIGURE 5. *Inverted Buckle crossing Raquette River below Bridge at Norfolk*

in figure 7. The close plications of the latter seem explicable only in terms of a lateral compression, involving necessarily the underlying crystallines. A slight pinching of the pre-Cambrian syncline is all that is required, as illustrated in the diagrams (figures 8 and 9).

FIGURE 6.—*Actual Cross-section of Potsdam Beds one Mile northwest of Brick Chapel, New York*

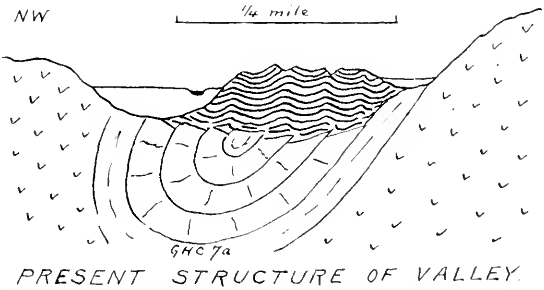


FIGURE 7.—*Cross-section of Potsdam Outlier on Harrison Creek. (Vertical × 3)*

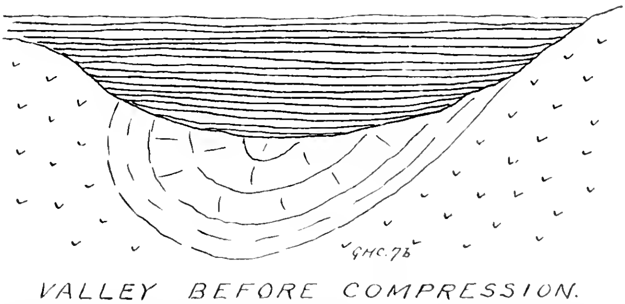


FIGURE 8.—*Ideal Cross-section of same Valley before Deformation began*

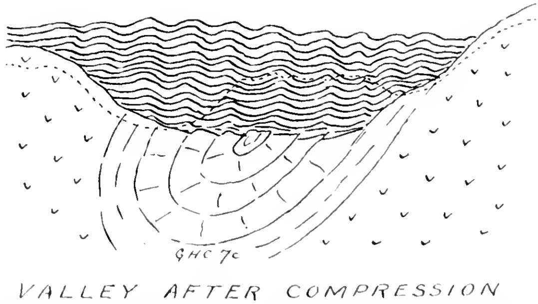


FIGURE 9.—*Same Valley after Deformation; dotted Line shows Present erosional Profile*

In the diagrams (figures 7, 8, and 9) the vertical scale is exaggerated three times and the amount of compression is also overdrawn for the sake of perspicuity, but dips as high as 30 degrees were measured here in the Potsdam, and at least four good synclines can be made out in less than a quarter of a mile, having always the steeper dips toward the southeast as do the crystallines. In figure 6 there is no exaggeration and the dips are shown as actually measured, reaching 15 degrees at one point on the east knoll. The amplitude of these folds is quite the same (about 300 feet) as of those on Harrison Creek, but the jaws of the pre-Cambrian vise are not so visible here, the conditions being probably more as in figure 9. At other near-by outcrops the Potsdam has suffered crushing and microfaulting or brecciation, and just north of Dekalb village ("Old Dekalb"), on the south margin of the Ogdensburg quadrangle, is the fine example of crumpling figured long ago by Emmons.[8]

Time and Cause of the Folding

These observations, which can be duplicated at many other points in the Saint Lawrence Valley, indicate that we are dealing here with a true deformation superimposed on the original stratification and involving rocks as young at least as the Beekmantown. Cushing[9] believes that these movements were under way even earlier, and in favor of this view the writer would urge the much greater disturbance of the Potsdam, and particularly the *red* Potsdam, in the Canton region, the difference being so marked as to lead to a search for an unconformity at the summit of the latter—a search that failed because no contact could be located. The most suggestive locality is the knoll just south of old Dekalb, on the Gouverneur quadrangle.

In casting about for an explanation of this deformation, which is widespread over the district between the Adirondacks and the Laurentide hills, beyond the Ottawa River (see key map), it is most natural to turn to the former as the seat of disturbance, since they have been repeatedly domed upward, besides block-faulted. The comparatively thin veneer of Paleozoics in the continually deepening trough of the Saint Lawrence could hardly fail to experience some crowding during such domings of the Adirondack massif, and all the facts seem to accord well with this inference.

---

[8] Dr. E. Emmons: Geology of the Second District, New York, p. 104.

[9] Op. cit., p. 114.

BULLETIN

OF THE

Geological Society of America

VOLUME 26 NUMBER 3
SEPTEMBER, 1915

JOSEPH STANLEY-BROWN, EDITOR

PUBLISHED BY THE SOCIETY
MARCH, JUNE, SEPTEMBER, AND DECEMBER

CONTENTS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

Subscription, $10 per year; with discount of 25 per cent to institutions and libraries and to individuals residing elsewhere than in North America. Postage to foreign countries in the postal union, forty (40) cents extra.

Communications should be addressed to The Geological Society of America, care of 420 11th Street N. W., Washington, D. C., or 77th Street and Central Park, West, New York City.

NOTICE.—In accordance with the rules established by Council, claims for non-receipt of the preceding part of the Bulletin must be sent to the Secretary of the Society within three months of the date of the receipt of this number in order to be filled gratis.

Entered as second-class matter in the Post-Office at Washington, D. C., under the Act of Congress of July 16, 1894

PRESS OF JUDD & DETWEILER, INC., WASHINGTON, D. C.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 295-302 AUGUST 17, 1915
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

CLOSE OF JURASSIC AND OPENING OF CRETACEOUS TIME IN NORTH AMERICA [1]

BY HENRY FAIRFIELD OSBORN

(Presented before the Paleontological Society December 30, 1914)

CONTENTS

FIRST SYMPOSIUM

A year ago the Paleontological and the Geological Societies united in a symposium on *The Close of Cretaceous and Opening of Eocene Time in North America*. That symposium brought out very clearly the wide differences of opinion and practice now prevailing among American geologists and paleontologists as to the kinds of evidence on which we must chiefly rely in geologic and paleontologic correlation, chiefly as to the relative criteria of earth movements and of paleontology.

SUBJECT OF SECOND SYMPOSIUM

We are now met to discuss the characteristic features of another important period of geologic time, namely, the Jurassic-Cretaceous limits, as they have been defined in Europe, from which, it can not be too

[1] This paper, which was delivered orally and has since been put in the present written form, is an introduction to the symposium on this subject held at the Philadelphia meetings of the two societies December 29-31, 1914. It is the second paleontological symposium presented before the two societies in joint session. Manuscript received by the Secretary of the Geological Society July 2, 1915.

strongly stated, we must take all our geologic time standards and demarkations. In this connection I would like to repeat the main statement in my address last year: "American events can be dated only by comparison of American with European faunas and floras, unless simultaneous and world-wide diastrophic movements can be demonstrated to have occurred." This statement does not refer to the general diastrophic theory, which we are not now discussing, but to the attempt through appeal to the diastrophic theory to determine such boundaries as the Cretaceous-Eocene and Jurassic-Cretaceous by reference to breaks in sedimentation which may be local rather than world-wide.

European Jurassic—Cretaceous Division Line

In Europe the Jurassic-Cretaceous division line is by most geologists drawn between the fresh-water series of clays and sands in England known as the Wealden, and the underlying Purbeckian; in other words, the demarkation may be expressed as follows:

Base of the Cretaceous = Wealden
Summit of the Jurassic = Portlandian-Purbeckian

The problem before us in this symposium is, how can this Old World stage of geologic time be most surely synchronized in the New World?

Having devoted many years to the special subject of correlation between the Tertiaries of Europe, North America, and southeastern Asia, I have formed the very strong personal opinion that in correlation between such *periods* and *stages* as these we must rely chiefly on paleontology. This is for the very important underlying reason that the most stable, orderly, measurable, and coincident phenomena are those deep-seated changes arising from the hereditary germ plasm which are outwardly and visibly expressed in the various forms of animal and plant life. Paradoxical as it may sound, hereditary protoplasm is much more stable than the surface of the earth.

Diastrophic and paleontologic Evidence as Basis for Determinations

Rising and falling coast or sedimentation lines in the pre-Tertiary and Tertiary, or even the larger earth movements causing true unconformities, such as the birth of mountain systems and the earth changes incident thereto, may or may not be coincident in time in two continents on opposite sides of the world. As a matter of fact, we know that the successive orogenic movements or birthdays of many great mountain ranges, like the Rockies, the Pyrenees, the Alps, the Himalayas, have not been coincident in time. Similarly it remains to be shown that great coastal movements, such as those of America and Europe in Tertiary time, were coincident. Many are certainly known not to be coincident, and it follows that at least a very large percentage of disconformity and unconformity is not diastrophic in the broad sense in which the term is properly used.

On the other hand, the progressive and retrogressive evolution of animal and plant types on the two continents, or even on the four continents, presents a most impressive array of precisely or closely similar coincidences of precisely or nearly similar events in time. If any great or striking discords could be demonstrated between the rates of evolution of animals and of plants of similar descent in different continental areas then correlation through paleontology would largely break down; but *uniform rates of evolution of organisms of similar ancestry even where widely separated geographically* is the prevailing law, notwithstanding that there are exceptional cases both of retardation and of acceleration.

It is absolutely necessary that those geologists who base their time determinations on appeals to the diastrophic theory should establish their first premise, namely, that the actual or alleged movements in America were coincident in time with similar diastrophic movements in Europe and Asia.

In the present Jurassic-Cretaceous problem it is necessary for the adherents of the diastrophic system of correlation to prove that large and coincident earth movements on both sides of the Atlantic marked the boundary between Jurassic and Cretaceous time. First, that at the close of the Jurassic a movement of elevation expelled the sea from the Rocky Mountain region, and that following this in Lower Cretaceous time a submergence took place. Second, that in England, where the close of the Jurassic and beginning of the Cretaceous was first clearly defined by paleontologists, a diastrophic movement took place during or immediately after the Purbeckian. Third, that in other parts of the world there are similar diastrophic boundaries between the Jurassic and Cretaceous.

To take but a single illustration: if we glance at the schematic section of the relations of the Jurassic and Cretaceous in Wiltshire, England, we find an entirely different set of conditions than those demanded by the diastrophists: not even the first condition is fulfilled, for the Jurassic, with its closing successive stages—the *Kimeridgian, Portlandian, Purbeckian*—passes gently and without marked change into the Wealden. There may be some disconformity; there is no angular unconformity. Only *after the time interval between the Jurassic and Cretaceous* has long elapsed, namely, after the long Wealden stage, there occurs a great earth movement, and the succeeding Cretaceous stages are deposited horizontally on the sharply upturned basal Cretaceous, or Wealden.

This is clearly shown in the accompanying figure (figure 1), reproduced from Haug.[2]

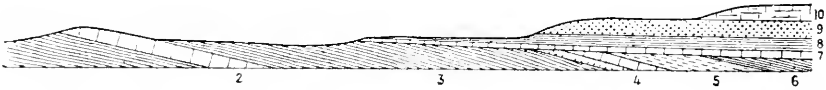


FIGURE 1. *Relations of the Jurassic (1-5) and the Cretaceous (6-10) in Wiltshire, England.* (After H. B. Woodward and E. Haug)

Cretaceous:
10. Turonian.
9. Cenomanian (= Base of Upper Cretaceous).
8. Albian.
7. Aptian.
(Great diastrophic movement, causing angular unconformity.)
6. Wealdian. Iguanodonts more specialized than those of the Morrison.

Upper Jurassic:
5. Purbeckian. Mammals similar to those of the Morrison.
4. Portlandian.
3. Kimeridgian. Iguanodonts similar to those of the Morrison.
2. Lusitanian.
1. Oxfordian. Marine invertebrate life similar to that of the *Sundance*. Sauropoda similar to the most primitive forms of the Morrison. Toothless ichthyosaurs, *Opthalmosaurus*, similar to the Sundance *Baptanodon*. Vertebrate and marine invertebrate fauna correlated with that of the *Sundance*, which is referred by Stanton (1909) to the lower part of the Upper Jurassic.
(Callovian.)

Fauna and Flora

Now, let us examine more closely the European stages and their fauna. In the classification of D'Orbigny the last stage of the Jurassic system was designated under the name Portlandian, derived from Brongniart. "This," observes Haug (*op. cit.*, page 1075), "can be extended to the upper Oölithic group by comprising within it the Purbeckian, which is simply a brackish facies of the superior portion of the Portlandian stage and which varies in thickness in different regions." Beneath the Portlandian is the *Kimeridgian*, beneath the latter the *Lusitanian*, and beneath this again the *Oxfordian*. It is in the Oxfordian that the earliest Sauropoda of the type of *Cetiosaurus* occur in Europe, a type of dinosaur which is in a stage of evolution similar to that of the *Haplocanthosaurus* of the Morrison of Cañon City, while within the Kimeridgian is found a species of iguanodont dinosaur known as *Camptosaurus prestwichi*, which is very similar (*teste* Gilmore) to the *Camptosaurus nanus* of the Morrison; in fact, all the camptosaurs of the Morrison are more generalized and primitive in structure than the iguanodonts of the Wealden.

---

[2] E. Haug: "Traité de Géologie, vol. ii, Les Périodes géologiques." 8vo. Armand Colin, Paris, 1908-1911, p. 1187.

Having brought the charge against the earth-movement theory that no evidence has been adduced that at the close of Jurassic time similar great diastrophic movements took place in America and Europe, but that, on the contrary, there is a striking discordance in the periods of diastrophism, I now desire to bring the charge against the paleontologists that those who have sought to solve this important and interesting question of the age of the Morrison through paleontology have never done their work thoroughly; most of the paleontologists, myself included, have made hasty conclusions, based on incomplete examination and comparison of material which is very rich and certainly affords ample basis for more exact correlation than has yet been made.[3] From the Morrison alone (the Jurassic or Lower Cretaceous age of which is in dispute) 151[4] species of animals and plants have been named as follows:

Mammals, 25
Birds, 1
Sauropodous dinosaurs, 31 (+ 3 in Arundel of Maryland)
Carnivorous dinosaurs, 13 (+ 3 in Arundel of Maryland)
Armored dinosaurs, 10-11 (+ 1 in Arundel of Maryland)
Iguanodont dinosaurs, 14 (Camptosaurs) (+ 1 in Arundel of Maryland)
Rhynchocephalians, 1
Crocodiles, 3 (+ 1 in Arundel of Maryland)
Turtles, 1
Pterosaurs, 1
Fish, 3
Species of invertebrates, 24 (+ 4 in Arundel of Maryland)
Species of plants, 23

Résumé of Conclsions of Paleontologists, Geologists, and Paleobotanists

A vast literature has accumulated. In preparation for the geologic section alone of my monograph on the Sauropoda for the United States Geological Survey, my research assistant, Dr. Charles C. Mook, has listed 239 titles in the bibliography of the Morrison formation, the greater part of which deal with the geologic structure of the formation itself in different regions. There are, besides, a large number of papers on the Morrison fauna and flora, for we have over 300 titles on the Sauropoda alone. The conclusions which have been reached by the authors of these various contributions and of the papers in the following symposium are as follows:

[3] An exception to this statement may be made in favor of Prof. S. W. Williston's excellent paper in the Journal of Geology for 1905 (vol. xiii, May-June, pp. 338-350), in which he discusses the faunal relations of the Morrison.

[4] The actual number of species is probably less than this as many of the species have been founded on fragmentary material and probably are synonyms.

Morrison of Upper Jurassic Age	*Morrison of both Upper Jurassic and Lower Cretaceous Age*	*Morrison chiefly of Comanchian or Lower Cretaceous Age*
C. A. White, 1883, invertebrate paleontologist.	J. B. Hatcher, 1903, geologist and paleontologist.	W. B. Scott, 1897, geologist and paleontologist.
Edw. D. Cope, 1884, paleontologist.	S. W. Williston,[5] 1905, geologist and paleontologist.	S. F. Emmons, 1896, geologist.
Henry F. Osborn, 1888, paleontologist.	W. D. Matthew,[6] geologist and paleontologist.	Logan, 1900, geologist.
Lester F. Ward, 1900, paleobotanist.	W. B. Scott, 1907.	N. H. Darton, 1915, geologist.
Wilbur Knight, 1900, geologist.	Chas. C. Mook, 1915, geologist.	W. T. Lee, 1915, geologist.
E. S. Riggs, 1901, paleontologist.	T. W. Stanton, 1909, geologist and paleontologist.	E. W. Berry, 1915, paleobotanist and geologist.
O. C. Marsh, 1896, paleontologist.	T. W. Stanton, 1915.	
F. B. Loomis, 1901, paleontologist.		
C. W. Gilmore, 1909, paleontologist.		
W. J. Holland, 1912, paleontologist.		
H. E. Gregory, 1914, geologist.		

Character of paleontologic Evidence

The fact that the evidence from paleontology has thus far not been found conclusive is largely due, as stated above, to lack of thoroughness in the comparison both of the carnivorous and of the large herbivorous dinosaurs of the Morrison, which include forms resembling those which range from the Oxfordian through the Kimeridgian into the Purbeckian and even into the Wealden. In general, it is said the Morrison dinosaurs are more specialized than those which have been found in the true British Jurassic formations, but there are some very striking exceptions. The mammals appear to be closely related in their stage of evolution with those of the Purbeckian of England. This would tend to correlate at least some parts of the Morrison with the Purbeckian of England as Upper Jurassic. This was the main strength of Professor Marsh's argument. The invertebrate fauna gives little satisfactory evidence as to age. The Morrison flora is scanty, consisting almost entirely of cycads. Lester F. Ward considered the cycads as proof of Jurassic age; but some-

[5] W. B. Scott: "An Introduction to Geology." 8vo. Macmillans, 1907, pp. 680-681. "It has been suggested by Professor Williston that different areas of the Morrison are of different dates, just as we saw that the Millstone Grit (Upper Carboniferous) of the Mississippi Valley is not a single uniform bed, but different beds of similar character, formed successively and corresponding to several horizons in the great mass of the Appalachian Pottsville. On this view, which is probably the solution of the problem, the Morrison includes several distinct horizons, extending from the Upper Jurassic into the Lower Cretaceous, but the discrimination of these horizons is yet to be made."

[6] Personal communication, 1915.

what similar cycads have been found in beds which are almost certainly Comanchian, so the cycads can not be used to finally determine this question. The relation of the age of the Morrison formation to that of the Potomac beds of the East and of the Kootenie in the West is important. The lower member of the eastern Potomac carries a flora which is very similar to that of the Kootenie in Montana, and the Kootenie flora, as pointed out by Berry, is closely related to the other well known Comanchian floras. Geologically the stratigraphic relations certainly appear to favor Lower Cretaceous, or Comanchian, age for large portions of the Morrison.

Phases of Problem, to whom Assigned

I have attempted by way of introduction to very clearly state the problem in regard to the age of the Morrison and the three answers which have been given to this problem.

In the succeeding contributions to the symposium Mr. W. T. Lee, of the United States Geological Survey, will apply the earth-movement theory to the problem and treat the subject from the point of view of the paleophysiographer.

Dr. Charles C. Mook, of the American Museum of Natural History, will point out the vast area of the Morrison formation, its variations in thickness and in lithological character, with reference to its mode of origin and the general sources of the material of which the formation is composed. He will show that the actual age of the individual exposures of the Morrison formation in one locality may differ considerably from the age of the formation in another locality.

Prof. R. S. Lull, of Yale University, will characterize the Sauropoda and Stegosauria of the Morrison, pointing out their means of migration and comparing the three great regions in which Sauropoda have been discovered, namely, the Morrison of America, the Oxfordian to the Wealden of western Europe, and the beds at Tendaguru in East Africa. The African beds contain certain large and highly specialized dinosaurs (*Brachiosaurus*) similar to those in the Morrison; they are also reported to be partly associated with or underlying Jurassic (Kimeridgian, Oxfordian) marine invertebrates.

Finally, Dr. T. W. Stanton, of the United States Geological Survey, will treat the subject rather from the invertebrate paleontologic standpoint in a comparison of the Morrison and the Comanchian in relation to the overlying and underlying formations in various parts of the western region.

Summary

When these contributions are published and can be carefully compared, it will probably appear as the chief result of this symposium that the intermediate theory is correct; that, as long ago suggested by Prof. S. W. Williston, the Morrison sedimentation was a very comprehensive and wide-spread process; that it began in certain localities earlier than in others, namely, during Upper Jurassic times; that it extended well into Lower Cretaceous times; that all the sediments known as Morrison represent a vast period of geologic time in which sedimentation was remarkably slow, because at no point does this so-called formation—which is rather a stage or series of stages in the European sense—attain any considerable thickness. The more primitive forms of Morrison life are partly, at least, truly Jurassic, while the more specialized progressive maybe are truly Lower Cretaceous.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 303-314 AUGUST 17, 1915
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

REASONS FOR REGARDING THE MORRISON AN INTRODUCTORY CRETACEOUS FORMATION[1]

BY WILLIS T. LEE

(Read before the Paleontological Society December 30, 1914)

CONTENTS

INTRODUCTION

The position in the time scale of a non-marine formation like the Morrison is difficult to determine unless it can be fixed in some way in a succession of conformable deposits, some of which at least are marine. Geologists have worked along the line of marine succession since the origin of their science, and on this succession mainly the commonly accepted stratigraphic columns and time scales are based. However, after all the excellent work of paleontologists, one of their number informs us that fossils alone too often lead to erroneous conclusions, and that "diastrophism affords the only means of finally attaining a reasonable, accurate, and systematically constructed classification" (1, page 605).[a] If this

[1] Contribution to the symposium held at the Philadelphia meeting of the Society December 30, 1914.

Published by permission of the Director of the U. S. Geological Survey.
Manuscript received by the Secretary of the Society April 3, 1915.

[a] For references see list at end of paper, p. 313.

be true for marine formations that have been most extensively studied, how much more is it true for non-marine formations whose fossils are often of questionable value in determining age?

It is safe to say that periods of erosion, with which might well be grouped periods of non-marine deposition, are comparable in duration to the recognized periods of marine deposition: but relatively little attention has been given to them. It would seem that a study of ancient land forms, together with a study of the physiographic conditions under which they developed, might lead to the establishment of a time scale that would be valuable for comparison with the scale now used, or at least serve as a check on it. In this connection it is evident that fossil plants are worth all the study and consideration they are now receiving, for although they are more difficult to collect than shells, they occur in non-marine deposits in number comparable to the shells in marine sediments. However, in the absence of an adequate study of paleophysiography it might be well to inquire if it is possible now to find and to apply physical criteria for determining the age of a formation like the Morrison, whose place can not be fixed in a marine conformable succession of deposits and whose age is not definitely indicated by its fossils. I may perhaps be pardoned, therefore, if, with due regard to the faunal evidence which I shall touch on very briefly, I attempt to find criteria outside the realm of paleontology that will aid in determining the age of the formation.

Faunal Considerations

It is well known to geologists that Marsh, who described so many of the Morrison dinosaurs, maintained that they prove the Jurassic age of the Morrison. The influence of his opinion is still strong, but geologists have gradually been drifting away from it. Marsh and others following him have regarded the Morrison as essentially equivalent to the Wealden (2, page 591); but, although the latter is now generally regarded as Lower Cretaceous, there are many who still hesitate to admit that the Morrison is post-Jurassic in age. The Arundel or middle formation of the Potomac group, as restricted by the Maryland Geological Survey, contains dinosaur bones which, according to the recent studies by Lull (3, page 178), correlate this formation with the Morrison. Berry (4, pages 163-164) also has recently shown that the Potomac plants, which occur mainly in the Patuxent formation below the dinosaur beds, are closely allied to the plants that occur in the Kootenai, which is possibly a little younger than Morrison (18, page 22).[2]

[2] There is doubt as to the relation of the Morrison to the Kootenai, but Fisher (18, page 22) has shown that the Kootenai lies with apparent conformity on beds which he

There is one other consideration connected with the fauna that I wish to submit before reviewing the physical evidence. It is well known that the dinosaur fauna of the Morrison is so extensive and varied that it has been regarded as the culminating fauna of the age of reptiles (5, page 97). It is not strange that land faunas, developed as they are in regions of general rock destruction, appear in maximum development without the preliminary stages where some exceptional condition makes possible their preservation. A fauna like that of the Morrison warrants the belief in a long period immediately preceding, during which physical conditions were favorable for its development. If the Morrison is Jurassic in age, the time available for the extraordinary differentiation of reptilian types seems insufficient and makes maximum development coincident with minimum land expansion. If, however, the Morrison is Lower Cretaceous and late Lower Cretaceous, as the physical evidence seems to indicate, ample time for this differentiation is afforded by the long intersystemic interval of maximum expansion of land areas which preceded its deposition. Furthermore, a natural consequence of such extensive and long-enduring land conditions is a corresponding extensive prevalence of surface erosion. Both the causal conditions of maximum land growth and its consequent erosional effects constitute criteria of generally admitted taxonomic value, the former being generally regarded as approximately delimiting geologic periods, while the latter results in the major unconformities which are properly used in separating geologic systems. That the results of this erosion are not more obvious in some places is doubtless due to the fact that the lands of the Rocky Mountain region were approaching the final stage of baseleveling.

Physical Considerations

IN GENERAL

Because the paleontologic evidence will be presented by others, I shall have little to say of it aside from the above brief remarks and shall approach the problem from a physical standpoint, taking what may be called a *physiographic* view. Inasmuch as many geologists maintain that it is improper to approach a question of geologic age from a physical standpoint, it seems advisable to make a brief statement of some of the principles on which my views are based.

---

recognized as the Morrison in Montana. Because of the close association and lithologic similarity of these formations, there is a feeling on the part of some geologists, among them Campbell and Berry, who have studied the question, that there is no essential difference in age between them.

PRINCIPLES

The position that I assume on this question is largely due to the principles enunciated several years ago by Prof. T. C. Chamberlin in a series of lectures that it was my privilege to attend. Some of these principles have been more recently amplified in his article on "The Shelf Seas of the Paleozoic and their Relations to Diastrophism" (7), and I take this occasion to express my appreciation of the service that Professor Chamberlin has rendered to the stratigrapher. It is sometimes difficult to adjust the time scale of one region to fit a standard previously established for another. It needs no argument to convince the reader that a scale appropriate for any one continent is imperfect and must eventually give place to a universal standard, and it begins to look as if the principles of diastrophism may eventually take a leading part in the adoption of such a standard, in the establishment of which the laws of terrestrial physics will play an important part; for I believe, with Schuchert (21, page 586), that "diastrophic action is at the basis of chronogenesis."

Without entering into a discussion of diastrophism, which, although pertinent in this connection, is too large a subject to discuss here, I may state that the basic principle that I shall use is this: A movement of land or sea of sufficient magnitude to make an appropriate separation of systems on one continent must be recognizable on other continents and is more likely to give exact time correlations than most groups of organisms. In Europe, with which comparisons in this case are made, the Jurassic closed with a retreat of the sea from the continent and the Lower Cretaceous was inaugurated by its return. It is not probable that the relations of land and sea would remain unchanged in America while such movements were affecting the European continent. It seems altogether probable that the withdrawal of the sea from Europe and from America was due to some common cause and took place at the same time, and that the ensuing early Cretaceous resubmergence began at the same time on both continents. However, this postulate, sound as it may be, falls short of complete solution of the Morrison problem, because the youngest marine formation below the Morrison is of late Jurassic age, being correlated on fossil evidence with the Oxfordian stage; and the oldest marine formation above it is of late Lower Cretaceous, of Washita age, leaving a possibility that the Morrison might belong either in the Lower Cretaceous or in the Jurassic.

It might be appropriate at this point to inquire what constitutes a geologic system. There are fundamental differences of opinion that find expression in the various schemes of classification, but I think that most geologists will agree that a system might properly be terminated by a maximum withdrawal of oceanic waters from land areas, and that the succeeding system might properly begin with the initial return of these waters.

During a retreat of the sea the emerging land is likely to be eroded, and a non-marine deposit laid down during its return is likely to be unconformable with the underlying formations and to be closely related structurally to the overlying formations. While this principle is applicable in ordinary cases, the physiographic conditions under which the Morrison was formed are so extraordinary that the possibility of an exception should be considered. Inasmuch as the Rocky Mountain region was low in Morrison time, it seems possible that slight changes in the altitude of land relative to sealevel would change aggrading to degrading streams, and *vice versa*. It is theoretically possible that a retreat of the sea into which such streams discharged might have so lengthened their courses as to reduce their gradients and cause them to deposit sediments. There is, however, a limit to the possible thickness of deposits laid down in this way, and this limit seems to preclude the possibility that Morrison deposition could be due alone to withdrawal of the sea. However, if the unexpected did happen in this case and the Morrison was formed during a time of retreat, it should be more closely related structurally and otherwise to the underlying than to the overlying formations.

If the diastrophic movement that caused the retreat of the Jurassic sea be accepted as terminating the period, the Morrison must have been formed either during a time of emerging land—or retreat of the sea—in which case it is Jurassic, or during a time of subsidence of land—or advance of the sea—in which case it is Cretaceous. Inasmuch as the sea did not return to the Rocky Mountain region until the latter part of the Lower Cretaceous[3] (Comanchean of Chamberlin and Salisbury), it remains to inquire whether the Morrison is more closely related to the overlying Cretaceous or to the underlying Jurassic. For this inquiry it is necessary to consider a group of formations that are either equivalent in age to the Morrison or are closely related to it.

EQUIVALENTS AND ASSOCIATES OF THE MORRISON

In character the Morrison formation throughout Wyoming and eastern Colorado corresponds essentially to the beds at the type locality at Morri-

[3] The reference of the Purgatoire formation, or Lower Cretaceous, of the Rocky Mountain region to the Washita epoch of the Lower Cretaceous is in accordance with the classification used by the Geological Survey (20). If, however, the Washita is Upper Cretaceous, as Berry asserts (4, pages 136-137) and as Haug (Text-book, pages 1169 and 1293) and other European geologists believe, the Purgatoire is also Upper Cretaceous and the overlying Dakota sandstone therefore holds a position somewhat above the base of this series.

son, Colorado, and are designated by the same name. However, in western Colorado the Gunnison formation, the upper part of which has been generally correlated with the Morrison, consists of two members (8, page 21), the upper of which is lithologically like the Morrison and contains the same kinds of dinosaurs, while the lower one consists of evenly bedded sandstone and some fresh-water limestone. The upper, or dinosaur-bearing, member is regarded as the direct equivalent of the typical Morrison east of the mountains and of the McElmo formation of areas farther to the west and south. The lower member has been considered equivalent to the La Plata sandstone of southwestern Colorado and to the White Cliff sandstone of eastern Utah (19), which underlies marine Jurassic. This may be correct, but it is not definitely known that the Gunnison includes rocks of such diverse age, nor is it beyond question that the La Plata and the White Cliff sandstones are time equivalents.

In northeastern New Mexico the typical bone-bearing Morrison rests on a massive sandstone, the Exeter (10, page 45), which is not present in all places. No fossils have ever been found in this sandstone and little progress has been made toward determining its age. When I first described it, I suggested that it might be as old as Triassic, but was probably younger. More recent investigations indicate that it is possibly a time equivalent of the La Plata sandstone. East of the mountains it has not been found north of New Mexico, but extends westward to Las Vegas (15, page 37), and occurs on the western slope of the mountains south of Lamy, New Mexico (16, page 649). Its extension farther to the northwest, in a region where little is known of the geology, is problematical, and the La Plata sandstone of southwest Colorado has not been traced eastward beyond Piedra Valley, in southern Colorado (9, page 14); hence its correlation with the Exeter rests on lithology, structure, and stratigraphic position.

CHARACTER OF THE MORRISON

The Morrison formation, including at least the upper part of the Gunnison, the McElmo, and other beds of equivalent age, extends from Montana to New Mexico and from the Black Hills and eastern New Mexico westward to Utah, an area about 600 miles long and 300 miles wide. It has been examined in hundreds of places and its character found to be so constant and its thickness so regular that it must originally have extended with practical continuity over this great area. It consists generally of shale of various colors and fine-grained sandstone, with a small amount of limestone; but in some places, especially in western Colorado, it contains some conglomerate. It is too well known to require extended description here, and it is perhaps sufficient to state that its character and distribution have been considered sufficient to indicate that it was probably deposited over floodplains on a nearly flat surface, in lagoons and temporary lakes, and in marshes along sluggish streams. The physical peculiarities of the Morrison are so striking and the fossils characteristic of it have been found in so many places that there is little difficulty in identifying it.

STRUCTURAL RELATIONS

I wish to call particular attention to the structural relations of the Morrison with the formations below and above it. At some of the localities where the Morrison has been examined there is an abrupt lithologic change from it to the rocks on which it rests. This suggests a time break, although in most places there is no obvious discordance in dip; but the reality of the hiatus becomes apparent when we find the Morrison overlapping older formations that range in age from Jurassic to Archean.

In most places the bedding planes of the Morrison are so nearly parallel with those of the formations above and below it that the structural relations can only be apprehended by taking a broad view. In some places in Wyoming, northwestern Colorado, and Utah the Morrison rests on marine Jurassic, and in other places on older rocks. In western Colorado the Gunnison is conspicuously unconformable on the older formations (8, 9), the upper part, or direct equivalent of the Morrison, overlapping the lower part, or possible equivalent of the La Plata sandstone. In eastern Colorado it rests on rocks of Triassic or Carboniferous age generally, but in some places, as near Pikes Peak (12) and east of the Greenhorn Mountains (13), it overlaps onto the pre-Cambrian granite. In northern New Mexico it overlaps the Exeter and rests unconformably on the Triassic. In brief, the relations of the Morrison to the underlying rocks are varied, and the unconformity below it denotes much more time in some places than in others.

In strong contrast with the unconformable relations at its base, the Morrison is obviously conformable with the beds above it. In relatively few places has the Purgatoire, or the lower part of the so-called Dakota, been proved to overlap the Morrison, and so many of the reported overlaps have been found erroneous (9) that there seems to be no good reason for postulating any considerable time break in the Rocky Mountain region at the top of the Morrison, although some geologists have regarded such a break as necessary in comparing the Rocky Mountains with other regions (5, page 109).

The contrast between the Morrison and the overlying sandstone has been pointed to by some geologists as evidence of a time break, and it might be interpreted as such if it were not negatived by other evidence. With few exceptions, the Morrison is present wherever the Dakota occurs in the Rocky Mountain region, and these exceptions are found near the areas over which the Morrison probably did not extend. Had any great length of time intervened between these formations, the soft beds of the Morrison would probably have been eroded away in some places; but no such place has yet been described. Be this as it may, there is no escape from the conclusion that the Morrison, as a formation, is structurally much more closely related to the overlying formations of Cretaceous age than it is to underlying formations. This was recognized long ago by Emmons (6, page 22), when he said: "From the point of view of the stratigrapher, the assignment of the Morrison beds to the Lower Cretaceous rather than to the Upper Jurassic is much more desirable . . . because it places the physical break whose effects are recognized over the whole continent between these two great time divisions rather than in the midst of one of them."

The same idea was recently expressed by Ulrich (1, page 615), when, in considering a question somewhat similar to the present one, he concludes: "Let us then be reasonable and practical and accept with proper valuation these diastrophic boundaries which nature has most clearly and widely indicated."

PHYSIOGRAPHIC CONDITIONS

Some fifteen years ago, when I began a study of the Morrison formation, it was generally spoken of as a lake deposit. It was difficult to conceive of a formation so wide-spread and so uniformly thin as having been formed in a lake, and several lines of evidence indicated that the formation is best explained as a series of fluviatile deposits. This hypothesis seems to harmonize with all the facts that have been gathered. It is evident to those who are familiar with the Morrison that the physiographic conditions under which it was formed were very unusual. In fact, it is doubtful if an area could be found at the present time that would even illustrate them. It is quite impossible to adequately present in a short paper the physiographic data affecting the Morrison problem, but a brief review may be useful.

The great sandstone formations of Carboniferous age that surround the Rocky Mountains and the presence in them of coarse conglomerate indicate that extensive highlands existed there in Carboniferous time. The Triassic formations also are conglomeratic in some places; but such highlands as may have persisted there from the Carboniferous were being eroded throughout the Triassic and Jurassic periods—a time amply sufficient for the reduction to a condition of low relief of large land masses. The time during which the Jurassic sea occupied the interior basin was probably only a small part of the period (11). The character of the Sundance (Jurassic) formation indicates that this sea came in over a well graded area. Later occurred what Emmons has called the Jurassic movement, which expelled this sea from the continent (6, pages 21 and 23), and which, in his opinion, should mark the close of the Jurassic period.

If the Jurassic movement produced any considerable highlands in the Rocky Mountain region, they seem to have been reduced nearly to base-level before Morrison time, for this formation bears evidence, as previously noted (5, page 119), of having been deposited on a nearly flat surface. There were land areas in the Rocky Mountain region somewhat above the level of Morrison deposition, for in some places the formation abuts against their flanks (9, 12, and 13). In a few places conglomerate is found in the Morrison (13 and 8, page 22), but on the whole the lithologic character of this formation indicates the presence in the Rocky Mountain region of lowlands rather than highlands. However, the distribution of the formation indicates that these lowlands were not extensive. Cross and Larsen (11, page 238) recognize this condition when, although they found the formation thinning out in some places, they state: "It seems . . . not unlikely that the Morrison beds on the east were connected originally with the Gunnison on the west."

The physiographic conditions of the time may be pictured as follows: After the long period of degradation that brought the highlands of the Rocky Mountain region to a condition of low relief, this region was uplifted sufficiently at least to expel the Jurassic sea. After a considerable interval of time, indicated by the extensive overlap of the Morrison, this region seems to have begun a slow general subsidence that resulted in the partial submergence of the interior of North America in the Lower Cretaceous and the more complete submergence in the Upper Cretaceous epoch. During this subsidence the streams deposited their silt farther and farther inland as the gradients were reduced until the lands of the Rocky Mountain region were finally submerged. The resulting fluviatile accumulations—the Morrison—were in turn buried by the sediments (Purgatoire formation) laid down in the encroaching Lower Cretaceous sea, which submerged the Morrison formation in eastern New Mexico and Colorado near the close of Lower Cretaceous time. These Lower Cretaceous sediments are so closely associated with the Dakota sandstone that until recently (17) they were regarded as parts of the Dakota. The Purgatoire and its possible time equivalents, Lakota and Fuson, and the lower part of the so-called Dakota, where a Lower Cretaceous portion has not yet been recognized, overlap the Morrison in only a few places (12). The Dakota appears to have entirely covered the areas now occupied by the Rocky Mountains. Although it is now absent in many places because of subsequent erosion, remnants of it occur on all sides of the mountains and in intermontane areas at elevations ranging to a maximum of 13,400 feet above sealevel (22). With very few exceptions, the Morrison is found below the Dakota (or Purgatoire, where that formation has been identified). The uniform distribution of these sandstones, taken in connection with their regularity in character and thickness, indicates that the sands were spread out over a nearly level plain. Although the Dakota in the Rocky Mountain region is plant-bearing and consequently a so-called fresh-water formation, it is probably a deposit of sand cleansed by wind and wave at the advancing front of the Cretaceous sea. It is believed that the sharp change from the Morrison to the overlying sandstone is due to this change in the conditions of deposition rather than to any lapse of time between them.

The essential points in this part of the geologic history of the Rocky Mountain region may be summarized as follows: That part of the region above sealevel already degraded to a peneplain near the close of the Jurassic period was disturbed by a movement that increased its relative altitude and expelled the Jurassic sea. The culmination of this movement is regarded as the close of the Jurassic period. This uplift was accompanied by continued degradation and followed by slow subsidence, which doubtless was intermittent and oscillatory, but which finally resulted in the formation of the basin occupied by the interior sea of Upper Cretaceous time. The Morrison was deposited on this graded plain by the streams made sluggish by reduced gradients. The region was partly submerged in late Lower Cretaceous time by the shallow waters of the sea, which reached at least as far inland as the present mountain front. This partial submergence was followed, either immediately or after a slight interval, by the greater submergence of Upper Cretaceous time, the first sedimentary expression of which is the Dakota sandstone, which in turn overlaps the marine Lower Cretaceous formations of the Rocky Mountain region and extends over areas that were above sealevel in Lower Cretaceous time.

Conclusions

The weight of physiographic and other evidence here considered seems to warrant the assignment of the Morrison formation to the Lower Cretaceous or Comanche series for the following reasons:

1. Its plant and vertebrate fossils indicate close relationship to the Arundel and Patuxent formations of the Potomac and to the Wealden, both of which are now generally regarded as Lower Cretaceous.

2. The evidence of a long period of erosion preceding the Morrison, together with the culmination of the reptilian fauna during this land stage, agrees best with the assignment of the Morrison to Lower Cretaceous.

3. It is much more closely allied structurally with overlying formations of mid-Cretaceous age—late Lower Cretaceous and early Upper Cretaceous—than it is to the underlying formations.

4. The overlap of the Morrison on a variety of older formations is indicative of a long interval of erosion.

5. The sea which occupied portions of the Rocky Mountain region in late Jurassic time was expelled by a movement that is regarded as a part of the diastrophism which brought the Jurassic period to a close.

6. The physical character of the Morrison and its relations to contiguous formations indicate that it was deposited on a peneplain at a time soon after the beginning of the Cretaceous subsidence, when the surface was too near sealevel for further degradation, but not yet low enough for marine submergence. It is therefore the first sedimentary expression in the Rocky Mountain region of the new order of events that culminated in the occupancy of the interior of North America by sea-waters in Cretaceous time. It is a non-marine forerunner of the Cretaceous marine formations and therefore of Cretaceous age.

References

1. E. O. Ulrich: The Ordovician-Silurian boundary. Congrès Gèologique International, XIIe session, Canada, 1913, pages 593-667, 1914.
2. T. W. Stanton: A comparative study of the Lower Cretaceous formations and faunas of the United States. Journal of Geology, volume v, 1897.
3. R. S. Lull: The Reptilia of the Arundel formation. Maryland Geological Survey, Lower Cretaceous, 1911.
4. Edward W. Berry: Correlation of the Potomac formations. Maryland Geological Survey, Lower Cretaceous, 1911.
5. T. C. Chamberlin and R. D. Salisbury: Text-book, volume iii, 1906.
6. S. F. Emmons: Geology of the Denver Basin in Colorado. U. S. Geological Survey Monograph 27, 1896.

7. T. C. Chamberlin: The shelf-seas of the Paleozoic and their relations to diastrophism and time divisions. Congrès Gèologique International, XIIe session, Canada, 1913, pages 539-553, 1914.

8. W. T. Lee: Coal fields of Grand Mesa and the West Elk Mountains, Colorado. U. S. Geological Survey Bulletin 510, 1912.

9. Whitman Cross and E. S. Larsen: Contributions to the stratigraphy of southwestern Colorado. U. S. Geological Survey Professional Paper 90-E, 1914, page 44.

10. W. T. Lee: Morrison shales of southern Colorado and northern New Mexico. Journal of Geology, volume x, 1902.

11. Whitman Cross and E. S. Larsen: The stratigraphic break below the Jurassic sandstone in southwestern Colorado. Journal of the Washington Academy of Science, volume iv, 1914.

12. Whitman Cross: U. S. Geological Survey Geological Atlas, Pikes Peak Folio (No. 7), 1894.

13. R. C. Hills: U. S. Geological Survey Geological Atlas, Walsenburg Folio (No. 68), 1900.

14. T. W. Stanton: Succession and distribution of later Mesozoic invertebrate faunas in North America. Journal of Geology, volume xvii, number 5, 1909, pages 410-423.

15. W. T. Lee: The Manzano group of the Rio Grande Valley, New Mexico. U. S. Geological Survey Bulletin 389, 1909.

16. W. T. Lee: Stratigraphy of the coal fields of northern central New Mexico. Bulletin of the Geological Society of America, volume 23, 1912.

17. T. W. Stanton: The Morrison formation and its relation with the Comanche series and the Dakota formation. Journal of Geology, volume xiii, 1905, pages 657-669.

18. C. A. Fisher: Geology of the Great Falls coal field, Montana. U. S. Geological Survey Bulletin 365, 1909.

19. C. T. Lupton: Geology and coal resources of Castle Valley, Utah. U. S. Geological Survey Bulletin (in manuscript).

20. G. W. Stose: U. S. Geological Survey Geological Atlas, Apishapa Folio (No. 186), 1912.

21. Charles Schuchert: The delineation of the geologic periods illustrated by the paleogeography of North America. Congrès Gèologique International, XIIe session, Canada, 1913, pages 555-592, 1914.

22. W. T. Lee: Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico. U. S. Geological Survey Professional Paper 95-C, pages 27-58, 1915.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 315-322 AUGUST 17, 1915
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

ORIGIN AND DISTRIBUTION OF THE MORRISON FORMATION [1]

BY CHARLES C. MOOK

(Read before the Paleontological Society December 30, 1914)

CONTENTS

INTRODUCTION

The age of the Morrison formation is necessarily bound up with the question of its origin and the physiographic conditions under which it was deposited. The present paper is a study in this direction. The writer was sent into the field in the summers of 1913 and 1914 by Prof. H. F. Osborn to study the Morrison formation in connection with his forthcoming monograph on the sauropod dinosaurs. Considerable time has been spent in the winter of 1913-1914 and in the past fall in assembling the results of this field study, together with a thorough study of the literature of the subject. Some of the conclusions from these studies are given in the present communication. The Morrison formation is one of those series of beds which have been the subject of considerable controversy. By the workers on the Hayden and other early surveys they were known as "variegated beds," Jurassic beds, Dakota beds, Lower Dakota beds, Atlantosaurus beds, and in part Flaming Gorge formation. Later they have been known locally as the Beulah shales, Como beds, McElmo beds, and Gunnison formation. These local names

[1] Contribution to the symposium held at the Philadelphia meeting of the Society December 30, 1914.

Manuscript received by the Secretary of the Society April 3, 1915.

are all given to parts of the same formation, and it is best to drop them, in a general discussion, in favor of the name Morrison.

Distribution and Thickness of the Morrison

The Morrison, in the broad sense, is widely distributed. At the type locality in Colorado it is poorly exposed. It occurs in the hog-backs along the eastern border of the Rocky Mountain front range, from the Laramie Mountains south to the central parts of New Mexico; in the Grand River Valley and tributaries in western Colorado and Utah; in the canyons of streams tributary to the San Juan River in southwestern Colorado; south of the Uinta Mountains and in the Grand Hog-back in

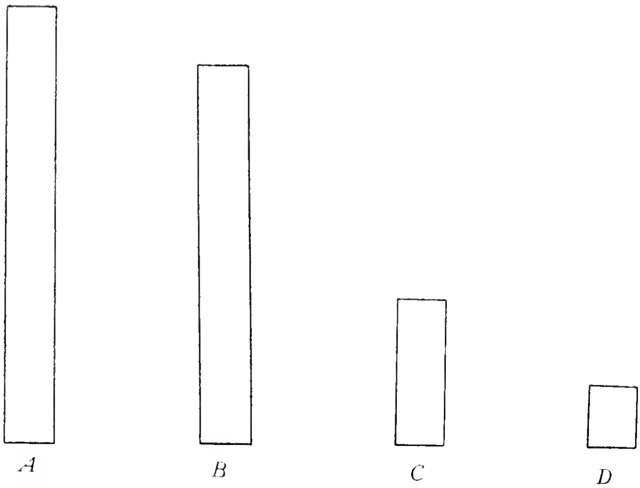


FIGURE 1.—*Diagrammatic Representation of the Thickness of the Morrison Formation in various Areas from South to North*

A, maximum thickness in the Telluride quadrangle, Colorado; B, thickness near Mack, Colorado; C, thickness near Tensleep, Wyoming; D, thickness near Belt Creek, Montana. Scale, 400 feet to 1 inch.

western Colorado and eastern Utah; in a few isolated areas in Montana, around the flanks of the Bighorn, Owl Creek, and Wind River Mountains; in local uplifts and faulted blocks in eastern and central Wyoming, and around most of the rim of the Black Hills.

In the southwestern areas the Morrison, or McElmo, has a considerable thickness; near Green River, Utah, it is over 1,000 feet thick, according to Lupton; in the Telluride quadrangle it is reported by Cross to be 900 feet thick; near Grand Junction and Mack, in the Grand River Valley, it is about 700 feet thick; south of the Uinta Mountains it is about 650 feet thick; in the Owl Creek and Bighorn Mountains it is about 200 to 250 feet thick, and in central Montana it is less than 100 feet thick. From this it is seen to thin out toward the north. It is possible, however, that the Kootenie may in part be equivalent to the Morrison. This would reduce this northward thinning.

Eastward from the Telluride area, the formation is about 450 feet thick in the Crested Butte quadrangle, 350 feet (possibly a little more) near Cañon City, and 200 feet or less in the canyons in eastern Colorado. There is thus a decided thinning toward the east.

Toward the northeast, the formation is about 400 feet thick in the Encampment district, in southern Wyoming, 200 to 250 feet in the

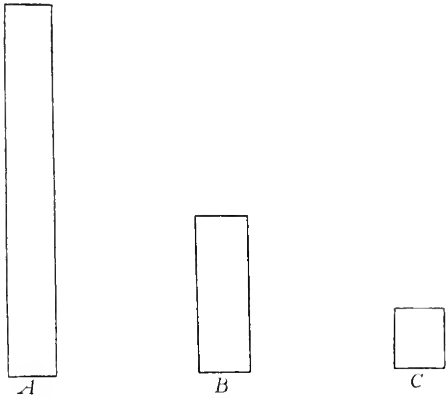


FIGURE 2.—*Diagrammatic Representation of the Thickness of the Morrison Formation in various Areas from West to East*

A, thickness near Mack, Colorado; B, thickness at Garden Park, near Cañon City, Colorado; C, thickness at Red Rocks Canyon, in eastern Colorado. Scale, 400 feet to 1 inch.

vicinity of Rawlins and Como Bluff, and 100 feet or less around the Black Hills. There is also, according to this, a decided thinning toward the northeast.

CRITERIA FOR DETERMINING THE ORIGIN OF THE FORMATION

The formation is made up essentially of rine-grained massive materials, often referred to as "joint-clays," of sandstone, shale, a very little medium-grained conglomerate, and some limestone in thin beds. Many of the sandstones are arkosic, especially those near the base of the formation. Many of the sandstones and some of the so-called clays are extremely calcareous, so that it is difficult to decide, in some cases, whether a certain specimen should be called calcareous shale or argillaceous limestone. Many of the "joint-clays," when examined with the microscope, are seen to be exceedingly fine-grained sandstones, sometimes with a matrix of hematite, and not clay at all. True kaolinic clays do, however, occur in some abundance. The colors of the formation vary to a great degree, giving rise to the term variegated beds, often applied to the formation. The clays are, in places, brick red or chocolate colored, due to the presence of large amounts of hematite: at other places they are gray, white, purple, or nearly black. The sandstones are usually yellow or white, but may be reddish. They are often made up largely of angular or rounded quartz, as the case may be, with replaced feldspars, calcite, and minor amounts of volcanic matters and other material. The lime-

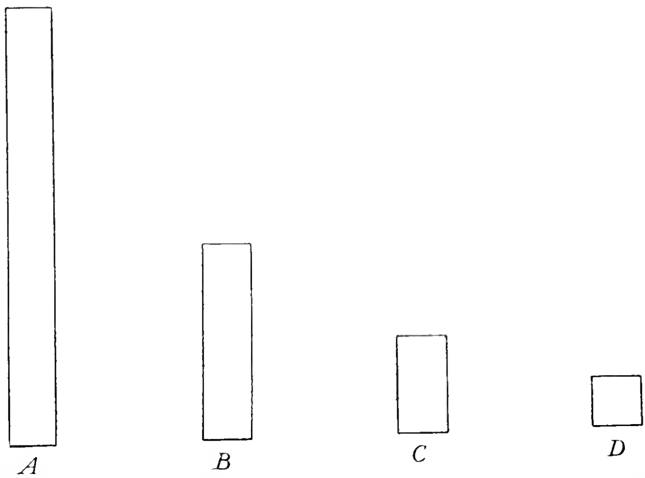


FIGURE 3. *Diagrammatic Representation of the Thickness of the Morrison Formation in various Areas from Southwest to Northeast*

A, maximum thickness in the Telluride quadrangle, Colorado; B, thickness in the Encampment district, southern Wyoming; C, thickness at Como Bluff, Wyoming; D, thickness near Devils Tower, Wyoming. Scale, 400 feet to 1 inch.

stones are usually thin, are often fine grained, and generally argillaceous.

Perhaps the most characteristic features of the Morrison are the variegated colors of most of the outcrops, the "uniformly variable" character of the succession of beds, and the presence of distinct channeling, with sandstone lenses occupying depressions in the underlying clays.

The origin of the Morrison formation has been the subject of a number of discussions in the past. Some workers have held that the beds were deposited in the sea; others, such as C. A. White, have held that the formation was deposited in a great lake. Riggs has advanced the theory that deposition took place in a number of small lakes, with deltas on the borders, and possibly by rivers as well. Hatcher maintained that the deposits were laid down in a series of floodplains, with alternating deposition and erosion at successive levels.

In discussing this subject several considerations are of prime importance, other factors being accessory. The important facts to be considered are these: 1, the formation was laid down on a comparatively level surface: 2, the fauna is exclusively of the continental type, either land or fresh water; 3, the nature of the sediments is such as to imply deposition in or by quiet water at times, and again in more agitated waters; 4, the thickness of the formation is much greater in the west, and especially the southwest, than in any of the other Morrison areas, gradually thinning out toward the east and northeast; 5, internal structures, such as channeling; 6, the "uniformly variable" character of the succession of beds. Other factors to be considered are: the presence and kind of cross-bedding, the condition of preservation of the fauna and flora, the variegated colors, etc.

Conclusions

From these facts as starting-points we may infer that the Morrison was deposited on a wide-spread plain of low relief, and probably of low altitude. It is the result of alternating deposition and erosion, there being no place, probably, where deposition went on continuously from the time when the first beds were laid down until the uppermost beds were deposited. The source of the material was to the west, and especially the southwest, of the present area of its outcrops.

These conditions may have been satisfied by such a history as the following: In Jurassic time there was a crustal disturbance and slight upheaval in the present Rocky Mountain area. This disturbance is shown in the undulating character of the Red Beds noticed by Lee in northern New Mexico. Following this upheaval, erosion progressed steadily until much of the Rocky Mountain area was reduced to a fairly level plain. At the end of the interval, when the mountains to the west were fairly well reduced in height and extent, the Rocky Mountain plain, if it may be so called, was low and flat and the site of numerous lakes and swamps. Erosion in the plain itself was no longer possible to any considerable extent. Erosion of the mountainous areas to the west was still possible, however, and went forward steadily. It is the products of this later erosion which now comprise the Morrison formation. A few large streams, flowing eastward or northeastward from the old mountains.

flowed across the swampy plains and deposited silt over broad floodplains. Lakes were probably present and were the seat of deposition of many of the fine-banded clays and sandstones. Deltas into these lakes, as suggested by Riggs, probably account for some of the coarser local sandstone bodies. Some of the streams from the old mountains were much larger than others and carried a greater load. From streams of varying size and with different loads the deposits formed could not be uniform throughout the whole area of deposition. Further than this, streams of low gradient, such as those postulated, would deposit much of their material before reaching a great distance from the original source. According to the evidence from the fauna and flora, the depositional area was not an arid one, certainly not through its entire extent. Rainfall was probably fairly abundant, throughout much of the area at least, and new systems of streams were produced on the plain itself. The basal beds of formation were derived to a certain extent from the strata of the formations underlying, as well as from the mountain areas. These streams consequent upon the deposition plain would also carry a considerable load, and in this way the formation would be built out from itself. Material at the outer fringe of the area would therefore be much younger than material deposited at the same distance above the base nearer the source of supply. Shifting of channels would also result in erosion of material already deposited. In this way a series of deposits might be formed over a wide area, comparatively thin, with very great lateral and vertical variation, and yet present the same kind of characters over the whole area. Most of the formation being fine grained, the streams were probably mostly sluggish. Occasional coarse beds, with cross-bedding of the stream type, testify, however, to a considerable amount of carrying power and a fairly swift current at times.

The whole area probably remained nearly level throughout the whole depositional interval, though there were probably slight irregularities. The difference in thickness between the beds at the southwest and those at the northeast, providing the base rested on a level surface, is not enough to contradict this statement. The southwestern areas, near the sources of the material, probably were, at times, slightly higher than the northern and eastern areas. The sediments in the southwestern areas contain a larger proportion of coarse material and may have been built up above the level of the larger part of the plain. It is also possible that depression took place in the southwestern part of the area in the later part of Morrison time, allowing fine silts to be deposited farther southwest. It is noticeable that the fine clays in the southwestern area are confined largely to the upper half or third of the formation.

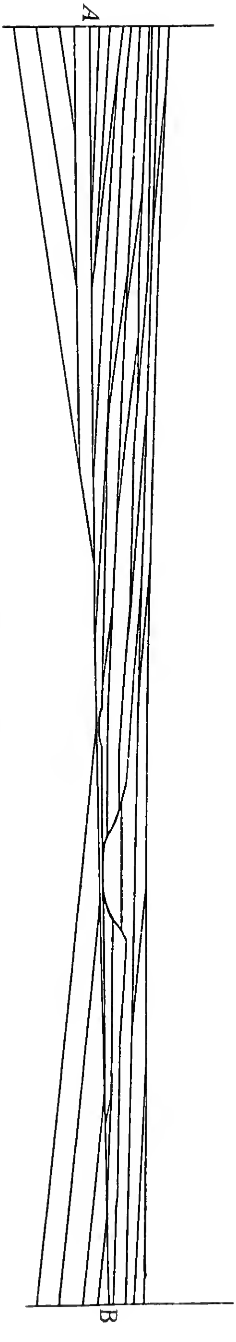


FIGURE 4. *Diagrammatic Representation of the probable Relations of the various Parts of the Morrison Formation with each other before Burial*

A B, peneplaned surface upon which the Morrison rests

Such a history as outlined above will fit the conditions observed in the Morrison formation, and it is probable that its history was something of that nature.

It is important to observe that a given thickness of beds deposited under the conditions of alternate deposition indicated would require a much longer time for its formation than beds deposited under conditions of continuous deposition. It is perfectly in accordance with the above outlined history for parts of the formation to be Upper Jurassic in age and for other parts to be distinctly later than the Jurassic, perhaps well up in the Comanchian. It could even be that practically all the beds represented in a single outcrop of the formation might be Jurassic, and that in another area, not a great distance off, be made up largely of beds of Comanchian age. The accompanying diagram is an attempt to show, in a very schematic way, the kind of cross-section the formation would have immediately after deposition and before being covered or disturbed.

If the above interpretation be correct, great care must be taken in judging the age of the formation as a whole, from a fauna or flora of definite age, in any one locality or level. *It will only be possible to decide definitely the age of the various parts of the formation when extensive collections have been made from a number of levels in many localities.*

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 323-334 AUGUST 17, 1915
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

SAUROPODA AND STEGOSAURIA OF THE MORRISON OF NORTH AMERICA COMPARED WITH THOSE OF EUROPE AND EASTERN AFRICA[1]

BY RICHARD SWANN LULL

(Read before the Paleontological Society December 30, 1914)

CONTENTS

INTRODUCTORY

In discussing dinosaurs from a stratigraphic point of view, only those groups are of value which are of a relatively high degree of specialization and whose evolutionary stages are so sharply marked that a comparison of those remotely removed geographically can be made with some degree of accuracy. On this account the conservative carnivorous forms, whose chief evolutionary change is increase of stature, are of little value. The

[1] Contribution to the symposium held at the Philadelphia meeting December 30, 1914. Manuscript received by the Secretary of the Society April 3, 1915.

Sauropoda, on the other hand, and especially the armored dinosaurs, which are highly specialized types, are horizon markers of importance.

Sauropoda

The Sauropod dinosaurs include some of the greatest of the world's creatures, exceeded in size only by the largest of existing whales. The huge size, while in itself a high specialization, can only be attained by members of a relatively primitive stock. Thus we see in the attainment of size the development of remarkable specialization on the part of skeletal detail, yet in the main plan of structure the Sauropoda were among the most generalized of dinosaurs.

They were quadrupedal reptiles, with a huge, relatively short body, borne on massive, pillar-like limbs which still retained the archaic number of five digits in fore and hind foot, although the outermost ones were in process of reduction. The neck and tail were of great length, while the head, with its battery of prehensile teeth in the forward portion of the mouth, was very small for so huge a beast, having a diameter less than the average of the neck which bore it. The limb bones were exceedingly heavy, long, and straight, with highly rugose ends, as though the articulation between them was in large measure cartilaginous. The vertebral column, on the other hand, is a marvel of lightness, and from the standpoint of strength, combined with rigid economy of material, is perhaps the most remarkable piece of nature's engineering known. The size, lightness of the vertebral column, especially of the neck, the compressed and powerful tail, the incomplete articulations of the limbs, such as are never found in terrestrial animals today, and the position of the external nostrils on the top of the head all point to an amphibious if not an exclusively aquatic habitat. The weight of the limbs would serve as ballast to permit the animal to wade in relatively deep water, while the tail would be very effective for more active locomotion through the water in case of need.

The feebleness of the dentition on the part of some genera at least has given rise to considerable argument as to the food of these creatures. All are pretty well agreed, however, that some luxuriant and nutritious aquatic plants which could be loosened by the sharp claws or by the rake-like teeth and then swallowed down in huge quantities, without mastication, would best subserve the creatures' need.

The habitat of the Sauropoda may best be visualized by imagining conditions such as now exist in tropical America, more especially over the coastal plain of the lower Amazon: low-lying lands, but little above sealevel, with sluggish bayous separated by numerous islands clothed in a dense tropical vegetation. In these fastnesses the creatures would be comparatively safe from their carnivorous enemies, while in the quiet waters they would find support for their huge bodies both against the burden imposed by gravity and the warning pangs of hunger.

Their structure of tooth, claw, and body points conclusively to a carnivorous ancestry, and Huene sees in the dinosaur *Plateosaurus*, from the German Keuper, a possible ancestral form. The change of habitat may well have been due to the growing burden of the flesh, which also may have caused the dietary change. Within some families of modern reptiles, notably the Iguanidæ, most of which are insectivorous, some are also herbivorous and their range of habitat is equally broad, as they are arboreal, terrestrial, burrowing, semi-aquatic, and one, *Amblyrhynchus*, is even semi-marine! Hence the conjectured change of habit and habitat on the part of the Sauropoda is not without modern parallel.

Stegosauria

The Stegosaurs are the armored dinosaurs belonging to a different sub-order, all of which are characterized, with a single known exception, by having the mouth toothless in front, but doubtless armed by a more or less turtle-like prehensile beak. The dental battery, which reached a remarkable degree of perfection in some of the latest types, is confined to the rear portion of the jaws and is amply fitted for the mastication of herbaceous food. The Stegosaurs were quadrupedal, though, as Dollo has shown, they doubtless descended from a bipedal ancestry, which the increasing weight of armor caused to reassume the four-footed gait of still more remote forebears. The armor takes the form of crocodile-like scutes, which in certain portions of the body tended to form broad protective shields through coalescence. In *Stegosaurus*, the aberrant genus which has determined the name of the group, the median fore and aft keel of the dorsal scutes has hypertrophied enormously, giving rise to the huge upstanding plates diagnostic of the genus. Other dermal elements took the form of spines, borne by *Stegosaurus* on the distal end of the tail, by other genera over divers portions of the frame, although I do not know that the evidence for their alleged position is always clear.

Of the habits of the Stegosaurs we know little; the teeth in known types, notably in *Stegosaurus* itself, are relatively feeble compared with those of the armorless type and with those of the Ceratopsia; hence the inference is that their food must have been of a very succulent character and of sufficient abundance to maintain the bulk of a creature whose substance was two or three times that of an elephant.

The habitat is also open to question, though, as I have shown, the Sauropoda and Predentate dinosaurs seem to have occupied different habitats—the one amphibious or aquatic, the other in the main terrestrial; for in no other way can we account for the marked differences in distribution of the two orders, which, reduced to a final analysis, have gone so far that the two groups are rarely found in the same quarry, even within the same region and geological formation. This statement is, however, in part refuted by Hennig, who remarks that at Tendaguru, German East Africa, such limitation does not hold, as the occurrence of Sauropoda and Stegosaurs seems rather to be a uniform one throughout.

In the genus *Stegosaurus*, which is perhaps the best known and least understood of armored dinosaurs, the evidence of imperfect limb articulation, which was given as partial evidence for aquatic life on the part of the Sauropoda, is also seen, though to a less extent. There is in *Stegosaurus* a powerful, laterally compressed tail, with long neural spines above and chevron bones below, which would serve as a very efficient swimming organ were the burden of armor plates and the rigidity of the body not too great a handicap to semi-aquatic life.

Migratory Roads

Both groups of dinosaurs were great travelers. I myself have followed their migrations over thousands of miles of the earth's broad surface. With the Sauropoda the route may have been along the continental margins from home to home, much as in the case of the hippopotami today, which, though denizens of the African streams, nevertheless swim boldly out to sea from river mouth to river mouth and thus pass by the inhospitable regions which would otherwise effectually bar their progress. In this way the occurrence of Sauropod remains in marine or brackish water sediments in Madagascar and East Africa may perhaps be partially explained. The Predentates as a whole, however, seem to have chosen the land route, and their lines of migration will be less surely traced even with the increase of our knowledge. This route distinction, however, may account for the peculiar faunal likenesses and unlikenesses between Europe, America, and Africa, which have yet to be told.

Geographic and Geologic Distribution

SAUROPODA

Geographically the Sauropoda were a very wide-spread race, being exceeded only by the carnivorous dinosaurs in the extent of their wanderings, the range including western and eastern North America, England, northern France and Portugal, East Africa and Madagascar, India and far Patagonia. Geologically they appear suddenly in widely remote localities as though "living forms, limb'd and full grown, out of the ground uprose," the earliest types being in rocks of early Middle Jurassic (Bathonian) age. This sudden apparition, of course, implies a long, as yet undiscovered, antecedent evolution. In ever increasing numbers Sauropoda appear with the passing of Jurassic time, until with the dawning of the Comanchian the full inflorescence of the race is attained, and not long after, geologically speaking, the huge forms are blotted out; for, as Hatcher has shown, they were so absolutely dependent on one peculiar type of habitat that, with their great size and consequent slow maturity and rate of increase, very slight geologic changes would bring about their extinction.

STEGOSAURIA

The armored dinosaurs are confined almost without exception to the northern hemisphere, but recent developments at Tendaguru, East Africa, have brought to light immense numbers of "Stegosaurs," the estimated number of bones in but two quarries being no less than 1,850! These represent apparently two species of an undetermined genus, small and highly spinescent; but we are not yet made aware of their exact relationship with others of the group. With this notable exception, the armored dinosaurs are unknown from the southern land-masses. Geologically the range is from the Lias to the close of Mesozoic time; *Stegosaurus* itself, however, represents an aberrant, short-lived race of late Jurassic and probably early Comanchian (Morrison) age.

THREE VISTAS OF DINOSAURIAN SOCIETIES

During the Upper Jurassic and the Comanchian we are given three vistas of dinosaurian societies in which the profusion of animals makes fairly accurate anatomical comparison in some instances possible. These are the American Morrison of Wyoming, Colorado, South Dakota, and Utah; the Tendaguru of German East Africa; and the late Jurassic, and especially the Wealden, of England and northern France. Of these the greatest variety of Sauropod genera and species are known from the Morrison, including five families from which no fewer than 10 genera and 23 species have been described, ranging from more or less generalized to highly specialized types. Of these families certain are exclusively American, some have representatives in Europe, while others include the dinosaurs of Tendaguru, there being, so far as my researches have taught me, no apparent direct connection between the allied English, French, and Portuguese Sauropoda, on the one hand, and the German East African forms on the other.

TENDAGURU DISTRICT OF GERMAN EAST AFRICA

General description.—The dark continent seems destined to furnish the data which will ultimately decide the age of the Sauropod-bearing beds of North America and possibly of Europe, for here the dinosaur-bearing strata are interbedded with marine zones rich in invertebrates, which will enable stratigraphers to fix their age with a great degree of accuracy. Professor Schuchert, in a review of Hennig's work, "Am Tendaguru," [2] thus describes the region:

"The hill Tendaguru, less than 100 feet high, lies isolated on a high, thickly wooded plateau averaging about 650 feet above the sea, and is the central point from which all of the diggings have been operated. It is in the midst of an extensive dinosaur cemetery, for at one time there were twenty exhumations in operation scattered over 30 square kilometers, or across one degree of latitude (between 9° and 10° south and 39° and 39° 30′ east).

"In a thickness of about 500 feet exposed along the stream Mbenkuru are found three distinct horizons of soft shale with dinosaur remains, separated from one another by hard coarse-grained sandstones to conglomerates that have an abundant marine invertebrate fauna. Each marine division has its own assemblage of forms, and makes terraces along the river valley. . . . All of the beds are of one continuous series of deposits, as the different horizons grade into one another. The conditions of deposition therefore appear to have been an alternation of exceedingly shallow marginal seas that came to be filled with detritus and changed into great mud flats flooded by rivers and possibly in part by high tides. Three such cycles are recorded. Dinosaur bones do not occur in the marine deposits but begin in the transition zones, where they occur with Belemnite guards, and may be so abundant as to make bone conglomerates. Where the bones occur in greater abundance there appear to be no marine invertebrates.

"In the lowest dinosaur zone there is but little good material, while the highest one is not at all so rich in remains as is the middle division, out of which most of the bones . . . have been taken."

Sauropoda.—The dinosaurian material, in so far as it has been made known to us, contains representatives of all three suborders of dinosaurs. Of these the Sauropoda are represented by three genera, each of which includes two species, and there are in addition at least two other forms as yet undescribed (1914). The Sauropoda thus far recorded are, first, *Gigantosaurus* Fraas, including the species *africanus* and *robustus*. These Fraas considers most nearly like the Morrison genus *Diplodocus*

[2] Amer. Jour. Sci. (4), vol. xxxv, 1913, p. 36.

from certain similar characters in vertebrae, chevrons, and other elements. Of this genus Janensch says: "So far as can now be seen, the later investigations confirm Fraas's view that *G. africanus* in its structure shows distinct accord with the North American genus *Diplodocus*."

The second group of Sauropods is still more remarkable, in that it is so very similar to a certain Morrison type as to be referred to the same genus, *Brachiosaurus*, proposed by Riggs in 1901. The members of this genus are described as of extremely massive build, with fore limbs equaling or exceeding the hind limbs in length, with an immense body—as the 9-foot ribs imply—and with cervical vertebrae which may exceed a meter in length. The total length of these animals, judging from the Tendaguru estimates, could not have been much less than 100 feet.[3] *Brachiosaurus altithorax* is the American species, while the African forms are known as *B. brancai*, with an extraordinarily long neck and a humerus from 2.10 to 2.13 meters in length; and *B. fraasi*, which was smaller, with an upper arm bone measuring but 1.70 meters.

The third genus is *Dicraeosaurus* Janensch, having neck vertebrae of moderate length, with two high, completely separated spinous processes. This pairing of the spines is continued back over the dorsal region as far as the rump. Bifurcated spines are not a unique feature, as they are present in *Brontosaurus* and *Diplodocus*, among other genera; but nowhere, to my knowledge, are they carried to the extreme of specialization seen here. The American genera in which these spines are paired generally show more or less deep lateral depressions, pleurocoeles, on either side of the vertebral centra, but these are lacking in the African form. Two species of *Dicraeosaurus* have been described. *D. hansemanni* has fairly heavy hinder extremities, and the vertebrae of the back and tail are strongly built; the femur, however, measures 1.23 meters long, which indicates a comparatively small animal. *D. sattleri* has the dorsal vertebrae lighter and smaller, but with still higher spines.

Predentata.—Of Predentate dinosaurs there have been found two species of Stegosauridae and one small Ornithopod form. The details of structure are not yet announced, but the Stegosaurs, neither of which is large, have a dermal armor consisting of "very strong spines, compared to which the bony plates seem almost to lose significance." As the latter are perhaps the most characteristic feature of the genus *Stegosaurus* itself, the inference is that the African forms are representations of a different genus; but we must await the conclusions of Doctor Hennig, who is describing them, before an opinion as to their affinities can be

[3] Doctor Matthew believes that these African forms probably did not much exceed in size those of America.

ventured. The small Ornithopod genus is described as similar to the American *Laosaurus* and the English *Hypsilophodon*. *Laosaurus* is a well defined genus from the Morrison and Potomac formations, while *Hypsilophodon* is a persistently primitive type from the English Wealden, the only Predentate dinosaur with teeth in the premaxillary bone.

Stratigraphically I can find no record of the level wherein *Gigantosaurus* was found, as Fraas did not clearly differentiate the three dinosaur beds, but speaks of *the* dinosaur horizon as though there were but one. Both species of *Brachiosaurus*, the Stegosaur quarry and the larger of the two Dicræosaurs, are in the middle beds, while *Dicræosaurus sattleri* is from the upper one. This places the Brachiosaurs, which are the dinosaurs of greatest present utility for comparison with the American types, in the strata which can be most surely dated, as they lie between the two marine horizons, and thus both the upper and lower limit can be fixed.

Unfortunately at this writing I can not obtain a report on the marine invertebrates of the Tendaguru, although such have been published by Hennig and others. The reviews of two of these papers in the *Geologisches Zentralblatt* (June 1, 1914) contain certain inconsistencies which are difficult to reconcile without reference to the original works. The evidence, however, subject to future correction, seems to be as follows:

1. *Trigonia schwarzi* zone (Lower-Middle Neocomian).
    I. Upper dinosaur horizon—upper Tithonian to lowest Neocomian: somewhat of Wealden—Wealden plants.
2. *Trigonia smeei* zone—typical Tithonian—in part uppermost Kimmeridgian.
    II. Middle dinosaur horizon—Lower Kimmeridgian.
3. *Nerinea* zone—Oxfordian.
    III. Lower dinosaur horizon—Lower Oxfordian to Kelloway.

The upper dinosaur beds seemingly belong faunally, florally, and as regards facies to the Neocomian or Wealden.

If this evidence be correctly interpreted, it places the majority of the dinosaurs, the horizon of which is known, between Upper Jurassic marine beds and those of the Comanchian, while the highly specialized *Dicræosaurus sattleri* is of still younger Comanchian time.

WEALDEN

Sauropoda.—England and northern France particularly have produced a long generic list of Sauropod dinosaurs, most of which are founded on very imperfect material; this, in the case of dinosaurs particularly, renders comparative study a matter of extreme difficulty and is apt to give rise to complications of synonymy. The best comparative study of Old and New World Sauropoda which I have seen is that by Professor Marsh, a summary[4] of which was first published in 1889, and later in "Dinosaurs of North America," in 1896 (page 185). In studying the European types, Marsh was impressed by three prominent features in the specimens investigated:

"(1) The apparent absence [in Europe] of any characteristic remains of the Atlantosauridæ, which embrace the most gigantic of the American forms.
"(2) The comparative abundance of another family, Cardiodontidæ (Cetiosauridæ) nearly allied to the Morosauridæ, but as a rule less specialized.
"(3) The absence, apparently, of all remains of the Diplodocidæ.
"The most striking difference between the Cardiodontidæ and the allied American forms is that in the former the fore and hind limbs appear to be more nearly of the same length, indicating a more primitive or generalized type. Nearly all the American Sauropoda, indeed, show a higher degree of specialization than those of Europe, both in this feature and in some other respects."

At least two American genera of Sauropoda have been recognized in Europe, but the identity in each instance seems open to question. These genera are *Morosaurus* and *Pleurocœlus*, the former a typical Morrison form, having been reported from the Oxfordian of Ourem, Portugal, and from the Wealden of England. *Pleurocœlus*, a genus which includes the smallest of the Sauropoda, has but a single rare Morrison species referred to it, while two forms, *Pleurocœlus nanus* and *P. altus*, are known from the Potomac formation of Maryland. There is reason to believe that in the first of the Maryland species at least the fore limbs were nearly equal to the hind in length, and in other respects, as well as in its relatively small size, the creature was of primitive type. *Bothriospondylus*, described by Sir Richard Owen, from the Kimmeridgian of England, was thought by Marsh to represent a very young, if not fœtal, individual, which might be nearly allied to *Pleurocœlus*, while species from the Wealden of Caen, France, and the Aptian of Portugal are referred to the American genus itself.

There are, so far as I know, no generic comparisons to be made between the European Sauropoda and those of Tendaguru, although the name *Gigantosaurus* appears in each faunal list, but apparently applied to forms which are not congeneric. On the other hand, it is difficult to make comparisons with the Morrison types which would be of strati-

[4] Amer. Jour. Sci. (3), vol. xxxvii, pp. 323-331.

graphic value, as the only genera which may possibly be common to both faunas are comparatively generalized types, neither of which is confined to a single geologic level in Europe nor, in the case of *Morosaurus,* in North America.

Stegosauria.—The European Stegosaurs include at least two phyla; of these the one represented by the small spinescent *Polacanthus* of the Wealden has no known Morrison equivalent, the group not appearing in America until the Lakota, possibly still later in time. Of another phylum, which included the American genus *Stegosaurus* itself, there seem to be Old World representatives in *Omosaurus durobrivensis*, of which the type specimen preserved in the British Museum is from the Kimmeridgian and shows great similarity to *Stegosaurus* in the character of the vertebræ and in the presence of the expanded armor plates, the chief distinction being the appearance on the femur of a well defined, crest-like fourth trochanter in *durobrivensis* which is obsolete in the several American species. A second specimen in the Woodwardian Museum at Cambridge, although labeled *Omosaurus leedsi* by Seeley, has also been referred to *O. durobrivensis* by A. Smith Woodward. The two specimens are very similar, and associated with that of Cambridge I saw a very characteristic caudal spine in addition to the armor plates. This latter species is from the Oxford clay of Felton, and therefore, if the level be correctly stated, from the Middle Jurassic. In neither of these Old World forms have the vertebræ reached the degree of specialization found in the Morrison types, and I should consider the reduction of the femoral trochanter in the latter an evolutionary advance as well; for, as Dollo has shown, its presence is correlated with a bipedal gait which was secondarily lost in the Stegosaurs.

The evidence from the European Stegosaurs, therefore, can not be taken as indicative of correlated age, but, as I read it, simply points to a greater antiquity on the part of Oxfordian and Kimmeridgian members of the group.

MORRISON

The American Morrison contains the greatest profusion of Sauropod dinosaurs which any formation or locality has produced. Of the five families recorded, one, the Atlantosauridæ, including perhaps the best known members of the suborder—*Atlantosaurus, Apatosaurus,* and *Brontosaurus*—is exclusively American. Nearest this family stand the Morosauridæ, smaller forms the stature of whose greatest member is but two-thirds that of *Brontosaurus.* The genus *Morosaurus* includes five or six American species, of which all but one, which has been identified from the Trinity sands of Oklahoma, are Morrison. As I have stated, *Morosaurus* is apparently represented in Europe by forms from the Middle Jurassic (Oxfordian) of Portugal and from the English Wealden. None of the family has been recorded from Tendaguru. An allied family, the Pleurocœlidæ, which includes the rather primitive dinosaur *Pleurocœlus*, is sparsely represented in the Morrison, more abundantly in the Potomac and in the Wealden of England and Aptian of Portugal. I should not consider the representatives of either of these families abroad of any great stratigraphic value; so that, as these are the only genera common to both Europe and North America, the Sauropoda throw little light on the age of the Morrison in terms of European stratigraphy. But the remaining families of Morrison Sauropoda—the long, slender Diplodocidæ and the robust Brachiosauridæ—represent two extremes of specialization and therefore, as they are known with a high degree of completeness, should be of marked importance as correlating fossils.

The Diplodocidæ, including the single genus *Diplodocus*, with its two or three American species, is unknown elsewhere, unless, as the Tendaguru authorities believe, the family is represented in that fauna by *Gigantosaurus* of Fraas. At all events, the comparison is not sufficiently close to be of more than corroborative value. The last family, the Brachiosauridæ, or Barosauridæ, as perhaps it should be called, includes three American genera—*Brachiosaurus* Riggs, *Haplocanthosaurus* Hatcher, and *Barosaurus* Marsh—which, as Doctor Matthew has suggested, may be the same as *Brachiosaurus*, in which case the older name, *Barosaurus*, takes precedence. Of these *Haplocanthosaurus* is evidently exclusively American, but *Brachiosaurus*, as I have emphasized, includes not only the American, but at least two well defined Tendaguru species also. The Morrison *Brachiosaurus* comes from a horizon which, according to Riggs, contains various species of *Apatosaurus* (= *Brontosaurus*) and *Morosaurus*.

The only Stegosaurs thus far recorded from the Morrison belong to the genus *Stegosaurus*, with three or four species, and to the closely allied, if not identical, *Diracodon*. As I have shown, *Stegosaurus* seems to be represented by species, probably ancestral, from the Oxfordian and Kimmeridgian of England, but apparently is very different from the so-called "Stegosaurs" of Tendaguru.

SUMMARY

The conclusions I would draw from this preliminary study of the problem serve to emphasize the difficulty of accurate comparison of fossil reptiles of huge size when we have only very incomplete material, which may not include common elements on which to rely, and this is the character of almost all of the European Sauropod remains.

On the other hand, one highly specialized genus is common both to America and Tendaguru, and here the comparison may be based on relatively perfect material.

With the Stegosaurs, opportunity for more perfect comparison lies between Europe and America, but only points to the conclusion that the Morrison beds which contain the American type are relatively newer than those which include the English relatives.

Correlation based on the Sauropod evidence between Europe and America is not to be relied on at present, but we can evidently point to the middle Tendaguru horizon of East Africa, which contains the genus common to the Morrison, as homotaxial with the latter.

As this middle bed at Tendaguru is bounded above and below by marine sediments, the study of their contained faunas, which doubtless can be definitely dated, should serve to determine the age of the Morrison formation of North America. From the evidence so far at hand, the age of this zone is certainly not older than uppermost Jurassic, with a decided likelihood that the invertebrate writers will agree on an early Comanchian (Neocomian) time.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 335-342 AUGUST 17, 1915
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PALEOBOTANIC EVIDENCE OF THE AGE OF THE MORRISON FORMATION [1]

BY EDWARD WILBER BERRY

(Read before the Paleontological Society December 30, 1914)

CONTENTS

INTRODUCTORY

The only fossil plants that have been recorded from the Morrison formation are the silicified fragments of cycad stumps which occur in such abundance in the Freezeout Hills of Carbon County and at one or two other localities in Wyoming. These were described by Ward[2] and referred to the genus Cycadella. About a score of so-called species which were based on external appearance were described. Neither the genus (*Cycadella*) nor any of the species have ever been found outside the Morrison formation, so that they furnish no direct evidence regarding the age of the deposits. They are, however, very close to the similarly silicified trunks of *Cycadeoidea* in their habit and general plan of organization. The *Cycadeoidea* remains are common in the Lakota formation of the Black Hills rim and in the Patuxent formation of Maryland. In the absence of studies of the internal structure of the Morrison genus *Cycadella* it is not certain that it can be maintained as distinct from *Cyca-*

[1] Contribution to the symposium held at the Philadelphia meeting December 30, 1914. Manuscript received by the Secretary of the Society April 3, 1915.

[2] L. F. Ward: Description of a new genus and twenty new species of fossil cycadean trunks from the Jurassic of Wyoming. Proc. Wash. Acad. Sci., vol. i, 1900, pp. 253-300. Jurassic cycads from Wyoming. Mon. U. S. Geol. Survey, vol. xlviii, 1906, pp. 179-203, pls. xlvi-lxlii.

deoidea, the at present most distinctive feature of the former being the profuse development of the ramentum, doubtless to be correlated with some local climatic variation, and scarcely of generic magnitude.

The most important paleobotanic evidence bearing on the age of the Morrison formation is to be derived from a consideration of the floras of the Potomac group of the Atlantic Coastal Plain and similar Lower Cretaceous floras in other areas. That the composition and age of these floras has an important bearing on the age of the Morrison will, I think, be admitted after the relation of the fauna of the Morrison formation and the flora of the Kootenai formation to the fauna of the Arundel formation and the flora of the Patuxent and Arundel formations has been discussed.

Age of the Potomac Group

Before making these comparisons it will be necessary to recall the evidence for the Lower Cretaceous age of the various formations of the Potomac group, since this also furnishes a strong argument for the Lower Cretaceous age of the Wealden, at least for the Lower Cretaceous age of the known Wealden floras.

The Cretaceous age of the Potomac group is indicated

(1) By the absence of any marine Jurassic deposits in North America east of the Mississippi River and the consequent implication that this eastern area was above sealevel during all of the Jurassic period.

(2) By the presence of a wide-spread peneplain (Weverton), indicating a long period of erosion, during which the eastern United States approached baselevel and on the tilted surface of which the sediments of the Potomac group were deposited.

(3) By the evidence of deep weathering of the crystalline rocks which supplied the materials of the Potomac formations.

(4) By the demonstrated synchroneity of the older Potomac floras—that is, of the Patuxent and Arundel formations—both individually and as a unit, with floras elsewhere, notably in eastern Asia, in South America, and in Portugal, where the floras are intercalated in a marine series of more or less abundantly fossiliferous deposits whose age is unquestionable.

The details on which this last assertion of synchroneity is based need not be repeated in the present connection, since they have been recently given.[3] It will suffice for the present discussion to say that it rests on all the facts entering into the question of correlation. Each shows essen-

---

[3] E. W. Berry: Lower Cretaceous floras of the world and correlation of the Potomac formations. Maryland Geol. Survey, Lower Cretaceous, 1911, pp. 99-172.

tially the same surviving generic types from the Jurassic, the same new generic types, both those peculiar to the Lower Cretaceous and those foreshadowing later floras, and a similar specific variation in the genera. The common genera are numerous; the common species are more numerous than might be expected, and finally the closely allied species are very numerous.

One additional fact should be emphasized in connection with the flora of the Potomac group, since it has an important bearing on the age of the Morrison formation. This is the essential unity of the floras from both the Patuxent and Arundel formations and their contrast with the flora of the overlying Patapsco formation. An analysis of these three floras develops the fact that the Arundel formation has only furnished five species (in five genera) not present in the underlying Patuxent, and four of these five genera are represented by closely allied Patuxent species, while the fifth has closely allied forms in the Barremian and Aptian of Europe.

The Potomac reptilian fauna, which all vertebrate paleontologists have compared with that of the Morrison, is found in the Arundel formation unconformably overlying the Patuxent formation, which is from 200 to 400 feet in thickness. The last authoritative study of the Arundel fauna was that of Lull, published in 1911. The following conclusions are quoted from his contribution.[4]

"The fossil reptiles of the Potomac, while not so abundant in numbers or kinds as in the Morrison of our Western States, nevertheless compare very closely with the latter, as nearly all of the Potomac genera and, in some instances, very closely allied if not identical species are found in the West.

"A striking similarity also prevails between the Potomac on the one hand and the Wealden of Europe on the other, while one important Maryland genus is reported from a lower horizon than the Wealden and none from a higher level.

"The dinosaurs represent all of the suborders, including two of the heavier, megalosaurian carnivores, *Allosaurus* and *Creosaurus*, and one of the lighter, Compsognathoid type, *Cœlurus*. The quadrupedal Sauropoda are represented by at least one genus, possibly two, *Pleurocœlus* and *Astrodon*, including two or three species in all, while of the Orthopoda there are two, one the unarmored *Dryosaurus*, the other, *Priconodon*, evidently belonging to the armored group or Stegosauria.

"The dinosaurs show none of the remarkable over-specialization of the later Cretaceous types, but, on the contrary, represent the order at the crest of the evolutionary wave before signs of decadence set in. Unfortunately, owing to an almost utter dearth of terrestrial Jurassic deposits, nothing is known of dinosaurian evolution in America from Newark time until we come to the

[4] R. S. Lull: The reptilia of the Arundel formation. Maryland Geol. Survey, Lower Cretaceous, 1911, pp. 173-178.

horizon under consideration. In Europe the record, though still meager, is more complete; but it represents in every instance more primitive types than those of the Arundel and the Morrison.

"The character of these dinosaurs, and of the crocodile as well, correlates the beds wherein they are found absolutely with the Morrison (Como) of the West. An accurate comparison with European formations is more difficult, as the faunas have fewer forms in common. *Pleurocælus* is reported from the Kimmeridgian as well as from the Wealden, but that from the former horizon may readily have been ancestral to the Arundel type, although the European material is too fragmentary to admit of a just comparison. Of the other dinosaurs, the affinities seem to be entirely with Wealden forms, *Cœlurus* being found therein, while *Allosaurus* compares in point of size and dentition with the Wealden *Megalosaurus*. *Dryosaurus* has its nearest European ally in *Hypsilophodon*, again a Wealden type, and the crocodile, *Goniopholis*, is reported from the Wealden and its marine equivalent, the Purbeckian, not from the older Jurassic levels.

"The weight of this evidence would seem to place this fauna beyond the Jurassic into the beginning of Cretaceous times."

Age of the Wealden

Whatever the present analysis of the Morrison faunas may indicate their relationships to be, it is an indisputable fact that the current tradition that the Morrison formation is of Jurassic age has had no other basis in fact than the late Professor Marsh's lifelong opinion that the European Wealden was Upper Jurassic. Possibly the last word has not yet been said regarding the age of the Wealden, but the consensus of opinion of those best able to form a reliable judgment—that is, European students of the Wealden stratigraphy—seems to be that the Wealden is of Lower Cretaceous age, and for the following reasons:

1. Where the Wealden is present, the oldest marine, Lower Cretaceous, is absent, and the Wealden may lie with a marked unconformity on the Upper Jurassic, as in the Boulonnais.

2. Its flora is similar to the older Potomac flora (Patuxent and Arundel), and likewise similar to Neocomian and Barremian floras of known age, as determined by invertebrate paleontologists in Portugal, Japan, and Peru.

The faunas of the Wealden offer little satisfactory evidence, since if Lower Cretaceous they represent survivals from the late Jurassic, and the comparable Neocomian deposits contain marine faunas and lack both terrestrial vertebrates and plants.

Age of the Kootenai

Turning now to a consideration of the Kootenai flora of the Rocky Mountain province, it may be noted that the flora of the Kootenai, as partially revised by me in my study of the Lower Cretaceous flora of Maryland and Virginia, comprises 86 species in 42 genera. Thirty-four of these genera occur in the Lower Cretaceous of the Atlantic Coastal Plain.

Of these 86 recorded forms from the Kootenai, 13 are so poorly preserved that they have never been specifically determined, although 12 of the genera to which they are referred are commonly represented in the Potomac. There are 31 species not yet discovered outside of the Kootenai deposits. These represent 24 genera, of which 18 are represented in the Potomac, several being confined to its uppermost formation, the Patapsco, which is clearly of Albian age.

Deducting the foregoing 44 species from the Kootenai total, there remains 42 species, or nearly 50 per cent, with an outside distribution. Before considering the significance of these forms with an outside distribution, there remains to be ruled out of the discussion the following forms that are without stratigraphic or chronologic significance for the reasons noted in connection with each:

Dawson identified two species of *Ginkgo* with forms described originally by Heer from the Upper Oolite of Siberia. These really represent a single species, and without the aid furnished by a known geologic horizon they can not be distinguished from Ginkgo leaves found as late as the Eocene. Another species, *Podozamites lanceolatus*, possibly composite, has a recorded range from the Jurassic to the top of the Upper Cretaceous and is obviously of no value in correlation. Similarly *Sequoia reichenbachi*, also possible composite, has a recorded range from the Portlandian to the top of the Upper Cretaceous, and has no chronologic value except as indicative of Mesozoic age.

This leaves 38 forms possessing chronologic significance. Twenty-five of these occur in the Lower Cretaceous of the Atlantic Coastal Plain, and of these 25, 19 range from the bottom to the top of the Potomac group, namely, from Neocomian to Albian, in terms of the standard European section. Only five are confined to the older Patuxent and Arundel horizons and 21 occur in the Patapsco formation, of Albian age and overlying unconformably the Arundel formation or horizon of the Potomac reptilian fauna.

This, it seems to me, is an important fact, namely, that over 55 per cent of the Kootenai species with an outside distribution are found in the Atlantic Coastal Plain unconformably overlying the Potomas dinosaurian fauna, which by both Marsh and Lull is said to show a distinct Morrison character. Whatever modern methods of comparison may make out of this faunal resemblance, it was sufficiently marked, according to

Professor Marsh's interpretation, to justify his astounding claim that the Atlantic Coastal Plain Cretaceous, as high as beds that I correlate with the Turonian and that Weller correlated with the Senonian, are of Jurassic age.

Nine of the Kootenai plants are found in the European Wealden, all but one of these being also common to the Potomac.

Compared with floras which, on the basis of their invertebrate faunas, have been referred to the Neocomian, we find two of these species in the Neocomian of Germany, six in the Neocomian of Portugal, four in the Neocomian of Japan, two in the Neocomian of Peru, and one in the Neocomian of Mexico. Compared with floras similarly determined as of Barremian age, it may be noted that two of the Kootenai species occur in the Barremian of Austria and four in the Barremian of Portugal. Two of the species occur in the Aptian of Portugal. In the European Albian there is a common species in Switzerland and five additional in Portugal. No less than nine of the Kootenai species survive as late as the Upper Cretaceous of Japan, Greenland, Europe (four species), and the Atlantic Coastal Plain. They also find a representation in the Trinity flora of Texas (two species), in the Fuson (five species) and Lakota (six species) floras of the Black Hills, and in the Shasta (nine species) and Horsetown (one species) beds of the Pacific coast.

Aside from the Potomac element in the Kootenai flora, the most prominent facts bearing on its precise age are furnished by comparisons with the Kome flora of western Greenland. There are 10 species, or 32 per cent, of the Kootenai forms with an outside distribution that are common to Kome. Seven of these, including two of the genera, are not found in the Potomac flora, and seven are likewise confined to the Kome and the Kootenai. In addition to the identical forms, there are a number of closely related forms in the two areas, and this Kome facies is so prominent in the Kootenai flora that it is emphasized by Dawson, Fontaine, and Ward. The age of the Kome flora is not positively determined as to its upper limits, but it is clearly not older than Barremian, which is the age assigned to it by Heer and by the Scandinavian and Danish geologists who have studied its relations, and it may even be of Aptian age.

The bearing of this conclusion on the age of the Morrison must be obvious. If the Kootenai flora is of Barremian age, then at least a part of the Morrison must be of Neocomian age, since the Kootenai is either partly the equivalent of the Morrison or, giving the utmost allowance for the contrary opinion, the southern extension of the Kootenai is conformable on the northern extension of the Morrison.[5] This is in a measure substantiated by the 25 species that range upward into the Albian (Patapsco formation) of Maryland and Virginia.

SUMMARY

1. Both the Wealden and Potomac floras, on the ground of the structural relations of the containing beds and on the ground of their synchroneity with floras of other areas of a known stratigraphic position, as determined by invertebrate paleontology, are referred to the Lower Cretaceous.

2. The eastern faunas, considered as of the same age as the Morrison by Marsh, Hatcher, and Lull, are underlain by from 200 to 400 feet of Cretaceous sediments containing a Lower Cretaceous flora which in the Rocky Mountain province is first found in the Kootenai formation, which is partially equivalent to or at most conformable on the Morrison.

3. The Kootenai flora appears to be most similar to the Kome flora of Greenland, which is not older than Barremian and possibly somewhat younger (perhaps Aptian).

4. If this correlation is correct, then at least some of the Morrison must be of Lower Cretaceous age.

In conclusion, it seems to me that in discussions of this sort we should not lose sight of the fact that human taxonomies have no objective existence. Those of geology are at best units of a filing system, by means of which we arrange our knowledge of earth history. It would undoubtedly be less troublesome if we could interpret this history in the way that Cuvier did.

As it is today, while we repudiate Cuvier's catastrophies and revolutions, all our arguments are tinged with the ancient heresy that floras and faunas developed almost intact up to a certain time, when, presto change!—Jurassic invertebrates were replaced by Cretaceous invertebrates. The last dinosaur left the world as precipitately as the last Moor quitted Grenada, or the Angiosperms sprang into existence like Pallas Athene.

It is inconceivable to me that faunas or floras have even undergone anything other than an orderly evolution, except where relatively sudden changes of environment caused a very local replacement of the kind the paleontologist assumes (not theoretically, but in practice) was on a universal scale. Even the latterly famed method of diastrophism is based

[5] C. A. Fisher: Economical Geology, vol. iii, 1908, p. 77. Bull. U. S. Geol. Survey, No. 356.

on phenomena that must have been essentially provincial in character and not continental or cosmopolitan, and, furthermore, continued over long periods of time. Presently we may expect some modern Huxley to enunciate diastrophic homotaxis as opposed to diastrophic synchroneity.

I am not seeking to depreciate continued effort to reach results, but I would wish that we all might be less dogmatic. The absurdities in the history of science are not confined to paleozoologist or paleobotanist; possibly, since invertebrate paleozoology is older than vertebrate paleozoology or paleobotany, it still retains more original sin than the other two.

My closing plea is, then, for less infallibility and a broader culture in the scientific life.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 343-348 AUGUST 17, 1915
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

INVERTEBRATE FAUNA OF THE MORRISON FORMATION[1]

BY T. W. STANTON

(Read before the Paleontological Society December 30, 1914)

CONTENTS

LISTS OF DESCRIBED SPECIES

When, in 1886, C. A. White[2] reviewed the invertebrate fauna of the formation now known as Morrison, he listed 21 species, as follows:

Unio felchii White
Unio toxonotus White
Unio macropisthus White
Unio iridoides White
Unio lapilloides White
Unio stewardi White
Unio nucalis M. and H.
Vorticifex stearnsii White
Valvata scabrida M. and H.
Viviparus gilli M. and H.
**Lioplacodes veternus* M. and H.
**Neritina nebrascensis* M. and H.
Metacypris forbesi Jones
Metacypris sp.

[1] Contribution to the symposium held at the Philadelphia meeting December 30, 1914. Manuscript received by the Secretary of the Society April 3, 1915.
Published by permission of the Director of the U. S. Geological Survey.

[2] C. A. White: Fresh water invertebrates of the North American Jurassic. U. S. Geol. Survey Bull. 29, 1886.

* The two species marked with an asterisk, from "near head of Wind River," probably belong to a later fauna.

Limnæa ativuncula White
Limnæa consortis White
Limnæa ? accelerata White
Planorbis veternus M. and H.
Darwinula leguminella Forbes
Cypris purbeckensis (Forbes)
Cypris sp.

Of these, seven species are referred to *Unio*, three to *Limnæa*, one each to *Planorbis*, *Vorticifex*, *Valvata*, *Viviparus*, *Lioplacodes*, and *Neritina*, and five are ostracod crustaceans. All are of fresh-water habitat. More than half of them come from a single locality near Cañon City, Colorado. The others are reported from the Black Hills, from two localities in southern Wyoming, and from the head of Wind River, Wyoming, the stratigraphic position of the species from the last-named locality being doubtful. Logan[3] has listed five species from the Freeze-out Hills, southern Wyoming, of which three species of *Unio* and a *Valvata* are described as new. The list is as follows:

Unio baileyi Logan
Unio knighti Logan
Unio willistoni Logan
Valvata leei Logan
Planorbis veternus M. and H.

All from Freeze-out Hills.

Undescribed collections from Morrison, Colorado City, and Uncompahgre Valley, Colorado, from the Black Hills, from the neighborhood of Como, Wyoming, and of Jensen, Utah, and from the Great Falls and Lewistown areas in Montana, have added to the Morrison fauna without changing its essential characteristics until, as now known, it includes about 30 species, practically all of which are referred to living genera.

Comparison with other non-Marine invertebrate Faunas

WEALDEN FAUNA

From the statement that the fauna consists of fresh-water Mollusca and Ostracoda belonging to modern genera, it is evident that it can offer little direct evidence on the exact age of the Morrison formation. Logan's argument for correlating the Morrison with the Wealden because, as he says, "four of the genera—*Unio*, *Valvata*, *Planorbis*, and *Viviparus*—which are represented in the two formations by species having practically the same degree of development are not known from older formations," is not valid because it does not agree with the facts of distribution as now known. *Unio*, *Planorbis*, and *Valvata* are all known from formations older than the Wealden, and the species of *Unio* from the Upper Triassic

[3] W. N. Logan: The stratigraphy and invertebrate faunas of the Jurassic formation in the Freeze-out Hills of Wyoming. Kansas Univ. Quarterly, vol. 9, 1900, pp. 132-134.

of Texas and New Mexico appear to be as well developed as those from the Morrison. It can not be justly claimed that there is anything in the Morrison invertebrates themselves that precludes their reference to an earlier epoch than the Wealden. They do not offer any evidence on the correlation of the Morrison with the Potomac group which has been advocated on the basis of the vertebrate fauna.

POTOMAC FAUNA

The five species of invertebrates which W. B. Clark[4] has named from the Potomac are apparently all distinct from Morrison species, but an examination of the published figures shows that they are all so imperfectly preserved that even their generic reference is very doubtful. The forms described are as follows:

Unio patapscoensis Clark	*Viviparus arlingtonensis* Clark
Cyrena marylandica Clark	*Bythinia arundelensis* Clark

All are from the Arundel formation except the *Unio*, which is from the Patapsco.

Further comparison of the Morrison invertebrates shows that specifically and as a fauna they are decidedly distinct from all other fresh-water faunas that are found geographically or stratigraphically near them. The faunas which deserve mention in this connection are those of the Kootenai, the Bear River, and the Dakota.

KOOTENAI FAUNA

In Montana the coal-bearing Kootenai formation has yielded nonmarine invertebrates at many localities, but they have not been thoroughly collected nor fully described. From a locality about 7 miles southeast of Harlowton I have described[5] the following six species:

Unio farri	*Goniobasis ? silberlingi*
Unio douglassi	*Goniobasis ? ortmanni*
Viviparus montanaensis	*Campeloma harlowtonensis*

When these species were described their exact stratigraphic position was not known, but it has since been determined that they came from the Kootenai formation, which in the Great Falls field has yielded similar forms, though not so well preserved, together with a *Neritina* and some other species. The so-called Dakota fossils of the Yellowstone National

[4] W. B. Clark: Lower Cretaceous, Maryland Geol. Survey, 1911, pp. 211-213.

[5] T. W. Stanton: A new fresh water molluscan faunule from the Cretaceous of Montana. Proc. Am. Philos. Soc., vol. 42, 1903, pp. 188-199.

Park probably also belong in this fauna. The only species that suggests a Morrison form is the *Viviparus*. The other gastropods, and the *Unios* especially, are very distinct from those of the Morrison. The evidence of the invertebrates, therefore, is opposed to Professor Berry's[6] suggestion "that this general horizon in the Rocky Mountain area has been regarded as Morrison where it contains vertebrate remains and Kootenai where it contains plant remains."

It is still questionable whether Fisher and Calvert were justified in identifying the Morrison beneath the Kootenai in Montana, and it may be that the beds which they so identified really form a basal member of the Kootenai, as Fisher suggested. The dinosaur bones collected from this part of the section were not well enough preserved for even generic identification, and fragments of bone were found at different horizons throughout the overlying Kootenai formation. In this connection I call the attention of vertebrate paleontologists to the fact that the Carnegie Museum at Pittsburgh has a collection of dinosaur bones obtained by Hatcher from supposed Kootenai at the locality near Harlowton, Montana, which yielded the invertebrates here listed, and it may be that there is another collection of them at Princeton University. Possibly these are good enough for determining whether or not they are distinct from Morrison forms. That post-Morrison formations do contain dinosaurs related to those of the Morrison is shown by the occurrence of Hoplitosaurus and Camptosaurus in the Lakota near Buffalo Gap, South Dakota, as recorded by Gilmore.[7] For this reason the finding of a bone of an unidentified sauropod dinosaur in the Comanche series of Oklahoma has never seemed to me very strong evidence that the Morrison is of Comanche age. If some groups of Morrison dinosaurs ranged into later formations, the sauropods also may have had a greater vertical range.

BEAR RIVER FAUNA

The Bear River fauna occurs in a thick formation at the base of the Upper Cretaceous in southwestern Wyoming. It is a large and greatly varied fresh-water fauna, with a few brackish-water species, which has been fully described by C. A. White.[8] It shows no relationship with the Morrison fauna other than a few common genera, and its resemblance to the Kootenai fauna is but little closer.

---

[6] E. W. Berry: Lower Cretaceous, Maryland Geol. Survey, 1911, p. 164.

[7] C. W. Gilmore: Proc. U. S. National Museum, vol. 36, 1909, p. 300.

[8] C. A. White: The Bear River formation and its characteristic fauna. U. S. Geol. Survey Bull. 128, 1895.

DAKOTA FAUNA

The Dakota fauna, as described[9] and as represented in collections, is small but complex. Eliminating the Comanche species from the neighborhood of Salina, Kansas, which were described as Dakota by Meek, there remains a number of fresh-water species, some of which are related to those of the Bear River, and several brackish-water and marine mollusks which show relationship with the succeeding Benton fauna. None of the fresh-water species suggests derivation from Morrison forms.

Time Limits of the Morrison Formation as determined by associated marine Faunas

GENERAL DISCUSSION

The Morrison fauna then stands by itself, distinct from the few fresh-water invertebrates that preceded it in the Triassic and distinct from the non-marine Cretaceous faunas which followed it. Of course, there is no basis for comparison with the marine faunas which are nearest to it in time, but the study of these marine faunas serves to fix definitely the time limits within which the Morrison formation must fall.

SUNDANCE FAUNA

The lower limit is fixed by the age of the marine Jurassic Sundance formation on which the Morrison rests in southern Wyoming. The Sundance is classified as Upper Jurassic, and for that reason it has been assumed by some geologists that everything above the Sundance must be post-Jurassic. But a study of the fauna of the Sundance shows that it is by no means the latest Jurassic, but that it belongs in the *lower* part of the Upper Jurassic. It is characterized by *Cardioceras cordiforme* and other invertebrates, which indicate approximate correlation with the Oxfordian of the European Jurassic. In Europe the Oxfordian is followed by later Jurassic sediments, classified by De Lapparent as Sequanian, Kimmeridgian, and Portlandian (including Purbeckian). In Alaska also the fauna most closely related to the Sundance fauna occurs in beds which are overlain by several thousand feet of later Jurassic strata. There is ample room, therefore, for the Morrison within the Jurassic.

The incursion of the sea which resulted in the deposition of the Sundance formation and its equivalents in the Rocky Mountain region

---

[9] F. B. Meek: U. S. Geol. Survey Terr., vol. 9, 1876.
C. A. White: Proc. U. S. National Museum, vol. 17, 1894, pp. 131-138.

was a comparatively brief episode in the long period covering a large part of the Mesozoic era during which continental conditions prevailed. If the retreat of this sea was immediately followed by a long period of uplift and erosion prior to Morrison time, the evidence of it seems to have been overlooked by geologists. There is evidence that there was erosion and baseleveling before the marine Jurassic was laid down. On the assumption that marine waters were finally withdrawn from the Sundance sea either by a slight general uplift or by the silting up of the shallow basin, it is not unreasonable to suppose that the formation of continental deposits like the Morrison might begin almost immediately over the same area and extend far beyond it. The alternative hypothesis requires a considerable interval between the Sundance and the Morrison apparently unrepresented by either deposits or erosion.

WASHITA FAUNA

It is not within my province to speak of the possible upper limit of the Morrison as determined by the age of the floras in the overlying Kootenai and Lakota formations of Montana and the Black Hills. The oldest overlying marine fauna is found above the southern extension of the Morrison in southeastern Colorado, northeastern New Mexico, and northwestern Oklahoma, where the Morrison, with its characteristic dinosaurs, is overlain by beds containing the fauna of the Washita group, which is the uppermost of the three groups forming the Comanche series. In America it has been customary to classify the Comanche series as Lower Cretaceous in contrast with the great Upper Cretaceous series beginning with the Dakota sandstone. A number of European paleontologists who have given some attention to the Washita fauna believe it to be of Cenomanian age, the Cenomanian being regarded as the base of the Upper Cretaceous in Europe. This determination being taken as the latest possible assignment of the overlying beds, the Morrison must be older than Cenomanian and probably younger than Oxfordian. That it represents all of this interval is not probable, but in my opinion the lithologic and stratigraphic evidence of a break in sedimentation is fully as great, if not greater, between the Morrison and the rocks of Washita age, where they are in contact as it is between the Morrison and the Sundance in the northern area where these two formations come together. So far as stratigraphy and invertebrate faunas are concerned, the Morrison is somewhat more likely to belong to the Jurassic portion of the interval just indicated than to the Cretaceous portion; but their evidence is not conclusive on this point.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 349-374, PLS. 10-15 AUGUST 17, 1915
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

STUDIES OF THE MORPHOLOGY AND HISTOLOGY OF THE TREPOSTOMATA OR MONTICULIPOROIDS[1]

BY E. R. CUMINGS AND J. J. GALLOWAY

(*Read before the Paleontological Society December 31, 1914*)

CONTENTS

INTRODUCTION

The results recorded in the present paper are the by-product of studies begun by the senior author in 1899, and since 1908 shared by both authors on even terms. At first our interest in the order was almost entirely faunistic and systematic, but as these studies were pushed further it became more and more evident that a much more detailed and minute examination of trepostome structure was necessary to the proper elucidation of generic and family relationships. It was necessary, however, first of all, to bring to a conclusive issue the vexed question of the systematic position of the group, and failing this from the direction of morphology

[1] Manuscript received by the Secretary of the Society April 3, 1915.

alone, the problem was finally successfully attacked from the standpoint of colonial development (astogeny). The senior author's paper on the development of the Trepostomata (8)[2], published in 1912, leaves no doubt of the Bryozoan affinities of the order.

The results presented now are only a part of the mass of exact data that has accumulated during these years. All of it is confirmatory of the relationships indicated by development, and has led us to express a degree of confidence in our interpretations of certain peculiar structures that, in the absence of such conclusive evidence, we could not have had.

Nearly all of our knowledge of the morphology of the Trepostomata has been gained through the work of Nicholson (22–25), Ulrich (28–34), Ulrich and Bassler (35), Bassler (1–4), and the writers (6–10). In this list the name of Ulrich stands preeminent. Had the internal structure of recent Bryozoa been studied with equal thoroughness our problem of the interpretation of trepostome structure would have been very greatly lightened. As it is, we are still left in the dark in regard to a number of points. We have, to be sure, the works of Milne-Edwards, Busk, Waters, Nitsche, Hincks, Smitt, and Harmer, and especially of Calvet and Levinsen. Nevertheless, one still looks in vain for an elucidation of colony-building in the recent Bryozoa, such as the absence of soft parts has made necessary in Paleozoic forms.

For example, the exact manner in which the interzoœcial wall must have been built up in the Trepostomata is beautifully revealed in the illustrations accompanying the present paper; but of the manner in which the interzoœcial wall is actually built in recent Bryozoa most closely related to the Trepostomata, namely, in Heteropora and in the Cyclostomata, we know little. It will be necessary to study the recent Bryozoa by the methods now employed with such success in the study of the Paleozoic Bryozoa. Until this is done some points at least must remain obscure.

Cysts and Cystiphragms

In General

One of the most striking, and indeed one of the most extraordinary, features of the Trepostomata is the structures known as cystiphragms. Cystiphragms occur regularly in several genera and sporadically in many others. In *Monticulipora*, *Homotrypa*, *Peronopora*, *Homotrypella*, etcetera, these structures are invariably present and preeminently characteristic. In *Amplexopora*, *Batostoma*, *Heterotrypa*, *Hallopora*, etcetera, they are usually absent. In fact, structures exactly like cystiphragms in

[2] Figures in ( ) refer to bibliography on page 366.

appearance, when seen in the genera last named, have been denied the name of cystiphragms and have been spoken of as curved diaphragms. We hope that we shall be able to show that in both cases these structures are the same in origin and function, and that the difference is only a matter of the regularity of their occurrence. We shall suggest an interpretation of cystiphragms in the light of certain associated structures, here described for the first time.

INFUNDIBULAR DIAPHRAGMS

The structures referred to are illustrated in figures 1 to 22, inclusive. Many years ago Ulrich (30) figured and described "infundibular diaphragms" in *Amplexopora robusta* and *A. cingulata*. We have not examined the sections on which his descriptions were based, but there can be no doubt, after an examination of his figures and the figures presented herewith, that he was dealing with the same structures, but failed to see that the infundibular diaphragms are in reality the upper portions of complete, bottle-shaped or vase-shaped cysts, and that in every case these cysts inclose a mass of brown granular material unlike anything ever seen in any other portion of the zoarium. The brown material and the cysts are never present in the mesopores of species in which mesopores occur.

CYSTS AND BROWN BODIES

The portion of the cyst that envelops these brown masses is usually excessively thin-walled and may easily be overlooked. It may be best studied with a 4 mm. objective in sections cut very thin (about 25 microns). The cyst and its narrow neck (*nk* in the figures) is usually round in cross-section, as shown in numerous tangential sections. In *Heterotrypa singularis* and *H. subramosa* there are thousands of these cysts. They are found in greater or less perfection in many other genera, and especially in *Amplexopora*, *Batostoma*, *Peronopora*, *Homotrypella*, *Monticulipora*, *Prasopora*, *Homotrypa*, *Atactoporella*, *Atactopora*, etcetera. In *Homotrypa* they are very rare, but in the other genera of the family Monticuliporidæ (*sensu strictu*) they are common. In many cases the cyst is imperfectly developed, and the brown mass is then associated with the cystiphragms and diaphragms, but always in a very special way. This latter arrangement is best shown in *Peronopora* (figures 18, 20, 22). In forms that normally have a large number of cystiphragms a perfectly formed cyst, such as is so common in *Heterotrypa*, is seldom seen.

The special relationships of the brown material and the cystiphragms and diaphragms are as follows in *Peronopora* (figures 18, 20, 22):

The proximal portion of the brown mass rests usually on a well defined diaphragm, and the mass itself occupies the space between the cystiphragms and the opposite wall of the zoœcium. Often near the top of the brown mass the cystiphragms line the zoœcial tube all the way round, so that the constricted space left between them forms a narrow neck. Tangential sections show that this neck is usually of tubular cross-section. A short distance above (distally to) this neck there is another well defined diaphragm, and above the latter diaphragm, in turn, there often appears (in *Peronopora* usually) another brown mass, with a repetition of the succession of cystiphragms, etcetera, as just described.

The arrangement of cystiphragms and diaphragms, just described, characterizes the Monticuliporidæ, in which cystiphragms are a normal feature. A precisely similar arrangement is sometimes seen in *Batostoma* (figure 10) and in *Heterotrypa* (figures 2 and 6). The relative positions of brown mass, cystiphragms, and diaphragms are identical. In these latter genera, however, the brown mass is usually surrounded by a well defined calcareous cyst, of which the typical cystiphragms constitute only the neck region (figures 3, 4, 5, 7, 11, and 14). Other figures show various arrangements intermediate between the two. In some cases the proximal end of the cyst is separated more or less from the basal diaphragm (*d′* of the figures). This is shown in figures 1, 3, and 7.

The neck of the cyst is nearly always clear and free from the brown material. It may be open above—that is, with a considerable clear space between it and the distal diaphragm (figures 2, 4, 14, etcetera)—or it may be securely stoppered by a diaphragm of greater or less thickness (figures 1, 9, 11, etcetera). Occasionally the neck contains foreign particles that can be very easily distinguished from the peculiar brown material. As shown in a number of the figures, the wall of the cyst is continuous, distally, with the inner tenuous lining wall of the zoœcium. The space between the cystiphragms and the main zoœcial wall, or between the neck of the cyst and the wall, is absolutely empty, never showing anything but clear, well crystallized calcite, with which it has, of course, become infiltrated during fossilization. That this space was originally merely a void between the endosarc of the polypide and the interzoœcial wall is certain.

The nature of the brown material is as suggestive as its position and relations to surrounding structures. It consists of minute rounded particles from a seventy-fifth to a hundredth of a millimeter in diameter, of a dark yellowish brown color, as seen by transmitted light, and marked by lighter bands, as shown in figure 31. These particles consist of minute concretions of some iron compound. They react for both ferric and ferrous iron.

In figure 40 is shown the space actually occupied by an individual polypide. The space occupied by a brown mass and its accompanying cyst or cystiphragms—that is, the space between the distal and proximal diaphragms—is the same as the space occupied by an ordinary polypide. Taking into consideration, therefore, the size, relations to surrounding structures, nature of the material, and its isolation, there can be no doubt that the brown material is due to the replacement, probably by iron sulphide or iron sulphate, of organic matter left in the zooecium after the death of the polypide.

ALTERNATIVE EXPLANATIONS

Either this is the case or we must suppose that material injested by the polypide during life has been left in the abandoned zooecium. We have failed to see any good evidence that the latter is the case, although there is some analogy for it among the recent Bryozoa. The appearance of the brown mass and its enveloping cyst is curiously suggestive of the brown body so characteristic of recent Bryozoa. One can not be too careful about being misled by such resemblances; nevertheless there are certain considerations that make it seem to us worth while to suggest the possibility that these cysts and their invariable accompaniment, the brown mass, may actually have been produced in connection with brown bodies.

First of all, let it be distinctly understood that the brown color of these masses, in the fossil forms, has no relation whatever to the brown color of the original brown body; nor is the material, in its present form, in any way similar. If there is any relation between the two, we must suppose that the organic matter of the original brown body caused the segregation of some iron compound during the decomposition of the former in the abandoned zooecium. There is plenty of warrant among fossils for such a supposition. It might also be possible that material absorbed by the polypide from solution or suspension in the sea-water in which it was living has been excreted and left behind in the zooecium, after the manner of the excretion of Bismarck brown and other reagents, as described by Harmer (13). We should also have to suppose that after the polypide degenerated into a brown body the endosarc withdrew or retreated from the zooecial wall and formed a new ectosarc enveloping the degenerated polypide. For the deposition of a calcareous cyst about the brown body there is no analogy among the recent Bryozoa, so far as we are aware; neither is there any analogy for such structures as cystiphragms, for that matter. It is a fact, however, that intrazooecial secretions are made much more freely and extensively in the Trepostomata than in any other order of Bryozoa. That the brown body itself should become enveloped by a calcareous cyst is therefore rather to be expected.

In the Bryozoa universally the calcareous deposits of the ectocyst are formed *in* the ectocyst, and not on it—that is, the whole zoœcial wall, whether calcareous or chitinous, is thoroughly permeated by the organic matter of the ectocyst (see Milne-Edwards, 21; Nitsche, 26; Ostroumoff, 27; Harmer, 12; Calvet, 5, and Levinsen, 20). Hincks (14) states that the ectocyst is a secretion of the endocyst, and this view has been definitely confirmed by Calvet (5). It is evident, therefore, that after the endocyst has retreated from the zoœcial wall it secretes a new ectocyst in its new position. By this process the space occupied by the polypide is restricted, and in the event of the formation of a complete cyst, as shown in figures 2, 7, etcetera, it is very severely restricted. It is this very limitation of the space occupied by the polypide that constitutes, in our view, the best argument that we are dealing here with a degenerated individual.

Gregory has suggested that the cystiphragms are for the purpose of strengthening the zoœcial walls (11). The fact that these structures are commonly absent near the surface and at the growing tips of branches, where such a function would be best subserved, is, we think, a sufficient answer to Gregory's view. Ulrich (33), with a good deal of hesitation, has suggested that the cystiphragms might represent ovicells. Their great number (in some species) and irregularities of size and arrangement and distribution, as well as their sporadic occurrence in many species, are all against this view of their function. The fact that they are invariably empty, that they never contain any foreign particles, would also indicate that they were never in communication with the exterior of the colony nor with the body cavity. That their function is the restriction of space within the zoœcial tube is, we believe, the natural conclusion from their appearance and relation to surrounding structures.

In functional zoœcia—for example, in the surface layer of zoœcia—cystiphragms are often absent or restricted to the proximal portion of the zoœcia, indicating that these structures were probably developed somewhat late in the life of the individual polypide. At the growing ends of branches cystiphragms are seldom developed—that is, they are usually absent from the axial region. It is likely that the budding off of new zoœcia goes on very rapidly in this region of the zoarium. Each individual is short lived and never develops the characteristics of maturity, much less of old age. When, as occasionally happens, the rate of growth in this part of the zoarium is checked, the individual zoœcia thicken their walls, secrete diaphragms and cystiphragms (in species in which the latter are a normal feature), and show all the various characteristics of maturity. In other words, a mature zone is carried across the tip of the branch. Such zones are often seen in longitudinal sections of zoaria. Again, in erect ramose or frondescent zoaria, in which the axes of individual zoœcia lie in a more or less horizontal plane, the cystiphragms are on the upper side of the zoœcia. This fact probably indicates that the endosarc tends to sag away from the zoœcial wall in response to the weight of the polypide and other zoœcial contents. Where the zoœcia stand in a more nearly vertical direction, as in *Prasopora*, the cystiphragms are about equally developed on all sides of the zoœcium. A further argument in favor of the view that the cystiphragms are concerned solely with the restriction of intrazoœcial space, especially in mature and senile stages of growth, is furnished by the peculiar relation of cystiphragms to secondary deposits on the zoœcial wall, as shown in figure 17. Here the greatly thickened cystiphragms are seen to pass directly into the secondary thickening (cingulum) of the wall, and indeed the cingulum of the distal portion of the zoœcium figured consists quite evidently of thickened cystiphragms laid on flush—that is, without any voids between them. This fact is shown at *cy'* in the figure. Similar relations of the cingulum to cystiphragms are shown in figures 1, 6, and 9. Lee (18) suggests that the thickening of the walls in the mature region is for the purpose of filling up the extra interzoœcial space due to the extension of the zoœcial tubes radially outward from the axial region. That it has this effect is obvious; but it is somewhat doubtful whether this is the primary reason for the thickening, and especially for the secondary deposits so common in thick-walled species. This subject will be further discussed under the head of wall structure.

It is well known that a single zoœcium may produce a succession of polypides, each in its turn degenerating into a brown body. It has also been pointed out by Levinsen (19) that the zoœcium may be regenerated *in toto*. Calvet (5) holds, we believe with very good reason, that these successive degenerations of the polypide are connected with successive ovulations. Such figures as 1, 2, 3, 4, 6, 9, 10, and 11 very forcibly suggest such a succession of reproductive efforts, with a progressive reduction of the size and vigor of the successive polypides, reaching a climax in the final extinction of the individual, with the sealing up of its zoœcial cavity and the retained products of the successively formed brown bodies. There is plenty of analogy among recent Bryozoa for such a life history. After the culmination of the process, we may suppose that a new zoœcium budded out of the distal region of the old one in the usual manner.

It is possible, following the suggestion of Levinsen, that the cysts are due to the total regeneration of the zoœcium; that we have here a zoœcium within a zoœcium. There is not much, however, to support such a view. It would be very difficult on such a supposition to account for the appearances shown, for example, in figure 2.

Another possibility is that the cystiphragms are due to a double-walled arrangement analogous to the hypostega of some recent Chilostomata. The overlapping character of the cystiphragms and their evident production in succession, together with their sporadic occurrence in many species, do not favor this interpretation.

The cysts, with their inclosed brown masses, may be pathologic, due to the entrance into the zoœcium of deleterious foreign material or to parasitic bodies, and the consequent degeneration and death of the polypide. This explanation would not be very different from the first explanation given above. It would merely supply an exceptional rather than a normal cause for the degeneration of the polypide, and it would fit particularly well those cases in which the occurrence of the cysts and brown material is rare. It would hardly account for the regular occurrence of such structures, for example, in *Peronopora*. In the experiments of Harmer (13), mentioned above, the degeneration of a majority of the polypides of a colony usually followed the introduction of the reagent (Bismarck brown or indigo carmine) into the water in which the colonies were living.

The occurrence of these cysts and their accompanying brown masses is not confined to material from any particular locality or horizon. We have found the structures in specimens from all portions of the Ordovician, from the Chazy up, and from all of the principal provinces in which these rocks are exposed. The structures are therefore not due to any local conditions, nor are they peculiar to any special time.

The cysts and brown masses are never found in the immature or axial regions, nor even in the submature region of a zoarium. They are often found in numbers just beneath an overgrowth. The indications are that they are features of the fully mature portions of the zoarium. This adds weight to the argument that they were produced in connection with degenerating polypides.

Communication Pores

In his original description of *Homotrypa curvata*, Ulrich (29) mentions and figures "connecting foramina," passing through the interzoœcial walls. These were seen by him in tangential sections only. The structures mentioned by Ulrich have since been seen and figured in several species of *Homotrypa* by Ulrich (28), Bassler (1), and Cumings and Galloway (10). We also discovered and figured connecting foramina or, as we prefer to call them, communication pores in *Batostoma* (9) and have recorded their presence in many other genera (9). Our researches of the past few years have shown that communication pores are present in abundance in many, in fact most, of the genera of the Trepostomata. They may be most satisfactorily studied in *Heterotrypa*, *Dekayia*, *Peronopora*, and *Bythopora*. Figures 23 to 30 will, we think, convince any one that the appearances are actually due to pores passing directly through the interzoœcial walls. Figures 23 to 27 show the pores as seen in tangential sections; figure 28 as seen in a longitudinal section, and figures 29 and 30 as seen in longitudinal sections cutting transversely to the direction of the pores. Figures 27 and 30 are from a specimen of *Heteropora tortilis*, from the Miocene of Petersburg, Virginia, kindly sent us by Doctor Bassler. Except that the communication pores of *Heteropora* are usually more flaring at the mouth (double funnel-shaped), there is no discoverable difference between them and the communication pores of the Trepostomata. The figures are drawn with absolute fidelity to the original sections. In both cases the laminæ of the walls appear to be cut squarely off at the pores. This suggests the possibility that the pores may have been formed by resorption.

The appearance just mentioned caused us for a time to entertain the possibility that the pores might be perforations made by some sort of parasite, possibly an alga or fungus. Perforation of calcareous tests by such means is not an uncommon thing. Against this possibility, however, is the regularity and universality of occurrence of the communication pores, the fact that they pass straight through the walls, usually in the thinnest place, their uniform diameter and appearance, and, more than anything else, the identity of appearance of the pores in the Trepostomata and in *Heteropora*. It the latter genus they are definitely known to be communication pores.

We have found these communication pores in greater or less abundance and perfection in *Heterotrypa*, *Dekayia*, *Homotrypa*, *Hallopora*, *Amplexopora*, *Bythopora*, *Eridotrypa*, *Homotrypella*, *Peronopora*, *Stigmatella*, *Batostoma*, *Rhombotrypa*, etcetera. It is likely that they were universally present in the Trepostomata. Similar structures have been seen in *Calloclema*, *Ceramoporella*, etcetera; but the typical *Heteropora*-like pore is developed only in the Trepostomata.

Intrazoœcial Spines

In a new species of *Nicholsonella*, *N. cornula*, Doctor Galloway discovered excessively minute, apparently hollow, spines projecting into the zoœcial cavity. These are represented in figures 32 to 39, inclusive. The spines are found only in the submature region, nearly always on the lower side of the zoœcium and always curving down toward the axial region. The various appearances presented by these spines are illustrated in the
figures. Figures 32, 34, and 36 show their appearance unde ostomata.
objective (× 65), and figures 33, 35, 37, and 38 under a 4 m it produc-
(× 287). The spine usually has the appearance seen in fi many spe-
end of the spine being bulbous and the wall appearing dou
the spine were hollow and continuous with the thin linin logic, due to
zoœcium. Some of the spines in this species, however, l or to para-
spines in a nearly related species have the appearance re the polypide.
and *q*, figure 33, and *n* and *m*, figure 32—that is, the sp explanation
and appears solid. Either it is solid or the wall is so thin than a nor-
resolved by the very high magnification used. Most of the fit particu-
hollow, and such examples as are shown in figure 38 coul and brown
interpreted in any other way, for they not only appear ho currence of
tain small particles of foreign matter, and moreover appear riments of
cate with pores in the wall (*x* in the figures). Some of th rity of the
tain a dark spot, resembling an air bubble, and it may very the reagent
these are actually bubbles (see figure 33, *n*). It is possible th he colonies
was originally solid, and that it became overlain by a second
If the original spine, acting as the core, were perfectly transpa sses is
appearances would be exactly the same as though the spine were origin e
hollow.

What possible function these spines could have had we do not ventu to say. The nearest analogy among recent Bryozoa is found in the spin figured and described by Nicholson in *Heteropora neozelanica* (24). I deed, the resemblance between his figures and our figure 32 is remarkably strong. We have not been able to obtain any specimens of *Heteropora neozelanica*. It is possible that the resemblances mentioned are without significance, but they are interesting enough to warrant further study, which we propose to give them at our earliest opportunity.

Wall Structure

INTEGRATA AND AMALGAMATA

The general characteristics of the wall structure of the Trepostomata have been known ever since the classic work of Nicholson (22–25). We believe that wall structure, properly understood, will prove important in generic and family classification within this order. This idea was emphasized by Cumings in his paper on the Heterotrypidæ (6). In their revision of the Trepostomata, Ulrich and Bassler (35), on the basis of wall structure, divided the order into two divisions: the Amalgamata, in which "the boundaries of adjacent zoœcia are obscured by the more or less complete amalgamation of their walls," and the Integrata, in which "the boundaries of adjoining zoœcia are sharply defined by a well-marked, divisional line" (31).

ISTOLOGY OF THE WALLS AND THE MEDIAN LINE

arrangement of the Trepostomata seemed to the writers to led and very useful. The first to express any dissatisfac- as Lee (18), who noted that a dark line was occasionally ecies otherwise referable to the Amalgamata. Our atten- been called to this same fact in certain species of *Hetero-* typical member of the Amalgamata. It presently occurred a careful restudy of the histology of the trepostome walls igher magnification than has hitherto been employed and l rather than in tangential sections, since the actual course minæ from face to face of the wall can not be followed in d of section. The results of these studies are shown in fig- inclusive. Figure 45 shows the median line in its sharpest ppears in *Batostoma winchelli*, while figures 42, 48, and 50 typical amalgamate structure as it appears in *Bythopora*, *ypa*, and *Dekayia*. These two types of structure certainly appear to be very distinct; nevertheless both may and do occur in the same species, and indeed in a single specimen. Figures 46 and 47 are sections of *Heterotrypa prænuntia*, both from the mature region. Figure 43 shows the amalgamate phase of structure in *Amplexopora septosa multispinosa*, a member of the Integrata, while figure 48 shows it in *Heterotrypa prolifica*, a typical member of the Amalgamata. There is no real difference between these two walls. It is very rarely indeed that the apparently sharp divisional line of the wall is not resolved by high magnification into an irregular zone, such as is shown in various phases in figures 43, 49, and 56. Figure 49 is instructive, since *Eridotrypa* is regarded as a member of the Amalgamata. It may with profit be compared with figure 45. The true meaning of this dark zone is revealed by comparison of figures 56 and 57. These sections are cut in portions of zoaria where the zoarial surface has been perfectly preserved by overgrowth. The growing edge of the wall is shown intact. In figure 56 (*Hallopora*

ostomata.
Dekayia, I
convince an
directly thro
as seen in tan
and figures
versely to th
specimen of
ginia, kindly
pores of *Het*
nel-shaped),
communicat
absolute fid
the walls ap
possibility t
The app
possibilit
parasit

splendens), a member of the Integrata, the growing edge of the wall is very thin, and the wall becomes gradually thicker farther in, finally receiving a secondary deposit, the cingulum. Because of this method of growth the laminæ of the wall have a very steep pitch, and the bend they make in the axis of the wall is sharp. On the other hand, the growing edge of the wall in *Dekayia* (figure 57) is smoothly rounded, and the laminæ pass across from zoœcium to zoœcium with a regular curve. For some reason, wherever the wall laminæ of the trepostomes are sharply bent the material appears dark. This is true also of sharp bends of diaphragms (figures 1, 9, 11, 44, 45, 46, 47). It is probable that the size and arrangement of the minute granules of which the wall laminæ are composed differ slightly at such points from the normal size and arrangement in other parts of the wall. In fact, in well preserved material and in very thin sections it can be shown that this is actually the case. Usually the granules are too small to show under the magnifications indicated in these figures. In some species, as in *Bythopora gracilis*, *Heterotrypa prolifica*, etcetera, the granules can be distinctly seen under a 4 mm. objective and 10 × ocular. Figure 12 shows very clearly their appearance in *Bythopora*. In the latter genus, and in the Amalgamata generally, these larger granules are distributed in more or less concentric bands from face to face of the wall, or they are distributed in a broad zone in the central portion of the wall. In the Integrata commonly, and occasionally in the Amalgamata, they are more closely concentrated in the axial region of the wall, and when bands of granules from either side of the wall are present they are often offset instead of continuing uninterruptedly across the median region of the wall. Such an arrangement can be seen in figures 44 and 56. The granules of the lighter appearing portions of the walls are so minute that they can scarcely be seen under any feasible magnification. It may be remarked that these minute granules of the trepostome wall probably represent each an individual cell of the original ectosarc, since we have good reason to believe that the calcareous deposits of the zoœcial walls of Bryozoa are made intracellularly.

There is no good evidence that either type of wall described above was double except in the sense that any bryozoan wall is double, namely, because it is secreted by the juxtaposed or coalesced ectosarcs of two adjoining individuals. Nor does the analogy of the Cyclostomata, the order nearest related to the Trepostomata, lead us to expect a double wall in the latter order. To say that the boundary between adjoining zoœcia is *obscured* in the Amalgamata does not go far enough. There is no such boundary. The wall was one and single and common to two zoœcia, as it is in the Cyclostomata (Levinsen, 20). On the other hand, such appearances as are shown in figure 45 might perfectly well be interpreted as indicating a double wall, were it not for the fact that this phase and the phase shown in figure 43 may and do occur in the same specimen.

In the recent Chilostomata, according to Calvet, Levinsen, and others, some genera have a double and some a single wall, and there is no important classificatory value to this difference. If the differences above described are due primarily to the steepness of pitch of the wall laminæ, it is likely that the classificatory value of this phase of wall structure in the Trepostomata is also of subordinate rank. The calcareous laminæ are laid down in the growing edge of the wall parallel to the two surfaces of the amalgamated ectosarc, as shown in figures 56 and 57. If the wall is knife-edged, as shown in figure 56, the laminæ will pitch very steeply and there will be a sharply defined central zone. If the growing edge of the wall is blunt, as shown in figure 57, there will be no definite median boundary. Phases intermediate between these two extremes will also be of common occurrence.

It has often been asserted that the duplex character of trepostome walls is proven by the tendency of the walls to split down the middle. If this were a fact, it would unquestionably be a good argument; but it is not a fact. We have examined thousands of fractures, under high magnifications, and have found that the split invariably follows the direction of the laminæ, crossing back and forth across the median region of the wall with perfect indifference. Where the laminæ are very steep, the wall often appears under low magnification to be split accurately in the middle; but a closer examination will always show that it is not. In the axial region, where the laminæ are parallel with the surface of the wall (figure 58, *ax*), the split may follow the median line, or any other line parallel with it, often for a considerable distance. The highest obtainable magnification (oil immersion) has failed to reveal any indication of duplex structure of the walls in the axial region of the zoarium. The whole wall under such magnification appears merely as parallel chains of granules. Figure 58 shows the wall of *Stigmatella spinosa* where it emerges from the axial region. Opposite *ax* there appears to be a dark dividing line, but farther in toward the axial region this entirely disappears. Farther out toward the mature region the dark median zone becomes interrupted and the laminæ bend more or less smoothly over the axial region of the wall. The mature region of the wall of this genus is like that of *Dekayia*, figure 50.

THE CINGULUM

The walls of the Trepostomata often show a greater or less amount of secondary thickening. These secondary deposits we have designated the *cingulum* (9), because in tangential sections (figures 23 to 26) they give the appearance of a well defined ring or zone of deposits adjacent to the zoœcial cavity. The cingulum is shown in longitudinal section in figures 43, 44, 46, 47, 56, and 58. In figures 45 and 48 there are also massive secondary deposits, which do not, however, form so sharply defined a layer as is shown in the other sections. These secondary deposits are intimately related to the diaphragms, as the figures clearly show. The diaphragms and the cingulum are continuous (figures 44, 46, 47, and 45). It appears, therefore, that the secretion of a diaphragm is coincident with the formation of a deposit over the entire inner surface of the zoœcium. The extremes to which this secondary thickening may go are illustrated in figures 1, 9, 14, 17, 45, and 47. An unusually extreme example is *Diplotrypa bicornis*, figured by Bassler in his volume on the Baltic Bryozoa (1).

The fact has already been pointed out that the cystiphragms may be very closely related to this secondary thickening of the walls. This is beautifully illustrated in figure 17. Thick-walled species with cystiphragms (for example, *Homotrypella*) afford numerous illustrations of the same thing. In figure 17 the boundary between the primitive wall and the secondary deposit is clearly shown by a distinct line, and the thickened cystiphragms have the same definite relation to the cingulum as do the diaphragms in the cases already cited.

The thickening of the interzoœcial walls, due to the development of the cingulum, is often very great—far greater than would merely compensate for the increasing separation of the zoœcia, as they extend radially outward from the axial region. There is an actual reduction of the size of the zoœcial chamber; indeed, in some cases, an extreme reduction (figures 1 and 17). We believe that this extreme development of secondary deposits is a senile feature, analogous to the great thickening of brachiopod shells and the shells of the Mollusca in old age. In recent Bryozoa the zoœcia of the older portions of zoaria often become almost or quite filled up with stony deposits, and it seems that the ectosarc may continue to secrete such deposits after the polypide has wholly disappeared from the zoœcium.

We can not dismiss this subject without calling attention to the striking resemblance between the wall structure of the Trepostomata and of the Brachiopoda. In such sections as are shown in figures 45 and 49 it amounts almost to identity. In figure 54 also the fascicles of wall laminæ look almost precisely like the similar fascicles of laminæ so often seen in sections of brachiopod shells.

Acanthopores

The function of acanthopores has long been a puzzle. It has been surmised that these hollow, thick-walled tubules were in the living colony surmounted at the surface by some sort of spine, avicularium or vibraculum. Waagen and Wentzel (36) made the mistake of supposing that they were young zoœcia (corallites). Several years ago we noticed among our sections of *Dekayia maculata* a few examples of overgrowths in which the entire spine, extending well above the surface of the zoarium, is preserved. Two of these sections are figured herewith (figures 51 and 52). In figure 51 every detail of the overgrowth, calcite structure and all, has been delineated, in order to eliminate, so far as possible, the personal interpretations of the authors. The drawing is photographically exact. The appearance at *t*, which might almost be interpreted as an avicularium, has probably been produced by the crushing of the end of the spine. The spine shown in figure 52 extended up into a mass of sediment that had coated the zoarium and had subsequently been covered by the overgrowth. It seems to be perfectly intact. The actual diameter of these spines is about that of a human hair and they extend about 2½ zoœcial diameters above the zoarium. Most acanthopores, however, were much smaller than these. In *Dekayia* the exsert portion of the spine was brittle, as shown by the fact that in overgrowths of specimens of this genus quantities of sharply broken fragments of spines are often seen. A bent spine is a rare occurrence. There is some evidence, however, that in certain other genera the spines were flexible (10). The laminæ of which the spine is composed run parallel with the axis of the spine. Their appearance under high magnification is shown in figure 53. This drawing is from the region *s* of the preceding figures. Figure 54 shows the region *s′* of a spine highly magnified. This part of the spine has been buttressed by extensive secondary deposits laid on it by the adjoining zoœcia. The primary wall of the spine can be distinguished in the inner fascicle of laminæ next to the lumen. In figure 51 this primary spine can be traced far down into the zoarium. It is obvious that as the zoœcia grow distally they submerge the exsert portion of the spine, which latter keeps lengthening. If the axis of the spine is not perfectly parallel with the axes of the surrounding zoœcia, the submerged portion of the acanthopore will trend more or less diagonally between adjoining zoœcial walls. This explains an appearance very often seen in longitudinal sections of species that have large and well defined acanthopores.

The protective function of such spines can scarcely be doubted. Their very number and relation to the zoœcial apertures indicate such a function beyond question. In addition, we have occasionally seen a whole battery of spines of unusually large size surrounding the hole of a parasitic boring worm that had penetrated the zoarium. There are, however, many different kinds of acanthopores, and it is not likely that they all had the same function. The type described above is common in the Heterotrypidæ, in some species of *Homotrypa*, in *Homotrypella*, *Peronopora*, etcetera. On the other hand, the minute acanthopores with ill-defined lumen, so often seen in *Homotrypa* and other genera, may have supported an exsert process of a very different sort.

Merlia Normani Kirkpatrick

After the senior author's paper on the development of the Monticuliporoids (8) was distributed, Dr. W. D. Lang, of the British Museum, called our attention to several notes that had been published in Nature and the Proceedings of the Royal Society by Doctor Kirkpatrick, of the Museum, in regard to a peculiar recent sponge, having an auxiliary skeleton, externally greatly resembling the zoaria of certain Monticuliporoids (16, 17). Doctor Kirkpatrick in these announcements states without hesitation that, on the basis of the resemblances mentioned, *Monticulipora* should be regarded as a sponge. In his elaborate paper on the morphology of *Merlia*, Doctor Kirkpatrick (15) had taken a much more conservative view of the resemblances.

Through the kindness of Doctor Lang and Doctor Kirkpatrick we were able to obtain several specimens of *Merlia*, preserved in alcohol. We have sectioned these and made a very careful study of the wall structure, which is shown in tangential section in figure 41. A glance will convince any one that there is not the slightest resemblance between this structure and anything ever seen in the Trepostomata. In *Merlia* the calcification evidently proceeds by spiculation from definite centers (*c*, *c*). At the growing edges of colonies of *Merlia* the skeletal elements have not yet coalesced, and one sees here nothing but chains of small erect pillars distinctly separated from each other. In later growth these coalesce by the radial extension of their spicules or fibers. In longitudinal sections of the walls these fibers are seen to arise vertically from the substratum and turn *outward*, like the straws in a sheaf of wheat. This explains the appearance shown in the tangential section. The central granular-appearing nucleus is where the fibers are cut transversely, and the zone of radiating fibers surrounding the nucleus is where the outward-turning fibers are cut more and more longitudinally. The boundaries between adjacent sheaves of spicules are very sharp. The structure shown in figure 41 may with profit be contrasted with the typical trepostome structure shown in figure 38 of the same plate or in figures 23 to 27. Again in longitudinal sections of *Merlia* the cross-partitions (diaphragms) have a large central perforation with a downward-turning collar—unlike anything ever noted in the trepostomes. The fact is that the structure of *Merlia* is about as different from that of the trepostomes as anything could well be. Kirkpatrick was completely mislead by superficial resemblances.

Summary and Conclusions

This paper deals with a number of morphological and histological characters of the Trepostomata which are either new or have heretofore been imperfectly understood.

Cysts and cystiphragms.—More or less perfectly formed calcareous cysts inclosing peculiar brown material are described and their relation to cystiphragms explained. It is suggested that these structures are developed in connection with successive degenerations and regenerations of the polypides, and that the purpose of cystiphragms is the restriction of intrazoœcial space.

Communication pores.—The histology of communication pores in the Trepostomata and in the genus *Heteropora* is described, and it is shown that not only are these structures probably universally present in the Trepostomata, but that the pores have the same characteristics and arrangement as in *Heteropora*.

Intrazoœcial spines.—Certain extraordinary spines projecting into the submature region of zoœcia of a species of *Nicholsonella* are described and their resemblance to the spines of *Heteropora neozelanica*, as figured by Nicholson, is pointed out.

Wall structure.—The structure and histology of the walls of the Trepostomata, as seen in longitudinal sections, is minutely described. It is shown that the divisions Integrata and Amalgamata, based on the supposed presence or absence of a definite divisional plane in the center of the wall, are open to some question, and that the trepostome wall was probably single and common to adjoining zoœcia, as it is in the Cyclostomata. The method of origin and the varying arrangements of the wall laminae are described, and it is shown that the presence or absence of a dark median line in the wall depends to a large extent on the steepness of pitch of the laminae, which in turn depends on whether the growing edge of the wall is thin and sharp or blunt and smoothly rounded. It is shown that the secondary deposits (or cingulum) are definitely related to the diaphragms, and in some cases to the cystiphragms, and that these massive deposits are probably best interpreted as senile characters.

Acanthopores.—It is shown that in *Dekayia* the surface of the colony was characterized by minute hollow spines, about the diameter of a hair and extending two or three zooecial diameters above the surface. The acanthopores are merely the submerged portions of these spines. The function of the spines was undoubtedly protective.

Merlia normani Kirkpatrick.—It is demonstrated by a study of wall structure that *Merlia* has no relation whatever to the Trepostomata.

Bibliography

1. R. S. Bassler: The structural features of the Bryozoan genus Homotrypa, with descriptions of species from the Cincinnatian group. Proceedings of the U. S. National Museum, volume xxvi, Washington, 1903, pp. 565–591.
2. ——: A study of the James types of Ordovician and Silurian Bryozoa. Proceedings of the U. S. National Museum, volume xxx, Washington, 1906, pp. 1–66.
3. ——: The Bryozoan fauna of the Rochester shale. Bulletin 292, U. S. Geological Survey, Washington, 1906.
4. ——: The early Paleozoic Bryozoa of the Baltic provinces. Bulletin 77, United States National Museum, Washington, 1911.
5. Louis Calvet: Contribution a l'Histoire Naturelle des Bryozoaires Ectoproctes marin. Trav. Inst. Zool. Montpellier, N. S., memoire 8, Montpellier, 1900.
6. E. R. Cumings: A revision of the Bryozoan genera Dekayia, Dekayella and Heterotrypa. American Geologist, volume xxix, Minneapolis, 1902, pp. 197–217.
7. ——: The stratigraphy and paleontology of the Cincinnati series of Indiana. Thirty-second Annual Report of the Department of Geology and Natural Resources of Indiana, Indianapolis, 1908, pp. 607–1189.
8. ——: Development and systematic position of the Monticuliporoids. Bulletin of the Geological Society of America, volume xxiii, Washington, 1912, pp. 357–370.
9. —— and J. J. Galloway: A note on the Batostomas of the Richmond series. Proceedings of the Indiana Academy of Science for 1911, Indianapolis, 1912, pp. 147–166.
10. —— ——: The stratigraphy and paleontology of the Tanner's Creek section of the Cincinnati series of Indiana. Thirty-seventh Annual Report of the Department of Geology and Natural Resources of Indiana, Indianapolis, 1913, pp. 353–478.
11. J. W. Gregory: Catalogue of the fossil Bryozoa in the Department of Geology of the British Museum (Natural History). The Cretaceous Bryozoa, London, 2 volumes, 1899, 1909.

12. S. F. HARMER: A revision of the genus Steganoporella. Quarterly Journal of Microscopical Science (N. S.), volume xliii, part 2, London, 1900, pp. 225–297.

13. ——: On the nature of excretory processes in marine Polyzoa. Quarterly Journal of Microscopical Science, volume xxxiii, London, 1892.

14. THOMAS HINCKS: A history of the British marine Polyzoa. Two volumes, London, 1880.

15. R. KIRKPATRICK: *Merlia normani*, a sponge with a siliceous and calcareous skeleton. Quarterly Journal of Microscopical Science, series 2, volume lvi, London, 1911, pp. 657–702.

16. ——: *Merlia normani* and its relation to certain Paleozoic fossils. Nature, volume lxxxix, London, July, 1912, pp. 502–503.

17. ——: Note on *Merlia normani* and the "Monticuliporas." Proceedings of the Royal Society, volume 85, London, 1912, pp. 562–563.

18. G. W. LEE: The British Carboniferous Trepostomata. Memoirs of the Geological Survey of Great Britain, Paleontology, volume i, part 3, London, 1912, pp. 135–195.

19. G. M. R. LEVINSEN: Sur la regeneration totale des Bryozoaires. Oversigt over det Kgl. Danske Videnskabernes Selskabs forhandlinger, number 4, Christiania, 1907, pp. 151–159.

20. ——: Morphological and systematic studies on the Cheilostomatous Bryozoa, Copenhagen, 1909.

21. HENRI MILNE-EDWARDS: Quoted by G. B. Simpson, in A Handbook of the genera of North American Paleozoic Bryozoa. Fourteenth Annual Report of the State Geologist of New York, Albany, 1895, pp. 407–667.

22. H. A. NICHOLSON: On the structure and affinities of the Tabulate Corals of the Paleozoic Period, with critical descriptions of illustrative species. Edinburgh, 1879.

23. ——: On the minute structure of the recent *Heteropora neozelanica*, Busk, and on the relations of the genus Heteropora to Monticulipora. Annals and Magazine of Natural History, volume vi, 1880, pp. 329–338.

24. ——: On the structure and affinities of the genus Monticulipora and its subgenera, with critical descriptions of illustrative species, Edinburgh, 1881.

25. —— and R. LYDEKKER: Manual of Paleontology, Edinburgh and London, 1889, chapter on the Monticuliporoids, pp. 346–357.

26. HINRICH, NITCHE: Beiträge zur Kentniss der Bryozoen. III. Ueber die Anatomie und Entwickelungsgeschichte von Flustra membranacea. Zeitschrift für Wissenschaftliche Zoologie, xxi, Leipzig, 1871, pp. 37–91.

27. A. OSTROUMOFF: Remarques relatives aux recherches de M. Vigelius sur les Bryozoaires. Zoologischer Anzeiger, viii, Leipzig, 1885, pp. 290–291.

28. E. O. ULRICH: American Paleozoic Bryozoa. Journal of the Cincinnati Society of Natural History, volumes v to vii, Cincinnati, 1882–1884; volume v, pp. 121–175, 232–257; volume vi, pp. 82–92, 148–168, 245–279; volume vii, pp. 24–51.

29. ——: American Paleozoic Bryozoa (see above), volume v, p. 242, 1882.

30. ——: American Paleozoic Bryozoa (see above), volume vi, p. 82, 1883.

31. E. O. ULRICH: Paleozoic Bryozoa. Geological Survey of Illinois, volume viii, Springfield, 1890, pp. 285–688.

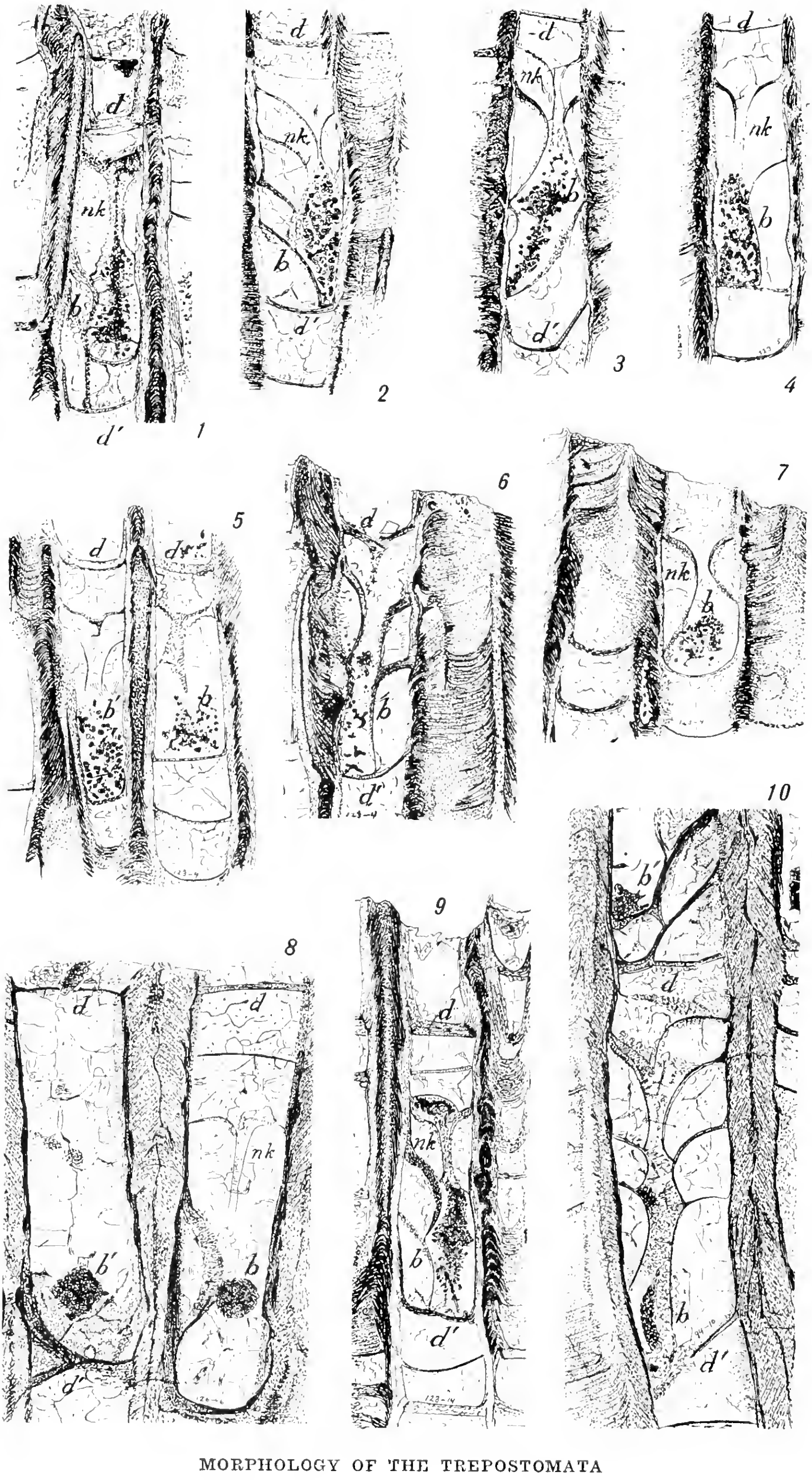
32. ——: On Lower Silurian Bryozoa of Minnesota. Geology of Minnesota, volume iii, part 1 of Final Report, Paleontology, Minneapolis, 1895, pp. 96–332.

33. ——: Text-book of Paleontology, by Karl A. von Zittel, translated and edited by Charles R. Eastman, London and New York, 1900, pp. 271–278.

34. ——: *Idem*, second edition, 1913, pp. 330–339, revised and extended by R. S. Bassler.

35. —— and R. S. BASSLER: A revision of the Paleozoic Bryozoa, Part II, Trepostomata. Smithsonian Miscellaneous Collections, volume 47, Washington, 1904, pp. 15–55.

36. WILLIAM WAAGEN and JOSEPH WENZEL: Salt Range Fossils. Cœlenterata, Memoirs of the Geological Survey of India. Paleontologica Indica, Series xiii, Calcutta, 1886.



MORPHOLOGY OF THE TREPOSTOMATA

Explanation of Plates

Plate 10.—Morphology of the Trepostomata.

Figures 1–7 and 9.—*Longitudinal sections of Heterotrypa subramosa Ulrich.*

The cysts and their inclosed brown masses (*b*) are shown in these figures. The proximal and distal diaphragms are lettered *d'* and *d* respectively, and the neck of the cysts *nk*. The distal diaphragm is often greatly thickened, while the zoœcium of which it forms the basal wall has an unusually thick cingulum (figures 1 and 9). All figures × 65. (123–16, 11, 5, 5, 4, 4, 1, 14.)

Figures 8 and 10.—*Longitudinal sections of three zoœcia of Batostoma variabile.*

Significance of letters the same as in preceding figures. In the right-hand zoœcium of figure 8 the neck of the cyst is very narrow and straight, and its connection with the lower part of the cyst has been obliterated. Figure 10 shows two successive sets of cystiphragms and brown bodies (*b* and *b'*). × 65. (126–6; 94–10.)

PLATE 11.—MORPHOLOGY OF THE TREPOSTOMATA.

FIGURE 11.—*Longitudinal section of a zoœcium of Heterotrypa subramosa Ulrich.*

In this example the cyst is stoppered by a very thick diaphragm. × 65. (123–19.)

FIGURE 12.—*Longitudinal section of Monticulipora epidermata U. and B.*

As in most of the Monticuliporidæ, *sensu stricto*, the brown mass is not enveloped by a fully formed cyst, but is more or less isolated by the cystiphragms and the proximal diaphragm. × 65. (50–23.)

FIGURE 13.—*Longitudinal section of Atactopora intermedia C. and G.*

The brown material is present in all three zoœcia, and there is a well defined cyst in the one to the right. × 65. (157–23.)

FIGURE 14.—*Longitudinal section of several zoœcia of Amplexopora pustulosa.*

The well defined cyst and brown mass have the same form as in Heterotrypa. × 65. (125–1.)

FIGURE 15.—*Longitudinal section of Homotrypa cf. subramosa.*

The arrangement of brown material and cystiphragms is the same as in Monticulipora. × 65. (186–9.)

FIGURE 16.—*Longitudinal section of Homotrypella rotundipora* n. sp.

A well defined neck is formed by the cystiphragm on the right-hand wall. × 65. (148–13.)

FIGURE 17.—*Longitudinal section of Homotrypa spissa* n. sp.

This section shows a well defined brown mass and an unusual thickening of the cystiphragms (*cy*), which are intimately related to the cingulum. × 65. (202–18.)

FIGURE 18.—*Longitudinal section of Peronopora vera.*

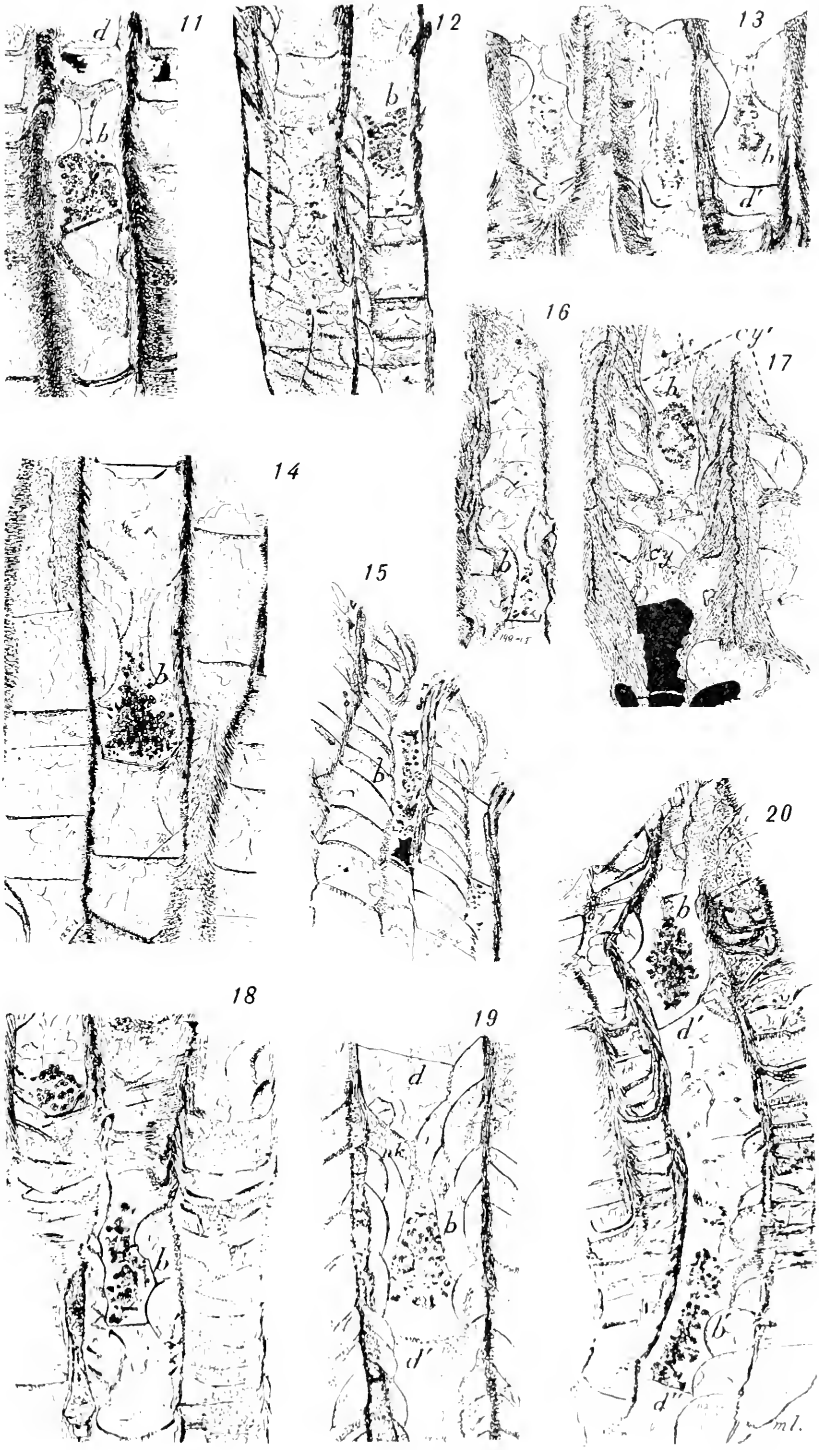
A very sharply defined brown mass and inclosing cystiphragms. × 65. (112–12.)

FIGURE 19.—*Longitudinal section of Prasopora simulatrix.*

Here the polypide chamber, in which is lodged the brown mass, is very greatly restricted in size, and the neck of the cyst is small and well defined. The distal and proximal diaphragms are also clearly defined. × 65. (114–16.)

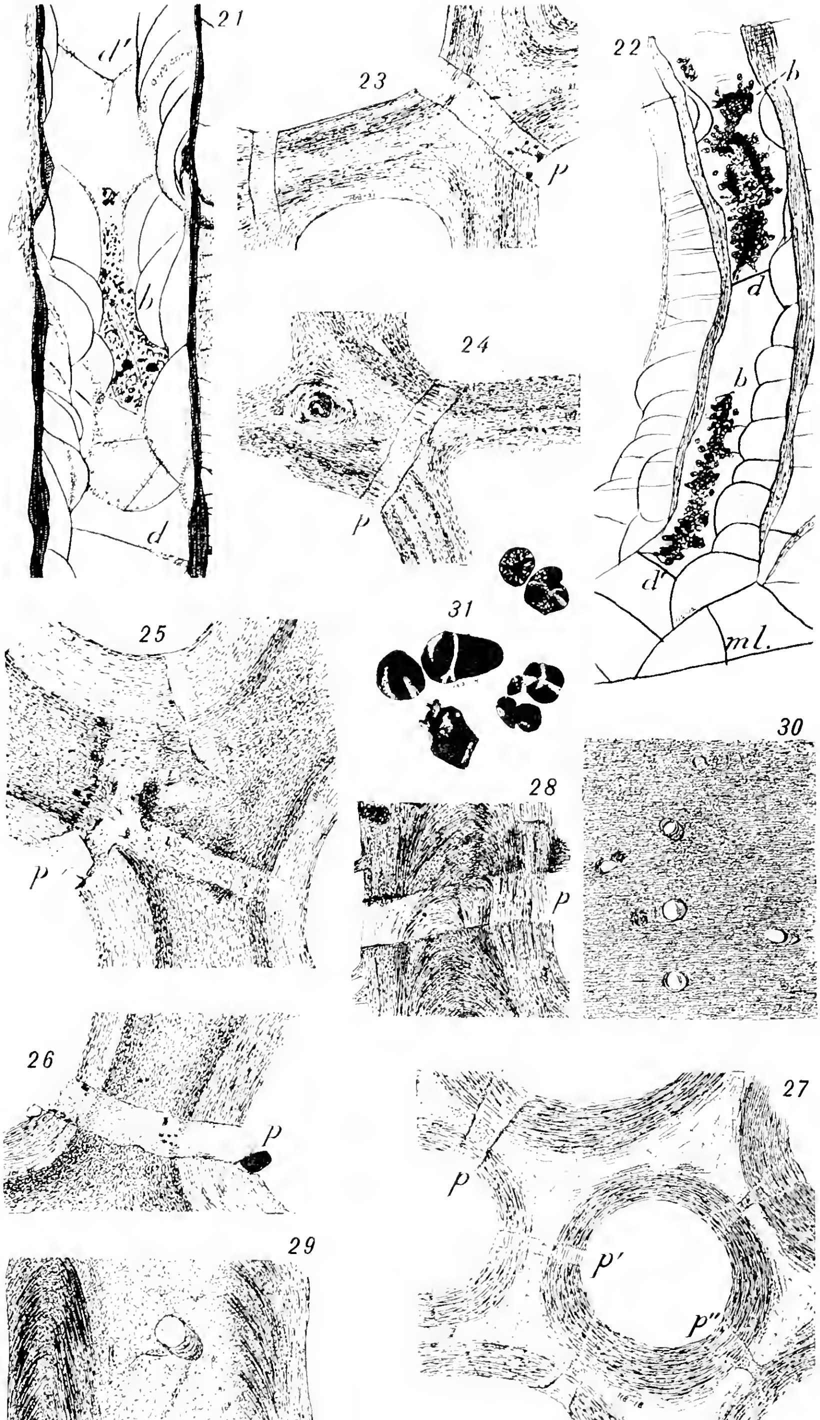
FIGURE 20.—*Longitudinal section of Peronopora vera.*

Two very typical brown masses with their accompanying cystiphragms are shown (*b* and *b'*). × 65. (112–12.)



MORPHOLOGY OF THE TREPOSTOMATA

XXVII Bull. Geol. Soc. Am., Vol. 26, 1914



MORPHOLOGY OF THE TREPOSTOMATA

PLATE 12.—MORPHOLOGY OF THE TREPOSTOMATA.

FIGURE 21. *Partially diagrammatic drawing of a longitudinal section of a zoœcium of Prasopora simulatrix.*

This is an extremely well defined brown mass with the cystiphragms developed all around the zoœcium, as is usually the case in Prasopora. × 65. (111–16.)

FIGURE 22. *Semi-diagrammatic drawing of a longitudinal section of a zoœcium of Peronopora vera.*

This shows the characteristic succession of brown masses and cystiphragms of this species. × 65. (112–12.)

FIGURES 23 TO 26.—*Tangential sections of Heterotrypa and Peronopora* (figure 24).

The normal appearance of communication pores is shown in these sections (*p*). The wall laminæ are cut squarely off at the pores. × 287. (168–21; 117–11; 101–20; 20.)

FIGURE 27.—*Tangential section of Heteropora tortilis from the Miocene of Petersburg, Va.*

The communication pores, except for the flaring mouths, present exactly the same appearance as in the Trepostomata. That the double funnel shape is not invariable is shown by the pores *p* and *p'*. × 287. (118–18.)

FIGURE 28.—*Longitudinal section of the wall of Heterotrypa prolifica.*

The pore presents the same appearance as in the tangential section. × 287. (168–21.)

FIGURE 29.—*Longitudinal section of the wall of Heterotrypa prolifica.*

This section cuts through the wall in such a way as to cross the pore in a direction somewhat oblique to the axis of the pore. × 287. (168–21.)

FIGURE 30.—*Portion of a longitudinal section of the wall of Heteropora tortilis.*

The wall is cut in the same manner as the wall of Heterotrypa of the preceding figure. Some of the pores are cut straight across and some more or less obliquely. The appearances are exactly the same as in figure 29. × 287. (118–18.)

FIGURE 31. *A few grains of the brown material of a cyst of Heterotrypa subramosa.*

The grains have the form of minute concretions or nodules. × 450. (123–4.)

PLATE 13.—MORPHOLOGY OF THE TREPOSTOMATA.

FIGURES 32 TO 39.—*Sections of Nicholsonella cornuta* n. sp., *showing the minute spines projecting into the zoœcia.*

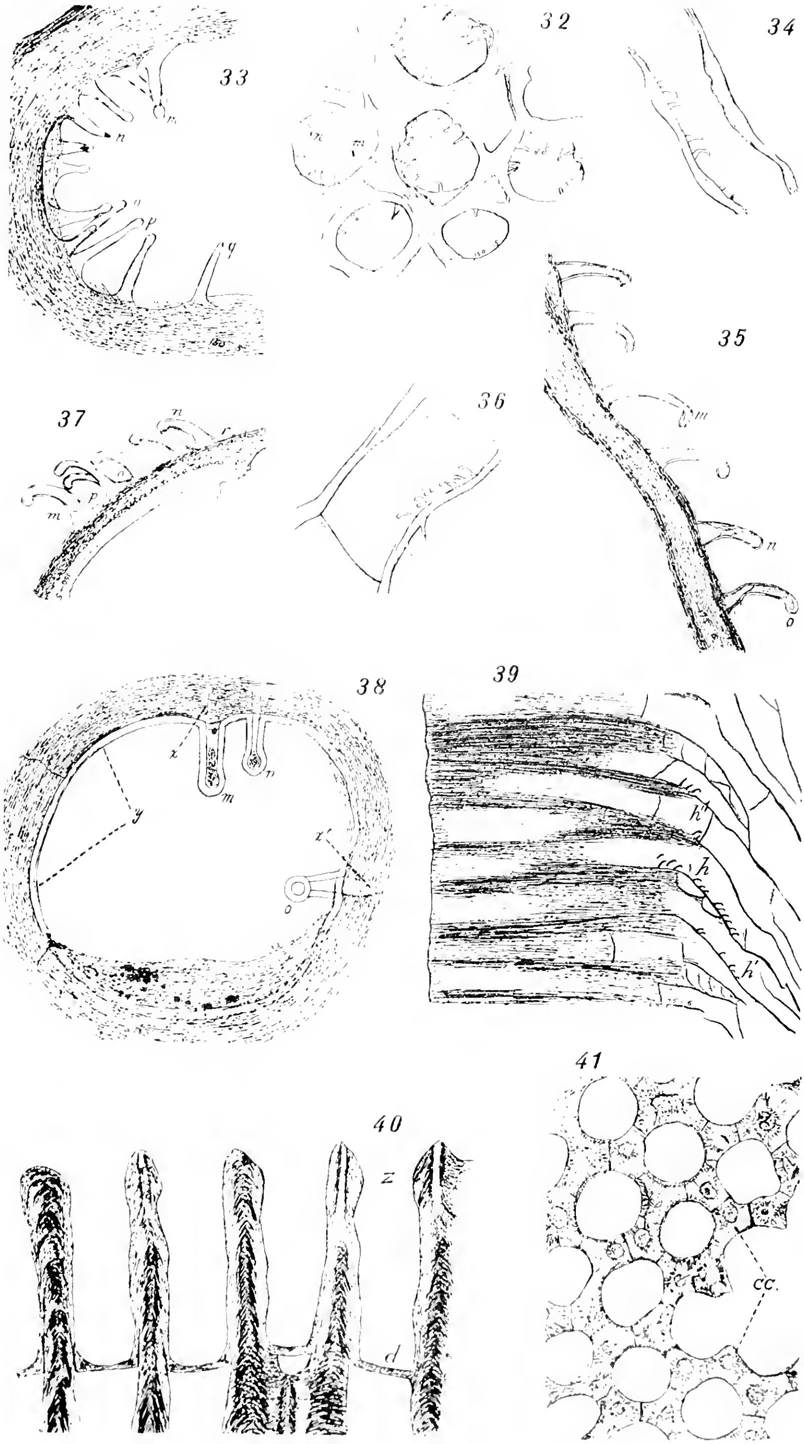
The usual appearance of the spines is shown in figures 35 and 37. In figure 33 are shown spines that are either excessively thin-walled or solid. At *n* in this figure and in the adjacent spine are seen black bodies that may be bubbles. The appearance shown at *m* is probably due to the double refraction of the calcite. Figure 38 shows unusually thick-walled spines and possibly excavations (*x*, *x'*) in the walls of the zoœcium, opposite the lumens of the spines. The spines *m* and *n* appear to contain foreign particles. The thin transparent lining of the zoœcium is continuous with the walls of the spines. This feature is also shown in figure 37. Figure 39 shows the region of the zoarium in which the spines are invariably found, together with the fact that they are usually on the lower sides of the zoœcia. Figures 34 and 35 show the same set of spines under different magnifications. This is also the case with figures 36 and 37. Figures 32, 34, and 36, × 65. Figures 33, 35, 37, and 38, × 287. Figures 39, × 25. (150–5, 5; 175–6, 6; 150–5, 5; 175–23; 175–6.)

FIGURE 40.—*Longitudinal section of Heterotrypa prolifica.*

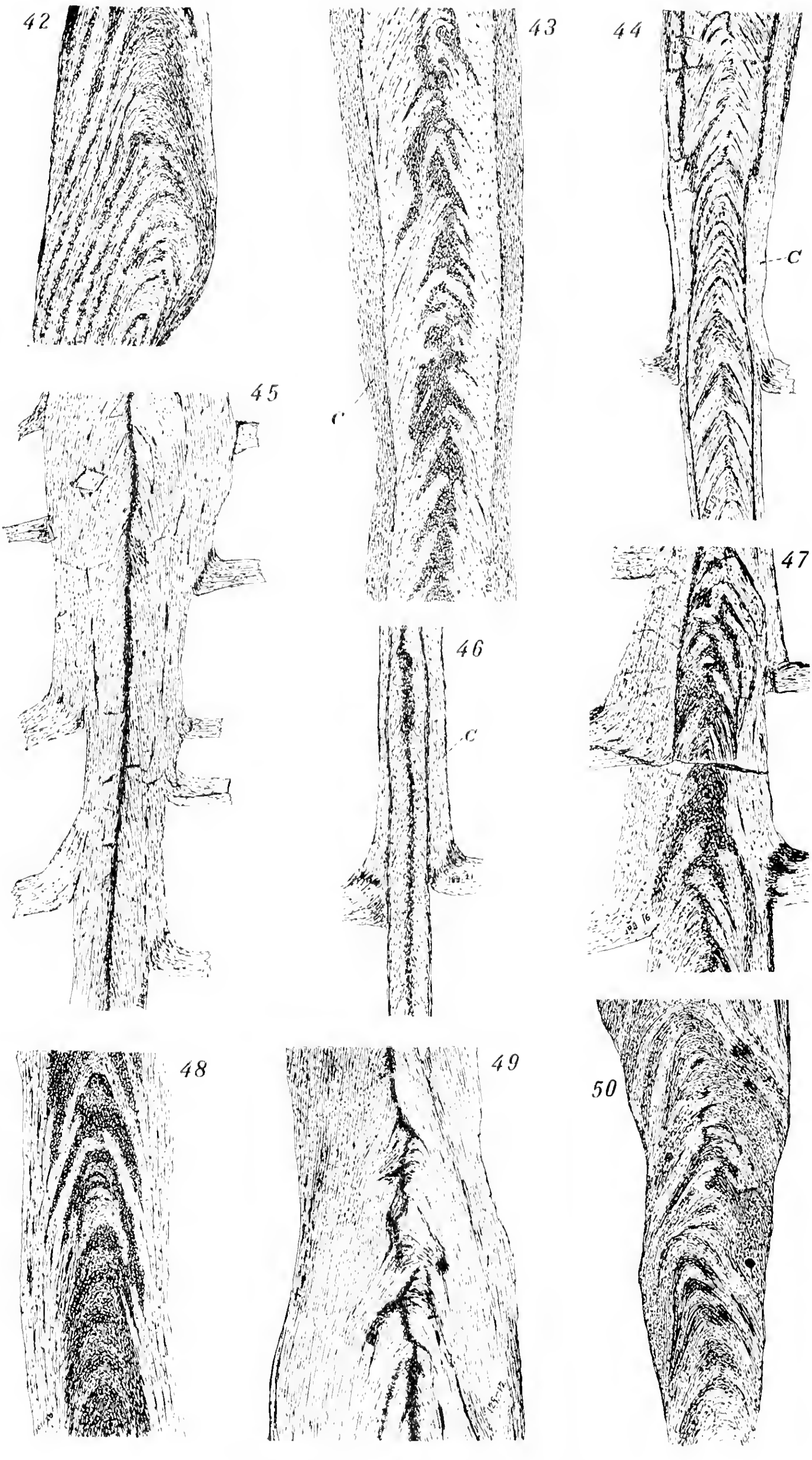
This figure shows four zoœcia emerging at the surface of the colony, with their walls completely intact and their proximal diaphragms all developed at the same level. The distance from the diaphragm *d* to the distal edge of the wall represents the length of a typical zoœcium. In the zoœcium *z* is shown the thickening of the walls often seen in the neck region of the zoœcium. In species with cystiphragms, there is often a circlet of cystiphragms at this level. × 65. (102–13.)

FIGURE 41.—*Tangential section of Merlia normani Kirkpatrick.*

The sheaves of fibers or spicules that make up the wall of this sponge, with the sharp lines of demarkation between adjoining sheaves, are clearly shown. × 65.



MORPHOLOGY OF THE TREPOSTOMATA



MORPHOLOGY OF THE TREPOSTOMATA

PLATE 11.—MORPHOLOGY OF THE TREPOSTOMATA.

FIGURE 42.—*Longitudinal section of a portion of the wall of Bythopora gracilis.*

Mature region near the surface of the zoarium. The granular appearance of the dark bands and the absence of any suggestion of a duplex wall are distinctly indicated. × 287. (139–7.)

FIGURE 43.—*Longitudinal section in the mature region of Amplexopora multispinosa* var.

This section shows the cingulum (*c*) and the indefinite character of the so-called dark line. Compare with figure 48. × 287. (126–21.)

FIGURE 44.—*Hallopora ramosa, mature region.*

The cingulum and its relation to the diaphragms is shown. The wall laminæ in some cases run across the axial region of the wall and in other cases are offset at the axial plane. Farther in toward the axial region, this species often shows a well defined dark median line in the wall. × 287. (128–17.)

FIGURE 45.—*Batostoma winchelli, mature region.*

This is the most extreme development of the dark median zone in the Integrata. Note the relation of the diaphragms to the secondary thickening of the wall. × 287. (188–20.)

FIGURES 46 AND 47.—*Sections of the wall in the mature region of two specimens of Heterotrypa prænutia* var. *simplex.*

These sections show the integrate and amalgamate phases of wall structure in the same species. The relation of the diaphragms to the cingulum is also well shown. × 287. (188–21; 198–16.)

FIGURE 48.—*Heterotrypa prolifica, mature region.*

The most typical amalgamate structure. The median dark zone is broad, and the laminæ pass across with a gradual curvature. The whole dark region has a distinctly granular appearance under high magnification, owing to the concentration in this region of the larger wall granules mentioned in the text. × 287. (101–20.)

FIGURE 49.—*Eridotrypa simulatrix, mature region.*

A member of the Amalgamata with a very sharply defined median dark line in portions of the wall, which becomes interrupted and indefinite in other portions. The wall laminæ pitch very steeply away from the axial region of the wall. Compare with figure 15. × 287. (129–12.)

FIGURE 50.—*Dekayia maculata, mature region near the surface of the zoarium.*

An extreme case of the amalgamate structure. The development of dark tissue is very irregular, and there is no suggestion of a definite median zone, nor of a duplex wall. × 287. (166–8.)

PLATE 15.—MORPHOLOGY OF THE TREPOSTOMATA.

FIGURES 51 AND 52.—*Longitudinal sections of the superficial region of a specimen of Dekayia maculata.*

The overgrowth that has preserved the delicate spine *s* has been delineated in detail in figure 51. At *t* the end of the spine has probably been crushed, though there may have originally been some special organ there. The submerged portion of the spine is shown at *s'*, figure 51. In figure 52 the spine was embedded in fine silt, which is not shown in the drawing. The rounded projections at *a* and *a'* show the appearance which acanthopores present in ordinary longitudinal sections. × 65. (166–8, 9.)

FIGURE 53.—*Longitudinal section of a portion of a spine in the region s of figures 51 and 52.*

The wall is very finely laminate and the lumen distinct. × 400. (166–10.)

FIGURE 54.—*Longitudinal section of a spine at the level s', figure 52.*

The inner fascicle of laminae is the primary wall of the acanthopore. The fascicles of laminae outside of this are secondary deposits, probably laid on by the surrounding zoœcia. × 287. (166–10.)

FIGURE 55.—*Longitudinal section of the wall of Monticulipora epidermata.*

This shows a fairly distinct median dark zone, as in the Integrata. × 287. (56–22.)

FIGURE 56.—*Hallopora splendens.*

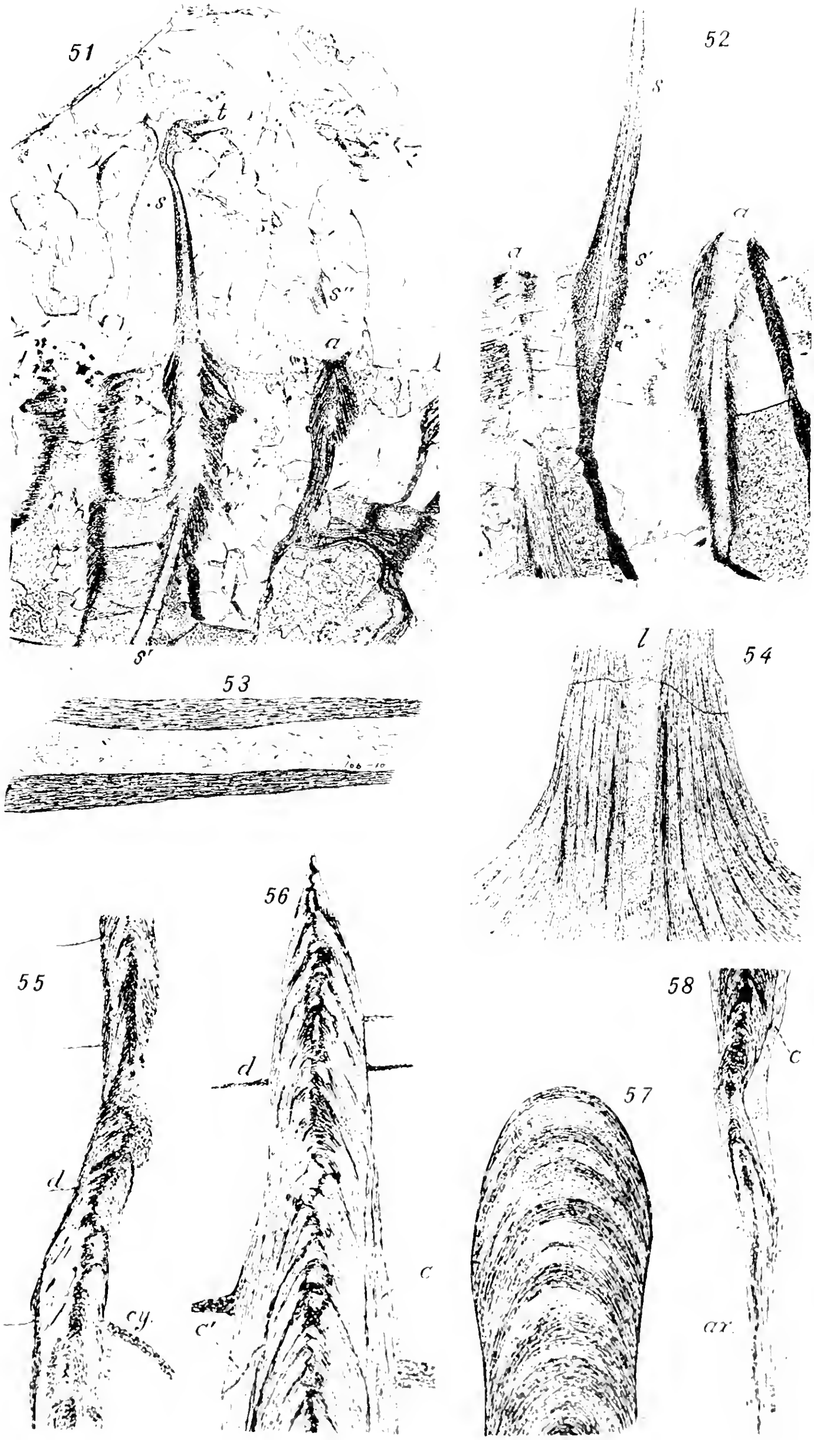
The growing edge of the wall, intact because of the protection of an overgrowth. The edge is very thin and the wall laminae have a very steep pitch. × 287. (230–8.)

FIGURE 57.—*Similar section of the growing edge of the wall of Dekayia maculata.*

The edge of the wall is very smoothly rounded and the laminae run across without interruption from zoœcium to zoœcium. × 287. (145–9.)

FIGURE 58.—*Section of the wall of Stigmatella spinosa where it emerges from the axial region.*

The median dark zone seen at *ax* disappears completely farther in toward the axial region of the zoarium. This section shows the manner in which the normal characters of the mature region are gradually acquired. The beginning of a cingulum is shown at *c*. × 287. (177–18.)



MORPHOLOGY OF THE TREPOSTOMATA

MATA

pect-

ıas been
spine has
ıally been
the spine
embedded
ne rounded
anthopores
9 8, 9.)

region s o

1.

51 ETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

VOL. 26, PP. 375-388, PLS. 16-24 SEPTEMBER 3, 1915

ONDITION OF THE VOLCANOES OF SOUTHERN ITALY [1]

BY H. S. WASHINGTON AND ARTHUR L. DAY

(Read before the Society December 31, 1914)

CONTENTS

INTRODUCTORY

The studies of Day and Shepherd[2] at Kilauea have demonstrated the presence of water in the unaltered lava gases at this volcano, and that chlorine and fluorine are present only in very small amount. They have also shown that the gases at the time of their escape from the lava were in a state of unstable chemical equilibrium, and that they were undergoing interreactions which, being exothermic, might in part explain the maintenance of the high temperature of the lava.

Without entering into discussion of these results, it may be said that they were of such a character that it was deemed advisable to extend the observations and studies to other volcanoes. There were several special reasons for this.

The confirmation of the presence of water at other volcanoes was a matter of interest in connection with Brun's hypothesis, though this may now be considered as definitely disproved by the Kilauea evidence. The possibility of internal, exothermic gas reactions serving to account, at least in part, for the high temperature of the lava made it a matter of importance to ascertain the composition of the magmatic gases, and their possible interreactions, at other volcanoes. Furthermore, as it is now recognized that the distribution of the rarer elements is correlated with

[1] Manuscript received by the Secretary of the Society May 25, 1915.

[2] Day and Shepherd: Jour. Wash. Acad. Sci., vol. iii, 1913, p. 457; Bull. Geol. Soc. Am., vol. 24, 1913, p. 573; Comptes Rendus, vol. clvii, 1913, pp. 958, 1027.

the general chemical characters of the igneous magmas,[3] it is of some petrological, and possibly of vulcanological, interest to ascertain whether the lava gases show analogous correlations with the composition of the magma in which they are found.

We visited the volcanoes of Vesuvius, Etna, and the Æolian Islands in the summer of 1911. The general results of our observations and studies of the material collected, including gases, salts, and rocks, will be published later. The object of the present paper is only to put on record the state of activity and other conditions obtaining at the several volcanoes during June, July, and August, 1911. Although the volcanoes were quiet during the summer, the record may be of some value, as it is coming to be generally recognized that study of the repose periods of volcanoes is or may be of great importance in the interpretation of their phenomena during activity, as well as useful in the prediction of eruptive periods.

We take this opportunity to express our great appreciation of the valuable assistance and many courtesies rendered us by all the Italian officials and scientists with whom we came in contact, among whom may be specially mentioned: His Excellency the Minister of Public Instruction; Professor A. Malladra, Director of the Vesuvius Observatory; Professor A. Ricco, Director of the Observatory at Catania; Professors L. Bucca, Gaetano Platania, and G. Ponte, of Catania, and Professor I. Friedländer, of Naples.

Vesuvius

Since the eruption of 1906 there has been a continuous condition of "repose," the features of which have been described by several geologists.[4] This period of repose has been the longest recorded since the beginning of the eighteenth century. According to Mercalli's[5] data, the average duration of the eleven well-marked repose periods which have followed the more prominent eruptive climaxes since 1712 has been about 3.3 years, while after the great eruption of 1906 some seven years elapsed before the volcano gave any decided evidence of entering on a new period of activity.

---

[3] H. S. Washington: Trans. Am. Inst. Min. Eng., 1908, p. 735.

[4] F. A. Perret: Am. Jour. Sci., vol. xxviii, 1909, p. 413.

G. Mercalli: Rend. Ac. Sci. Nap., vol. xix, 1913, pp. 134, 137.

A. Malladra: Rend. Ac. Sci. Nap., vol. xviii, 1912, p. 224.

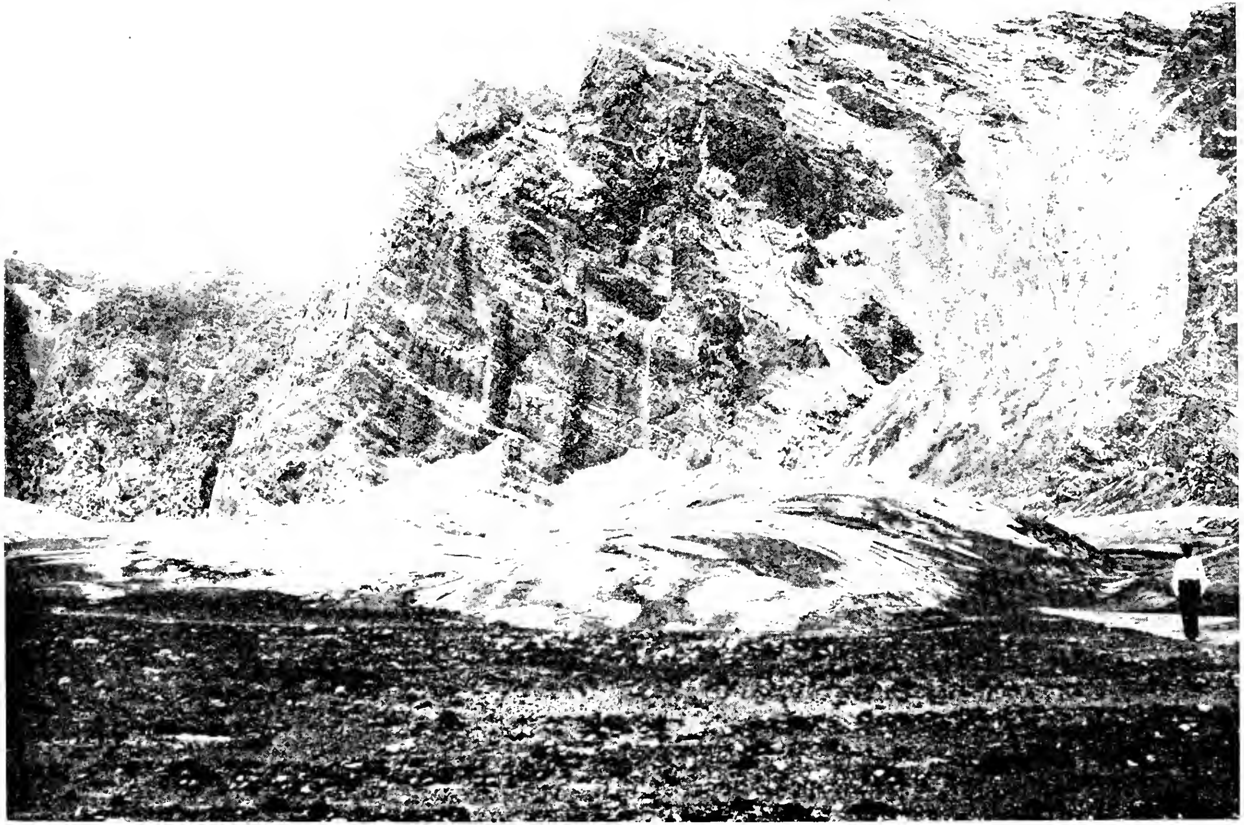
A. Malladra: Rend. Ac. Sci. Nap., vol. xix, 1913, p. 153; Boll. R. Soc. Geog., 1914, p. 753; Rend. Ac. Sci. Nap., vol. xx, 1914; Boll. R. Soc. Geog. Ital., 1914, p. 1237, with map of crater; Zeits. Vulk., vol. i, 1914, p. 104.

I. Friedländer: Naturw. Wochens., vol. x, 1911, p. 454.

I. Friedländer: Naturw. Wochens., vol. xii, 1913, p. 389; Peterm. Mitth., 1912; maps of the cone and crater of Vesuvius, Naples, 1913.

O. de Fiore: Atti. Ac. Sci. Nap., vol. xv, 1913 (contains bibliography); Rend Ac. Sci. Nap., vol. xix, 1913, p. 106.

[5] G. Mercalli: Vulcani Attivi, Milano, 1907, p. 207.



FUMAROLES IN THE ATRIO DEL CAVALLO

View taken below Punta di Nasone. The (white) saline incrustations are well shown.

Since 1906 the volcano has been in a solfataric state, no outflows of lava or definite explosions having taken place. With the exception of certain portions of the crater floor, to be mentioned later, the changes have been largely those due to non-volcanic agencies.

Fumarolic activity began shortly after the cessation of the eruption; that is, as soon as the vapors could open a way through the superincumbent ash. The chemical effects of these hot, very acid gases have, of course, considerably disintegrated the rocks and have contributed materially to the progressive demolition of the cone.

In the Atrio del Cavallo, close to the face of Monte Somma, is a group of about 30 fumaroles, some of which are shown in plate 16, which resemble the so-called hornitos of Jorullo. These have been described especially by Malladra[6] and Bernardini.[7] They have formed relatively low, domal elevations, from one to eight meters high, with circular or elliptical outlines, elongated parallel to the Somma scarp. These accumulations are composed of ashes and claylike decomposition products, cemented by sulphur and various salts, chiefly sulphates. Those which form a row nearest the central cone have a constant temperature of about 97° C., and the analyses of the gases by Bernardini show a decided percentage (7–11) of H_2S. Those in the next row show about the same temperature, though somewhat variable and with only traces of H_2S, while those nearest the Somma scarp are still more variable in temperature and with no H_2S. At the time of our visit the activity of all these fumaroles appeared to have diminished nearly to the point of extinction.

The fumaroles inside the crater are of special interest and were in a state of considerable activity, the humidity which prevailed during our stay rendering them more prominent than would have been the case in dry weather. Some were also in action on the upper part of the outer slope, these being confined to the north and northeast sections. The temperatures of these have been measured by Perret, Mercalli, Malladra, and Friedländer and are somewhat variable. Their temperatures and activity seem to be decreasing.

Inside the cone fumaroles were in activity in all parts of the walls. Of these, those on the north and northeast form a prominent group, or "battery," as such a line of fumaroles has been named by Mercalli. The temperatures of these have not been measured, as they are inaccessible.

The largest, most prominent, and most active battery is on the southwest and west inner scarp. These begin in the southwest, below the point to which tourists are taken by the guides, about 20 meters above the bottom of the crater, and extend obliquely upward to a point below the

[6] A. Malladra: Rend. Ac. Sci. Nap., vol. xix, 1913, p. 153.
[7] L. Bernardini: Rend. Soc. Chim. Ital. Nap., 1913.

ruined funicular station house. Of these the greatest is the Fumarola Gialla (Yellow Fumarole), so called by Malladra because of the bright yellow and orange coloration of the cliffs in its vicinity. This was in a state of intense activity, great clouds of vapor issuing from it. The temperature of this fumarole as measured by Capello in September, 1911, was 128°, while Malladra found 295° in May, 1912, 330° in September, and 347° in October, 1913.

Since the eruption of 1906 there have been continual slips of material from the crater walls. Especially noteworthy slides of large sections of the southwest scarp took place in March, 1911, and January, 1912, the last being coincident with and apparently due to a marked subsidence in the southern part of the crater floor.

In April, 1913, there took place what was regarded by Mercalli as the beginning of a reawakening of activity at Vesuvius, shown by a decided increase in the number and activity of the fumaroles in the crater floor, especially near the slight subsidence of 1912, and by almost daily slight local earthquake shocks. This culminated during the night of May 9–10 in the formation, at the site of the previous subsidence, of a large funnel (*imbuto*), estimated to be some 150 meters in diameter and about 70 deep, from which issued continuously a dense column of white smoke. On the 5th of July direct connection with the interior was established by the opening of a "bocca," or mouth, near the lowest point of the funnel and just below the steep scarp formed by the great subsidence. This orifice was incandescent even in full daylight, and from it issued large puffs of yellowish smoke, accompanied by loud roarings.

Taking advantage of the acquired relative stability of the long slope formed by the slide of the previous March, Doctor Capello, at that time assistant at the Vesuvius Observatory, made the first descent into the present crater in September, 1911. In May, 1912, Dr. A. Malladra, Director of the Observatory, descended the crater for the first time, and has since then gone down several times, on some occasions accompanied by other scientists. These descents were made from a point on the south-southeast rim near the tourist viewpoint, the slip of 1912 having rendered parts of Capello's route impracticable. One of us (Washington) had the opportunity of accompanying Doctor Malladra in a descent on June 9, 1914, during which observations were made of the conditions then obtaining within the crater.

It may be mentioned that the intention at the outset was not to make the complete descent, but to discover a favorable locality for the placing of a steel cable for the transport of instruments and specimens into and out of the crater. On this account no thermometers, collecting tubes for gas, protective masks, or instruments were carried, and consequently some highly desirable observations could not be made. On attaining a certain distance, however, it was found that a return by the same route was impossible, so that we were fortunately obliged to go to the bottom and ascend by the usual track.

The descent was begun at a low point on the northwest rim, about 200 meters north of the abandoned funicular station. The upper part was steep, the wall consisting of faces of lava-sheets interbedded with somewhat consolidated agglomerate and beds of scoria. There were no well-defined fumaroles along this portion, but considerable steam, highly charged with HCl and SO_2, was emitted from the crevices.

At a depth of rather over 100 meters the head of a talus slope at least 200 meters long and with a slope of 31° was reached, and the descent continued down this.

The floor of the crater is somewhat domed toward the center, covered with ash, in which small, loose augite crystals may be gathered, and is strewn with many angular blocks fallen from the walls above. Many of these are several cubic meters in size. No saline incrustations were seen, probably because of their removal by the prolonged rainy weather. There were no fumaroles proper, a central group formerly present having ceased activity after the subsidence of 1912, but hot vapors issued continuously from the crevices and the loose material. HCl and SO_2 could be readily detected. There were also present unquestionably SO_3 and probably CO_2, but no H_2S was observed. The blue mist produced by these gases and the abundant steam made good photographs impossible.

At the foot of the north and east walls was a long, narrow, and deep crescentic valley, which was formed toward the end of November, 1911. The highest point of the floor, near the center, is 327 meters below the highest point of the rim, and the depth of the valley is about 60 meters, as determined by Malladra in 1913.

In the southwest part of the floor is the funnel, the diameter of which was judged to be about 120 meters, with a depth of about 30 meters. The sides of this slope at 30° and are composed of loose ash and scoria, with comparatively few large blocks.

Slightly above and to the northwest of the lowest point of this is the "bocca" or mouth—a roughly circular or elliptical orifice some 10–15 meters across—with rough, approximately vertical walls, which could be approached within a few meters. Beyond this on the north was a vertical wall of lava, sprinkled with driblets and small stalactites of lava.

From this mouth issued two jets of smoke, in large rounded puffs, every four to six seconds, accompanied by rather loud roars, while a continuous low rumbling could be heard below. The eastern jet was somewhat the larger, and the puffs of the two were not usually synchronous.

though sometimes exactly so—apparently a chance effect. The color of the smoke of both columns was generally a tawny yellow, changing suddenly every now and then to white. As felt by us, the smoke was warm but not oppressively hot, though the abundance of HCl and SO_2 vapors made it and the air in the funnel rather suffocating to breathe.

No liquid lava nor red glow on the smoke could be seen, but the vicinity of the bocca was sprinkled with small fragments of very fresh, light brown, pumiceous lava, to which adhered short (5–10 cm.) strands of Pele's hair. This pumice was thought by Doctor Malladra to have been ejected but a few days before. An analysis of it, recently made and to be published elsewhere, shows that it closely resembles in chemical composition the lavas of 1872, 1903, and 1906. There were also many fragments of a porphyritic lava, much decomposed by the acid vapors, but with the euhedral augite phenocrysts fresh and unattacked. According to Doctor Malladra, this dated from December, 1913. An analysis (by H. S. W.) of salts collected by Doctor Malladra in May, 1913, from near the orifice, shows that they consist largely of aphthitalite, a double sulphate of potassium and sodium, with less alum and ferronatrite and a very small amount of cupric chloride.

On the first part of the ascent, up a long talus slope of large blocks, the very active Yellow Fumarole was passed, but unfortunately, owing to the lack of protective masks, it could not be approached very closely, and no temperature measurements were possible in the absence of a thermometer. On this slope, which extended above the bocca and along the battery of fumaroles, the acid vapors were very troublesome.

Continued rainy weather caused us to abandon Vesuvius temporarily for Etna, and shortly after our departure, as we were informed by Doctor Malladra, the crater filled with a "sullen" heavy smoke, which slowly poured over the edges and absolutely precluded any descent. Doctor Malladra has recently (December, 1914) written us that there is much increased activity, a small cone having been formed in the funnel above and around the opening and the funnel being half filled with lava.

Etna

The last great eruption of Etna took place in March and April, 1910, when a series of bocche (mouths) was formed along a north and south (radial) fissure which opened on the south slope of the mountain. These formed a line of explosion craters followed by cones of ash and scoria, to the last and largest of which, situated some 1,324 meters below and 5.5 km. to the south of the summit, was given the name of Monte Ricco. From the south side of this cone issued the great stream of lava, which

CONE OF ETNA FROM NEAR OBSERVATORY (SOUTH)

View of the southeast flank. Shows the varicolored salts covering the slope. The numerous small steam jets not shown. Typical outburst of smoke. Large, pure steam fumarole in right foreground.

flowed almost due south for a distance of about 10 km., nearly reaching the Monti Rossi, near Nicolosi.[8]

It was succeeded by a period of strombolian activity in the central crater, and at the end of May, 1911, a large bocca opened on the main platform, northeast of and close to the summit cone.[9] This was followed by a short but violent eruption in September, 1911, on the northeast flank, but far down the mountain, some 6 km. from the summit.[10] Since then the volcano has been quiescent and generally in a solfataric condition, with only occasional strombolian activity.

The summit crater of Etna is situated approximately in the center of an ash cone 1,000 feet high rising from the Piano del Lago (cf. plate 17). It is nearly circular in form, about 500 meters in diameter, and receives its color for the most part from fresh, light gray ash which, during the period of our visit, was thrown out almost daily. The crater rim, except for a small section just above the observatory, is a sharp edge formed by the steep outer slope of the cone and the precipitous wall within, due to slips which the extensive concentric cracks show to be the present process of enlargement of the crater. The inner walls, with the exception noted, are nearly vertical near the top, and will average 90 per cent in pitch from top to bottom on the northeast, north, west, and southwest walls. The southeast wall appears to have sagged rather than broken abruptly, and presents a somewhat rounded contour both outward and inward for a few meters, beyond which it breaks abruptly over a talus pile on the bottom of the crater below. The depression caused by this sagging is no more than 15 or 20 meters. It affords a platform from which a beautiful view of the interior of the crater can be obtained in those rare intervals when the crater is free of smoke. It is, nevertheless, a most treacherous point because of the concentric cracks which cross it and which have been bridged over by recent ash so as to be entirely invisible. The view of the crater shown in plate 18 was taken from this point.

At the time of our visit in June and July the central cone and the surrounding plateau were covered with a layer of fine, dark gray ash, from 15 to 30 cm. thick, with many small stones (10 to 30 cm. diameter) imbedded in the ash. The greater part of this had fallen about two months previously, according to Alfio Barbagallo, the custodian of the observatory. It is quite practicable to walk entirely around the rim of the crater, though the footing is everywhere slimy and the gases to lee-

[8] The best descriptions of this eruption are to be found in papers by S. Arcidiacono, A. Ricco, O. de Fiore, P. Vinassa de Regny, F. Stella Starrabba, and L. Taffara in Atti. Acc. Gioen. (5), vol. iv, 1911, and in a paper by G. Ponte in Atti. Acc. Linc. (5), vol. viii, 1911, p. 663.

[9] Cf. A. Ricco: Atti. Acc. Gioen. (5), vol. iv, 1911, mem. xi.

[10] Gaetano Platania: Riv. Geog. Ital., vol. xix, 1912.

G. Ponte: Boll. Club Alp. Ital., vol. xli, 1913, No. 74.

ward strongly acid, dust-laden, and very irritating. This ash was damp in many places, especially near the top and down the south and southeast slopes, where it was impregnated and covered with salts. Most of these saline incrustations were white, but there were also yellow and greenish patches, these last being especially prominent on the southeast slope, where they extended quite to the bottom of the cone and are well shown in plate 17. The salts, mostly white, were also abundant down the north slope and about the bocca on the northeast, as shown in plate 19. A preliminary examination shows that these salts are mostly mixed sulphates and chlorides of soda and less potash and ammonia. In places there was sufficient copper present to copper a knife blade.

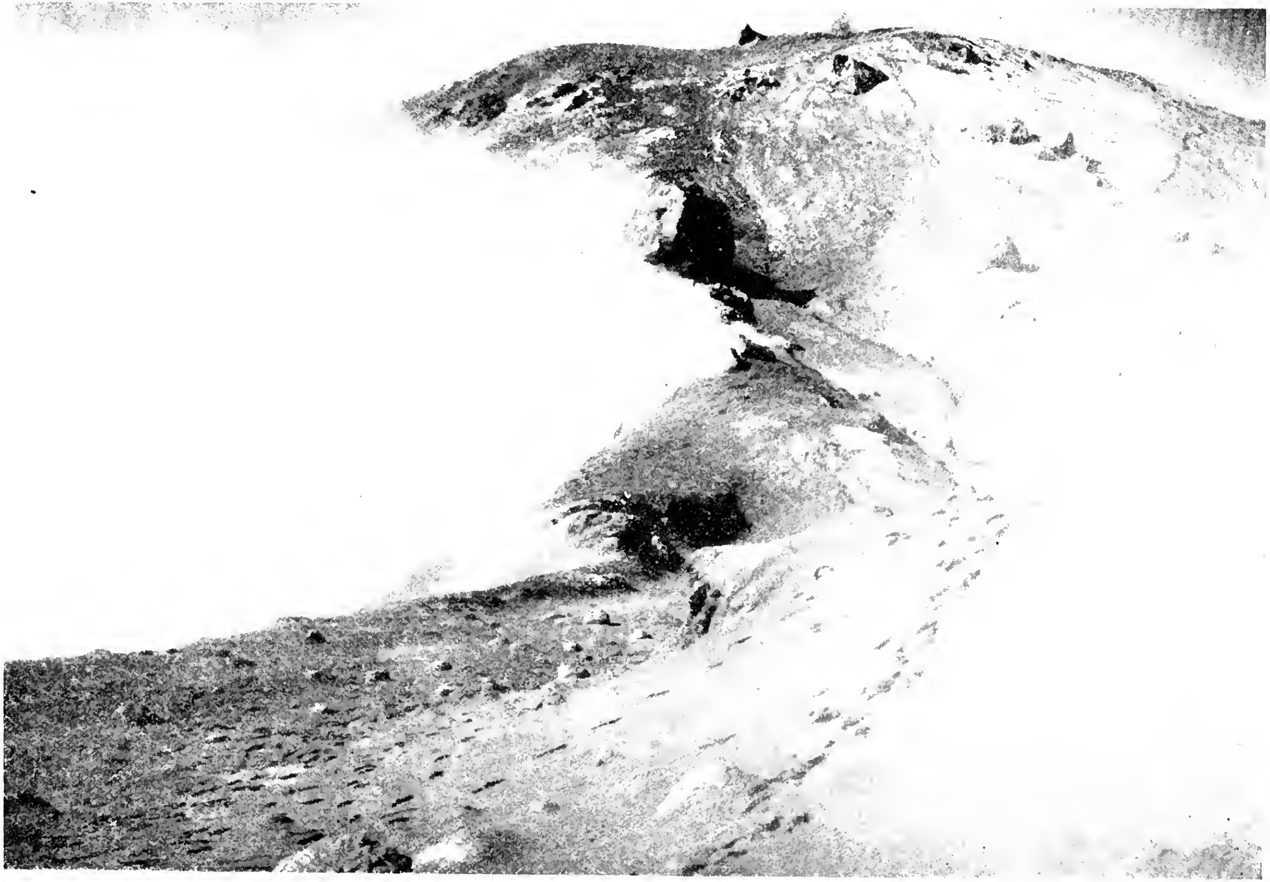
Considerable steam was rising from the south and east slopes of the cone, issuing from small fumaroles at possibly fifty more or less fixed spots. The other slopes of the cone were quite free from these emanations.

The inside walls of the crater from top to bottom are covered by a somewhat festooned arrangement of fresh ash which reveals little structure to the observer. The bottom of the crater is something over 450 meters below the present rim, and appears to be entirely inaccessible, not alone because of the steepness of the walls, but because of the treacherous ash deposits and the smoke, which is usually so thick that few who have made the climb to the summit have been rewarded with a view of the interior. We were fortunate enough to obtain a clear view of the bottom of the crater, obscured only by a thin film of bluish smoke, on two occasions the smoke, by the way, being much more transparent to the eye than to the camera, even when the lens is moderately screened against blue. A photographic view down to the bottom of the crater is therefore exceedingly difficult to obtain and is not altogether satisfactory when obtained (plate 18).

In appearance the bottom of the crater is nearly flat in the west half and is usually covered with ash. The guides are accustomed to call attention to five openings, of which only two could be clearly distinguished at the time of our visit—one a round well perhaps 40 meters in diameter and 20 meters deep, with a flat floor of ash. This well is located near the north wall, a little to the west of the middle, and has at least two openings, both in its side walls. The smoke which emanated from this well at intervals came invariably from the northeast opening, and usually emerged from the top of the well into the open crater. Occasionally it appeared to roll across the floor of the well and disappear into the opening in the opposite wall without emerging into the crater at all—an extraordinary phenomenon which is perhaps to be explained through a subterranean connection between the central crater and the outside crater, to be described below. No fresh lava was visible in the well or elsewhere in the

INTERIOR OF ETNA CRATER FROM SOUTHEAST

Note the steepness and stratification of the ash-draped walls and small fumaroles above. Smoke from the "well" is seen in the lower right hand corner.



OUTER BOCCA OF ETNA FROM NORTH

The rim of the main cone appears above. Note the abundant smoke in the bocca and the deeply ash and salt covered surface.

crater during the period of our visit, but an excursion to the top in the early morning of July 23 made by the guides alone revealed several bright cracks, both within the well and to the eastward of it.

The second conspicuous opening is a cone filling the eastern half of the crater floor and perhaps 100 meters high. The present appearance of this cone indicates an explosive origin. This opening is exactly opposite the outside crater and immediately suggests a connection between the two. We did not, however, during the limited period of our observations, discover any connection between the occasional explosions emanating from this cone and the activity of the outer crater. The explosions from this inner cone were often violent and yielded tremendous volumes of smoke, which emerged in the usual cauliflower form, very black and heavily dust-laden (plate 17). On one excursion to the summit during the evening of July 16 a considerable outburst was seen coming from this opening, accompanied by a flash of light and a dense cauliflower cloud, but with no sound of explosion nor of falling rocks following the flash. No incandescent matter was visible at that time. On another occasion (July 22) loud explosions were frequent, accompanied by the usual cauliflower clouds, but no flashes.

In appearance this inner cone is jagged and irregular, though roughly square in form, with very steep, smooth inner walls closing together to a narrow black throat in which all detail was lost in smoke, even on the most favorable days. The outer surface of the inner cone is concealed under fresh ash. Surface slides are frequent and appear to indicate that the ash is dry and has the maximum steepness of slope at which such material can come to rest.

The bottom of the crater was over 450 meters deep, according to measurements with a plummet-line in the hands of our guides, A. Barbagallo and D. Caruso, who returned to the crater after our departure for that purpose. The line did not quite reach the bottom.

The new outer "bocca," or crater, on the northeast slope of the cone is about 80 meters below the summit. It is shown in plate 19. When first formed it was roughly triangular and about 100 meters across. It is now approximately circular and about 200 meters in diameter. Owing to falls of the sides, especially on the side toward the main crater, it is cutting rapidly into the cone and its southwest edge is now less than 100 meters from the crater rim. So far as could be seen through the clouds of smoke which filled it, the sides are vertical, but not even a glimpse of the bottom was to be had and no estimate of its depth was possible. No glow or flash could be seen in this crater during any of our visits, day or night.

There was a constant emission of clouds of a dense, dark gray smoke, which came in huge puffs at irregular intervals, sometimes welling slowly up and sometimes sent high into the air, always accompanied by a loud noise, as of hissing steam, which was nearly constant in volume. The sound from this crater was never paroxysmal in character, though the smoke puffs frequently appeared so and were often of great volume. The character of this noise and the forms of the cloud puffs led us to believe that there was more than one orifice below. The smoke was hot, very acid, and suffocating, and field tests revealed the presence of H_2O, HCl, SO_2, and H_2S.

From the observations made it was evident that Etna is now showing both solfataric and strombolian phases at intervals without marked activity. It was the opinion of various observers of the volcano, especially Professors Platania and Ponte, Custodian Barbagallo and the guide Caruso, that the activity of June and July, of which we were witnesses, was distinctly greater than it had been during the previous six months or so, and it was regarded as probable that a renewal of more intense activity is not far off. At the rate at which the outer "bocca" is cutting into the cone, it seems certain that within a short time it must break through into the main crater and may precipitate a more serious disturbance then, though an eruption from the main crater has been in recent times a somewhat rare occurrence at Etna.

Vulcano

Since the last eruption of Vulcano, in 1888-1889, the volcano has been in an almost continuous state of solfataric activity and has attracted little attention. Of the papers which deal with this aspect of the volcano may be cited those by Bergeat,[11] Ponte,[12] and de Fiore,[13] the latter describing the fumaroles in considerable detail. The general relations of the present crater, the crater walls of the early phase, and Vulcanello are shown in plate 20, taken from the south end of Lipari.

The walls of the crater—the so-called Fossa di Vulcano—are composed of fragmentary andesitic material, much of which was thrown out by the last eruption, which raised the rim considerably. This material is a coarse agglomerate, more or less consolidated and cemented by the abundant salts and by the decomposition products formed by the action of the acid vapors. Large angular bombs, one of which is reported to have had a volume of 45 cubic meters, are scattered over the slopes. On the crater slopes and rim these bombs, even the largest, are gradually disintegrating, traversed by fissures due originally to internal strains and intensified by the action of the acid vapors, so that they eventually break down into a heap of angular fragments.

[11] A. Bergeat: Die Äolischen Inseln. Abh. Bay. Ak. Wiss., vol. xx, 1899.
[12] G. Ponte: Atti. Acc. Gioen., vol. iii, 1891.
[13] O. de Fiore: Zeits. vulk., vol. i (2), 1914, p. 57.

VIEW OF VULCANO FROM LIPARI (NORTH)

Vulcanello in left foreground. Forgia Vecchia half way up in right center. Piano delle Fumarole above, and rim of crater of Fossa above this. Beyond, right and left, the pre-Fossa crater walls.

CRATER OF VULCANO

Taken from north rim, showing terrace, salts at bottom of crater, and lower part of first phase crater wall above.

The crater (plate 21) is circular, about 600 meters in diameter, the western and northern rim rather flat, while to the southwest, south, and east the rim is lost against the steep wall of the first phase crater. It is much less deep than it was prior to the last eruption. The interior shows two well-defined terraces, which run almost completely around the circle, the upper being about 25 meters below the southern rim and the second about 15 meters below the first. The slopes between these are gentle: not over 25°.

The second terrace forms the edge of the funnel of the crater, the bottom of which is about 30 meters below the terrace and with sides sloping (except on the north) at about 32°. The bottom of this funnel (about 70 meters below the northern rim) is formed of two circular, shallow depressions, each about 25 meters across and separated by a narrow ridge of ash and agglomerate. The small lake previously occupying the bottom has disappeared, and the floors of the two basins are dry and covered with salty crusts in varicolored patches of fawn, buff, yellowish, gray, and white. The southern basin shows little activity, but from around the northern one there is considerable emission of hot vapors, and an active fumarole exists on the steep north wall, with abundant deposition of sulphur.

The fumarolic activity is intense over much of the cone and may be referred, as pointed out by de Fiore, to two distinct types—the diffuse exhalations and the fumaroles proper.

The first consists in a gentle, quiet, and noiseless emanation of hot vapors, which appear to be mostly steam, with SO_2 and little or no HCl or H_2S, through crevices and the less coherent lapilli and ashes, accompanied by the deposition of more or less abundant salts but little or no sulphur. Exhalations of this type are abundant at the bottom of the crater and over the inner slopes and crater rim, especially on the north. They are especially so in the north upper slopes over the so-called Piano delle Fumarole and below this as far down as about the 100-meter level. Here there is a broad zone which is so thickly covered with salts that one sinks ankle deep in them.[14]

For the most part these salts are pure white, but there are extensive patches of yellow, bright orange, yellowish brown, greenish gray, and at one place the snowy white salt surface is marked with patches of pale blue and bright green, due to copper. These salts are damp and warm to the hand.

In the crater on the northern rim and generally over the Piano delle Fumarole the saline deposits are not so thick and are of a different char-

[14] It may be noted that the time of our visit (in August) was exceptionally favorable for the collection and study of these salts, as no rain had fallen since January.

acter. Here they are dry and do not form thick continuous beds, but occur as narrow streaks along innumerable crevices in the ground, or else delicate flat "rosettes" from 1 to 5 cm. in diameter and with concentric series of petals (plate 22), or else tulip-like forms.

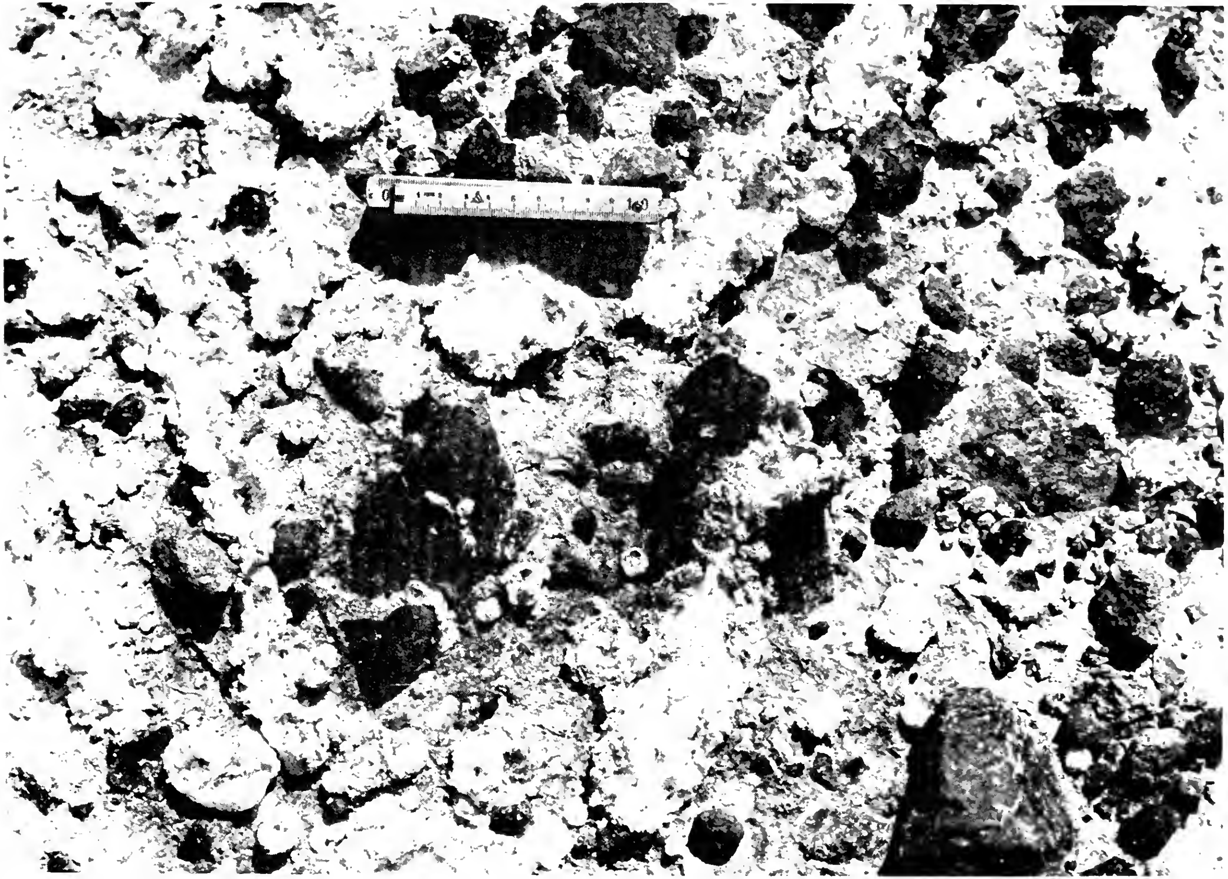
A preliminary examination of these salts shows them to consist for the most part of sulphates, chiefly of alumina and potash, with less soda and ammonia and little lime and magnesia. Iron is present in all, even the purest white specimens. With the exception of a few bright yellow specimens, colored by ferric chloride, these deposits seem to be quite free from chlorides, and boric acid, while present in certain spots, does not seem to be as abundant as it was before the eruption. It appears that thiosulphates are present in the salts from inside the crater, while they are absent from those on the crater slopes. These salts are now being investigated chemically and optically.[15]

The fumaroles proper were very active and numerous, occurring both over the upper part of the cone and in the crater. The gases issue either from beneath the large bombs which strew the rim and the inner slopes of the crater or else from narrow, irregular holes in the ground. A small group of these fumaroles is seen at the bottom of the crater, near the north wall, and many of them (possibly fifty) are scattered over the inner north and east slopes of the crater. There is also a "battery" of them issuing from the steep face of the tuff beds which form the inner wall of the early crater on the south and southwest. On the Piano delle Fumarole itself there are few or no fumaroles of this type at present except at the west end of the terrace, above the upper end of the Pietre Cotte, where several occur. The most important and most active group is that just below the east end of the Piano delle Fumarole, around the upper end of the old conveyer cable, above the Forgia Vecchia, at an altitude of 210 meters, shown in plate 23.

These fumaroles give off a great deal of white vapor—chiefly steam, with much SO_2 and H_2S—which issues with considerable violence and a loud hissing noise. Their temperatures generally varied from 99.6° to 109°, but that of the largest was 118.5°. They do not deposit salts, but an abundance of sulphur, in masses of transparent bright yellow acicular crystals of the utmost delicacy, which are dewed with drops of water. These crystals are of the monoclinic modification and on contact break down to powder and lose their transparency through inversion to the orthorhombic form.

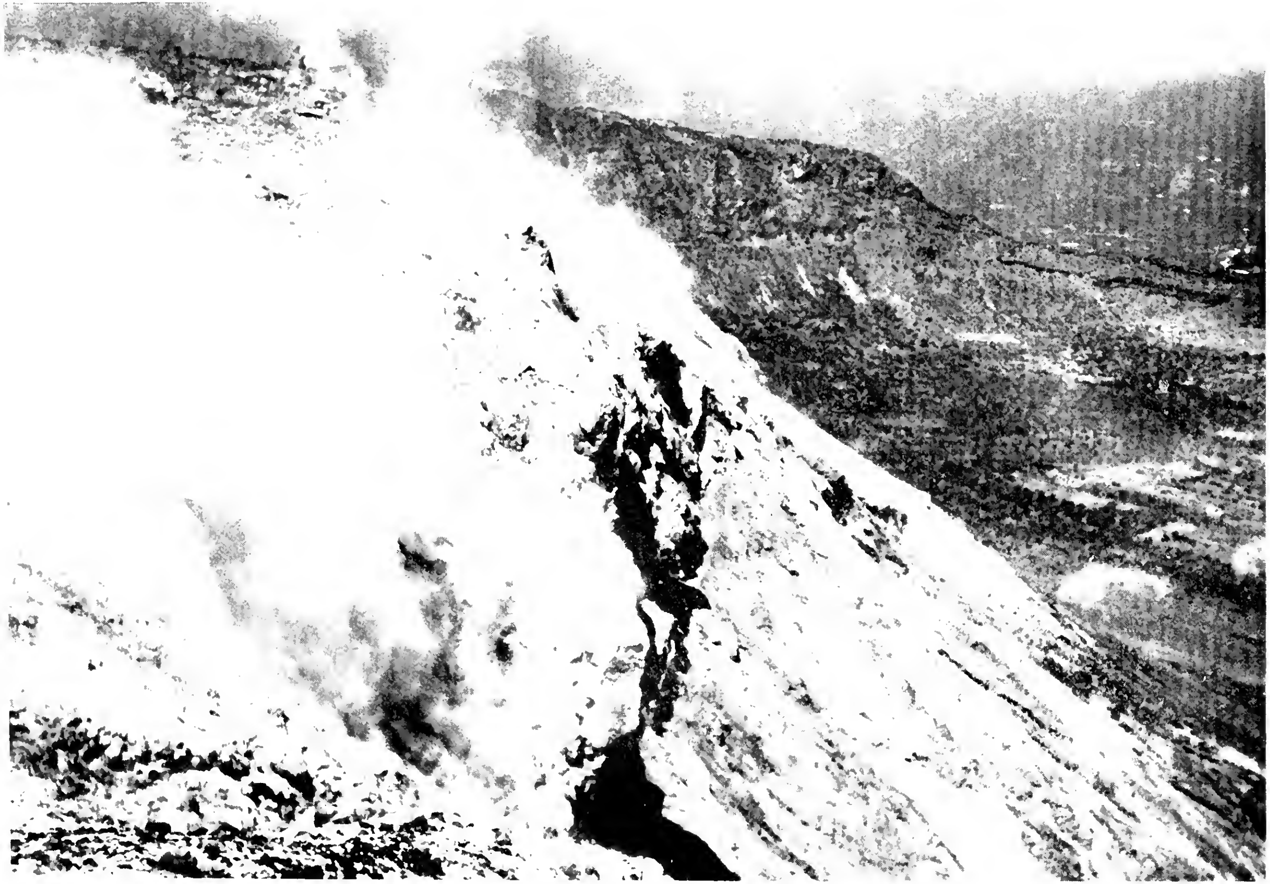
A characteristic of these fumaroles, as noted by de Fiore, is their apparent permanency of location. Some of the larger ones antedate the great eruption, and the largest, that at La Portella, shown in plate 23, is

[15] Cf. J. Koenigsberger and W. J. Müller: Zeits. Vulk., vol. i, 1915, p. 196.



SALTS AT VULCANO

Shows the rosettes on Piano delle Fumarole. Note alignment along a crevice on left and scattered rosettes elsewhere. Black fragments of andesite.



LARGE FUMAROLE AT VULCANO

Taken from east, showing Piano delle Fumarole to left above. Note abundant salts below to right. White above is mostly sulphur. Monte Lentia in background.

possibly identical with one seen by Dolomieu in 1781. The diffuse exhalations, on the other hand, seem to lack this stability and shift their locations. While the two types are quite distinct in their normal and extreme forms, yet there are intermediate forms, some diffuse exhalations from cracks depositing sulphur needles, and a few of the fumaroles proper being accompanied by salts.

Stromboli

This volcano is usually cited, from the time of Pliny on, as being in a continuous state of eruption. The record of its activity is, however, interrupted and very scanty, and recent investigation leads to the conclusion that "Stromboli presents long periods of varied, but for the most part moderate, activity, interrupted by relatively brief periods of repose." [16] Violent eruptions would seem to be infrequent, the last having taken place in 1907.

The crater was visited on August 7 and 12, 1914, and it was seen that marked changes had taken place since it was last reported on in 1909.[17] The large gulf or funnel of 1907 has been filled up and the crater plateau forms a plain about 250 meters below the crest above, with a low elliptical, dome-shaped elevation occupying the northwestern part, built up of material ejected from Bocche B and C. On the north the plain ends sharply at the beginning of the Sciarra. The plateau is practically inaccessible because of the constantly falling stones and the precipitousness of the other three sides. Five active vents were seen.[18] A view of its general features is shown in plate 24, taken from a point above, to the north (× in figure 1). It was impossible to reach a nearer point below the Filone Baraonda on account of falling stones.

The most prominent and violent vent was that marked A in the annexed sketch map, figure 1, based on Bergeat's map. This is near the head of the Sciarra, just below its upper edge at the eastern end, so that it was not visible. This exploded at short, irregular intervals with a sudden loud roar, like the discharge of a large-caliber gun. Many red-hot fragments of half-molten rock were ejected to a height of several hundred meters, accompanied by a tall column of generally brownish smoke. This vent seems to be the oldest of those now present and was apparently in existence as far back as 1776 and 1782.

Bocca B, near the lower end of the Filone di Baraonda, an orifice about 10 meters in diameter, was in continuous activity. There was an

[16] Gaetano Platania: Ann. Uff. Centr. Met., vol. xxx, part 1, 1910, p. 8.

[17] F. A. Perret in Platania, loc. cit.

[18] As their detailed description and relations to earlier vents will be taken up in a separate paper, they will be only briefly described here.

intermittent emission of many half-molten stones, accompanied by puffs of generally white smoke, few explosions, but a pretty continuous roar. The stones did not rise much above 50 meters or so, many of them much less. The hole below was filled with thin, long, wavering, bright red, flamelike tongues, which seemed to be spurts from the liquid lava not far below. This vent seems to have been in existence as far back as 1891, if not earlier.

Bocche C and D are of a quite different type and much less active. C is in a solfataric state and emitted puffs of white smoke, with little noise and without stones. D showed little activity, occasionally filling quietly with sluggish yellow smoke. C seems to be later than D, as its outline cuts into that of the latter.

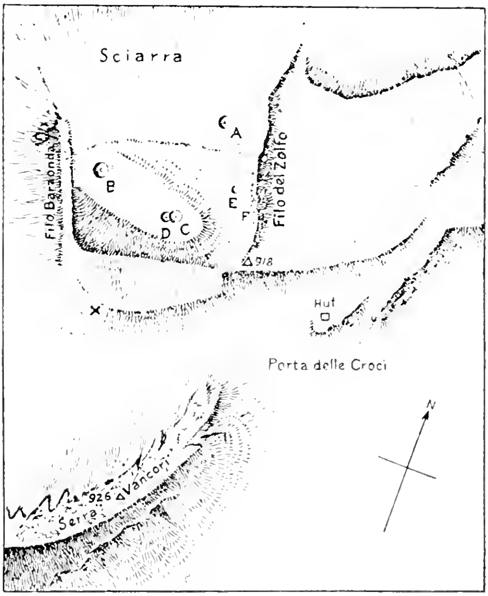


FIGURE 1.—*Sketch Map of the Crater of Stromboli*

The last bocca, F, is the most peculiar. It "blows off" at intervals of from 20 to 10 minutes from a small, shallow, scarcely noticeable depression in the scoria-strewn floor near the eastern Filone, visible to the right in plate 24. There is a loud, startlingly sudden blast, like the letting off of steam from a gigantic boiler, and the rapid ascent of a narrow, very tall column of white or gray smoke from a small orifice which makes its appearance at the bottom of the depression. The edges of the orifice become red hot and there is a small, low spatter of molten material. The blast continues with increasing loudness for from half a minute to two minutes and then ceases, generally suddenly. During the last few seconds the dense smoke generally ceases and the noise of the blast continues with the emission of faint whitish or bluish vapor. After the outburst the orifice closes and the depression becomes again black and scarcely detectable.

There was not much fumarolic activity, this being confined chiefly to the battery (F on the map) along the Filo del Zolfo and some slight vapor spires over the crater floor. The general smoke, as observed on the ridge above the crater, was acid and smelt somewhat strongly of SO_2.

CRATER OF STROMBOLI

Taken from south, looking down. Bocca B to left, ejecting stones. Bocche C and D in center. The depression of Bocca E visible below line of fumaroles on right. Bocca A (behind C and D) not active.

BULLETIN

OF THE

Geological Society of America

VOLUME 26 NUMBER 4

DECEMBER, 1915

JOSEPH STANLEY-BROWN, EDITOR

PUBLISHED BY THE SOCIETY

MARCH, JUNE, SEPTEMBER, AND DECEMBER

CONTENTS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA

Subscription, $10 per year; with discount of 25 per cent to institutions and libraries and to individuals residing elsewhere than in North America. Postage to foreign countries in the postal union, forty (40) cents extra.

Communications should be addressed to The Geological Society of America, care of 420 11th Street N. W., Washington, D. C., or 77th Street and Central Park, West, New York City.

NOTICE.—In accordance with the rules established by Council, claims for non-receipt of the preceding part of the Bulletin must be sent to the Secretary of the Society within three months of the date of the receipt of this number in order to be filled gratis.

Entered as second-class matter in the Post-Office at Washington, D. C., under the Act of Congress of July 16, 1894

PRESS OF JUDD & DETWEILER, INC., WASHINGTON, D. C.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 389-408 NOVEMBER 22, 1915

PROCEEDINGS OF THE SUMMER MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT THE UNIVERSITY OF CALIFORNIA AND AT STANFORD UNIVERSITY, AUGUST 3, 4, AND 5, 1915[1]

J. A. TAFF, *Secretary pro tem.*

CONTENTS

[1] Manuscript received by the Secretary of the Society October 13, 1915.

Session of Tuesday, August 3

The first session of the Society was called to order at 10 o'clock a. m., Tuesday, August 3, in the auditorium of Bacon Hall, University of California, by C. F. Tolman, Jr., Chairman of the Cordilleran Section, in the absence of President Arthur P. Coleman. Seventy-five members and visitors were present. After announcements in regard to proposed excursions, the dinner, and the official program, the Chairman declared the reading of papers to be the regular order.

It was proposed to take up the papers in the order given in the printed program: those under Topic A, "Erosion and Deposition in Arid Climates," at the first session, held at the University of California, August 3; those under Topic B, "Petrologic Problems of the Pacific Area," at Stanford University, August 4; and those under Topic C, "Diastrophism of the Pacific Coast," at the University of California, August 5; but it was soon found that absent and tardy members on the list to read papers would disorganize the program. The program, however, was followed as closely as circumstances would permit. As carried out, the papers were presented as follows:

TITLES AND ABSTRACTS OF PAPERS PRESENTED AND DISCUSSIONS THEREON

EPIGENE PROFILES OF THE DESERT

BY ANDREW C. LAWSON

(*Abstract*)

This paper was a discussion of the development of the characteristic profiles of the relief of arid regions, with particular reference to the penultimate and ultimate stages of the processes involved.

Read in full from manuscript.

Discussion

Mr. R. S. Holway: Is there a limit on the Pan-Fan stage, and can it be readily perceived?

Professor Lawson replied: The limit is reached only occasionally. A change of climate usually interrupts the Pan-Fan stage and a degradational cycle ensues.

Prof. Bailey Willis: Instances in China and Patagonia show that the Pan-Fan stage is rarely reached. Wind erosion is a vital and important agent. Many agencies that cause modifications have not been indicated in the ideal Pan-Fan.

Professor Lawson replied that the Great Basin furnished the ideal region to illustrate instances cited, and that he was inclined to limit his paper to a consideration of Great Basin features.

BAJADAS OF THE SANTA CATALINA MOUNTAINS, ARIZONA

BY C. F. TOLMAN, JR.

(*Abstract*)

A description of the composition, structure, and origin of these desert slopes.

Presented in full extemporaneously.

Discussion

Mr. Sidney Paige discussed the use of the term "bajada."

Professor Tolman replied: Bajada, coalescing fans that connect the mountain with the bolson.

Prof. A. C. Lawson expressed the feeling that the term is superficial and does not refer to other dimensions of space.

Professor Tolman replied that bajada should be applied only to the surface feature.

ORIGIN OF THE TUFAS OF LAKE LAHONTAN

BY J. C. JONES[2]

(Abstract)

In the earlier study of the history of Lake Lahontan, Professor Russell believed that the tufas were chemical deposits caused by the saturation of the lake waters with calcium carbonate. A study of the recent tufa forming in the Salton Sea led to the conclusion that the deposit was due to the activities of blue-green algæ. Carrying the research into the Lahontan Basin, it was found that the algæ were responsible for the tufa forming at present about the shores of Pyramid Lake. An examination of the dendritic and lithoid tufas of Lahontan age disclosed the remnants of algæ in the tufa. Other lines of evidence indicated that the tufa was formed by the algæ, the only essential difference between the lithoid and dendritic types being that the latter was apparently formed whenever and wherever the conditions of growth were more favorable for the algæ.

Measurements of the more perfect thinolite crystals showed that they originally formed as aragonite crystals, and it was discovered that when the water from Pyramid Lake was saturated with calcium carbonate similar crystals of aragonite were deposited. It is concluded that the waters of Lake Lahontan approached saturation with respect to calcium carbonate only at the time that the thinolite was deposited, and that the history of the ancient lake as written, based on the origin of its calcareous deposits, will have to be modified.

Discussion of this paper was deferred.

The session adjourned at 12.10 p. m. to convene after the session of the Paleontological Society.

The Society convened at Bacon Hall, University of California, after the meeting of the Paleontological Society, 28 members and visitors being present.

SOME PHYSIOGRAPHIC FEATURES OF BOLSONS

BY HERBERT E. GREGORY

Read in full from manuscript by Prof. C. F. Tolman, Jr.

Discussion

Prof. C. F. Tolman, Jr., discussed five types of wind erosion, as follows: Protected surfaces—(1) by vegetation; (2) coarse gravel and boulders; cites boulders 1 foot in diameter 8 miles from mountains, near Tucson, Arizona; (3) caliche and surface cements 1 to 6 feet thick; (4) desert pavements—sheet of pebbles left on wind-swept surface as mosaic; (5) clay in bottom of playa becomes polished and hardened, protecting from erosion of wind.

[2] Introduced by J. C. Merriam.

Prof. Horace B. Patton: Wind is a transporting rather than abrading agent.

Mr. E. E. Free: Salt crust in desert bolsons is a protection against erosion by wind.

Prof. Erasmus Haworth: Caliche as protection against wind erosion has not been given sufficient importance by geologists. (Cites coarse caliche conglomerates in western Kansas as "mortar beds."

Mr. J. C. Jones: If erosion by wind is marked, evidence should be shown in its deposition. Wind does transport, but how much? I am inclined to the opinion that wind erodes but little.

Prof. Erasmus Haworth: Wind transports sediment to streams and by them is carried away.

Mr. E. E. Free: Wind transports sediment back and forth, but does not remove. (Cites oscillating sand-dunes in the Imperial Valley as instance.)

SCULPTURING OF ROCK BY WIND IN THE COLORADO PLATEAU PROVINCE

BY HERBERT E. GREGORY

Read in full from manuscript by Prof. C. F. Tolman, Jr.

Session of Wednesday, August 4

The Society convened at 10.55 o'clock a. m., in the Geological Department of Stanford University, Dr. A. C. Lawson acting as Chairman and J. A. Taff as Secretary.

Seventy-nine members and visitors were present.

TITLES AND ABSTRACTS OF PAPERS PRESENTED AND DISCUSSIONS THEREON

SOME CHEMICAL FACTORS AFFECTING SECONDARY SULPHIDE ORE ENRICHMENT

BY S. W. YOUNG [3]

(*Abstract*)

An account of some laboratory experiments which have led to artificial replacement by chalcocite, covellite, and chalcopyrite, and to the artificial disintegration of bornite into calcocite, covellite, and chalcopyrite, all at ordinary temperature and under easily attainable conditions; also a discussion of the probable chemical constitution of bornite and chalcopyrite, together with some considerations on the rôle of the amorphous and colloidal sulphides and of electro-chemical phenomena on secondary enrichment. (Experiments, artificial crystals, etcetera, forty-five minutes.)

Presented in full extemporaneously.

---

[3] Introduced by C. F. Tolman, Jr.

DISCUSSION

Prof. C. F. TOLMAN, JR., remarked that hydrogen sulphide is now recognized as a great mineralizing agent and not a precipitant alone. High temperature veins carry H_2S.

Prof. J. E. WOLFF stated the work on sulphides is to be revised.

ROLE OF COLLOIDAL MIGRATION IN ORE DEPOSITS

BY JOHN D. CLARK [4]

(*Abstract*)

As a result of observations made on the action of chalcocite* in becoming colloidal in mildly alkaline solutions, under the influence of hydrogen sulfide, and of flocculating or precipitating in contact with calcareous or argillaceous material, a series of experiments were carried on to see if other sulfides, arsenides, and sulfo-salt minerals would also change from the massive to the colloidal condition in alkaline solution, under the influence of hydrogen sulfide.

Experiments showed that nearly all important primary minerals do become colloidal.

The effect of contact with limestone and alumina on such colloidal solutions was investigated, and in all cases these materials caused a flocculation of the colloidal mineral.

The work suggests the possibility of all important primary minerals having been carried in the ore-bearing solutions as colloids, and that escape of hydrogen sulfide or contact with limestone or argillaceous material has caused the migrating colloids to gather into ore bodies.

Presented in full extemporaneously.

DISCUSSION

Dr. C. S. BASTIN suggested that other substances than H_2S will play a similar rôle in the accumulation of ore deposits. The presence of silica may play a part in transforming minerals to the colloidal state.

Prof. A. C. LAWSON challenged the statement that alkaline solutions come from magmas.

Mr. J. D. CLARK replied that he would establish Ojo Caliente experiments to show colloidal migration in natural waters.

EXAMPLES OF PROGRESSIVE CHANGE IN THE MINERAL COMPOSITION OF COPPER ORES

BY C. F. TOLMAN, JR.

(*Abstract*)

This paper was a discussion of the occurrence of high temperature minerals and of low temperature minerals in the so-called "primary" chalcocite deposits

[4] Introduced by C. F. Tolman, Jr.

* A chemical study of the enrichment of copper sulfide ores. Bulletin No. 75, University of New Mexico.

of the Bonanza Mine, Alaska; two-colored chalcocite; meta-colloidal chalcocite, and the use of the terms primary and secondary as applied to minerals.

Presented in full extemporaneously.

DISCUSSION

Prof. A. C. LAWSON questioned the propriety of such definite conclusions on interpretations from examinations of ore sections.

SERICITE, A LOW TEMPERATURE HYDROTHERMAL MINERAL

BY A. F. ROGERS[5]

(*Abstract*)

Microscopic study of ores of various types indicate that sericite is a rather low-temperature mineral formed at or toward the close of the hydrothermal period. Few, if any, of the hypogene minerals are later than sericite. Sericite not only replaces quartz and the silicates, but also various sulphides and sulpho-salts, such as pyrite, chalcopyrite, bornite, chalcocite, etcetera. The sericite of metamorphic rocks is also formed at a late stage.

Presented in full extemporaneously. Discussion was deferred.

DINNER

A joint dinner of the Geological, Paleontological, and Seismological Societies was held at the Engineers' Club, at 7.30 o'clock p. m., about 50 persons participating.

SESSION OF THURSDAY, AUGUST 5

The Society convened at 10.15 o'clock a. m., in Bacon Hall, University of California, Dr. C. F. Tolman, Jr., in the chair and J. A. Taff acting as Secretary.

TITLES AND ABSTRACTS OF PAPERS PRESENTED AND DISCUSSIONS THEREON

PHYSIOGRAPHIC CONTROL IN THE PHILIPPINES

BY WARREN D. SMITH

(*Abstract*)

The author presented a résumé of Philippine geology and the resulting physiographic sectors and a consideration of their effect on the distribution,

[5] Introduced by C. F. Tolman, Jr.

history, economic life, and probable future movements of various Philippine tribes. Some comparisons were drawn between Malaysian geology and that of the west coast of America.

Read in full from manuscript.

Discussion

Prof. R. A. Daly offered expressions of appreciation and inquiries as to relations of recent to Tertiary coral reefs.

Professor Smith replied that no break or disconformity has been noted in the coral formation of the Philippines.

Prof. A. C. Lawson asked if there are special types of topography in these regions of excessive rainfall.

Professor Smith called attention to the fact that in Luzon valleys are V-shaped and contain no soil.

Further remarks were made by Professors William H. Hobbs and C. F. Tolman, Jr.

ORIGIN OF THE BASINS WITHIN THE HAMADA OF THE LIBYAN DESERT

BY WILLIAM HERBERT HOBBS

(*Abstract*)

The intense aridity, the nearly uniform wind direction throughout the year, and the small areas of many of the basins when compared to that of the surrounding hamada are conditions which greatly facilitate a solution of the problem of origin. In the distribution of the trains of sand-dunes and of the deposit of loess, reason is found for believing that the basins have resulted from deflation which has been initiated wherever local faulting has so disturbed the hard mesa capping of Mokattam (Eocene) limestone as to bring the inferior and soft Cretaceous shales under the influence of the undermining action of the sand-blast.

Presented in full extemporaneously. Discussion was deferred.

LIMITED EFFECTIVE VERTICAL RANGE OF THE DESERT SAND-BLAST, BASED ON OBSERVATIONS MADE IN THE LIBYAN DESERT AND IN THE ANGLO-EGYPTIAN SUDAN

BY WILLIAM HERBERT HOBBS

(*Abstract*)

Observations made at numerous localities in northeastern Africa indicate that the effective action of the desert sand-blast does not there extend to a height of more than a meter above the surface of the ground. Some explanation for the sharp delimitation of this action was offered.

Presented in full extemporaneously. Discussion was deferred.

CHARACTERISTICS OF THE LASSEN PEAK ERUPTIONS OF MAY 20-22, 1915

BY RULIFF S. HOLWAY AND J. S. DILLER

(*Abstract*)

Lassen Peak, an old volcanic cone, unexpectedly burst into eruption in May, 1914. The most violent explosions came during the period from May 20 to 22, 1915. On the 22d a column of steam and volcanic dust was projected to a height of at least 30,000 feet above sea, as measured by a nephoscope at Red Bluff. A localized explosion projected rock fragments over a narrow, fan-shaped zone extending eastward 10 to 15 miles. Some time during the latter part of this period of activity the bottom of the crater was pushed bodily upward, forming a plateau-like top. The eruptions caused floods down Hat and Lost creeks on the northern slope of the mountain. The initial flood came down the slope of the main cone with avalanche-like velocity, preceded or accompanied by a blast which leveled forest trees beyond the flood area.

Presented in full extemporaneously.

DISCUSSION

Prof. J. S. DILLER read a brief paper on the recent activity of Lassen Peak.

Mr. R. S. HOLWAY remarked that he had observed the eruption of Mount Lassen June 1, and that red-hot debris shot up. One red-hot boulder was seen to roll down from the crest.

Further remarks were made by Mr. J. C. Jones.

The Society then adjourned for lunch.

The Society convened at 2.15 o'clock p. m., with Prof. C. F. Tolman, Jr., in the chair and J. A. Taff acting as Secretary.

GEOLOGY OF PORTIONS OF WESTERN WASHINGTON

BY CHARLES E. WEAVER

(*Abstract*)

The oldest formations existing in western Washington are of probable Carboniferous, Triassic, and Jurassic ages. They consist of quartzites, crystalline limestones, schists, slates, and a complex assemblage of intrusive and extrusive igneous rocks of pre-Tertiary age. Deposits of Lower Cretaceous are unknown within the State. The Upper or Chico Cretaceous occurs in the northern portion of the Puget Sound Basin as an extension of that from the northwestern side of Vancouver Island.

Presented in full extemporaneously. Remarks were made by Mr. John P. Buwalda.

PROBLEM OF THE TEXAS TERTIARY SANDS

BY E. T. DUMBLE

(*Abstract*)

Five separate sandy formations occur in a comparatively narrow belt in the Texas coastal Tertiaries. Of these, only one is certainly represented on the Sabine, while two of entirely different age are present on the Rio Grande. In the area between these rivers two additional sandstone belts are found, but so far as known there is no one section in which all five of the sands can be found. Because of the lithologic resemblance, scarcity of fossils, and lack of detailed stratigraphic work, much confusion has arisen regarding these beds and erroneous correlations of them have been made.

The results of recent investigations between the Sabine and Brazos rivers appear to clear away some of the misunderstandings which have arisen concerning the identity and age of these several beds as they occur in this region, and to open the road for the final solution of the problem in the areas between the Brazos and the Rio Grande.

Read in full from manuscript. Remarks were made by Doctors Alexander Deussen and W. D. Matthew.

Published in full in this volume.

PISOLITES AT SAN ANTONIO, TEXAS

BY ALEXANDER DEUSSEN [6]

(*Abstract*)

A description of pisolitic pebbles in stream terraces of San Antonio River was given, with a discussion as to the possible origin of the pebbles. A map showing the location and photographs illustrating sections of the pisolites were exhibited.

Presented in full extemporaneously. Remarks were made by Dr. W. D. Matthew and Messrs. Bruce L. Clark and H. W. Turner.

GEOLOGIC AGE OF THE COAL CREEK BATHOLITH AND ITS BEARING ON SOME OTHER FEATURES OF THE GEOLOGY OF THE COLORADO FRONT RANGE

BY HYRUM SCHNEIDER [7]

(*Abstract*)

The name Coal Creek batholith is here given to a mass of granite exposed in parts of Gilpin, Jefferson, and Boulder counties, Colorado. This granite has heretofore been considered as pre-Cambrian and probably Archean.

In mapping the Coal Creek quartzite, what appears to be good field evidence

[6] Introduced by J. A. Taff.

[7] Introduced by H. B. Patton.

has been found showing that the granite is post-Algonkian, and probably post-Pennsylvanian, in age.

The probable Mesozoic age of the granite simplifies the interpretation of the structure of the Coal Creek quartzite and does away with the necessity of faulting to explain the relation of the igneous to the sedimentary rocks in the vicinity of the South Boulder peaks.

The lithology and structural relations of the granite suggest a thick covering of sediments at the time of its intrusion, which throws additional light on this part of the front range as a positive block in the earth's crust.

Presented in full extemporaneously.

DISCUSSION

Prof. ERASMUS HAWORTH asked if there are fragments of granite in quartzite.

Mr. SCHNEIDER replied that the granite is not gneissoid; that it shows no indication of crushing, and the quartzite pebbles are mashed and elongated.

Further remarks were made by Prof. H. B. Patton and Dr. E. S. Bastin.

OCCURRENCE OF FLOW-BRECCIAS IN COLORADO

BY HORACE B. PATTON

(Abstract)

That igneous magmas intruded through and into the overlying rock formations are prone to pick up and incorporate fragments of all kinds and sizes on their way to and over the surface is, of course, no recently recognized phenomenon. The occurrence of such foreign inclosures has long been recognized as one of the common features of volcanic action. It would seem, however, that sufficient emphasis has not been laid on this subject by most investigators of igneous phenomena, and that the extent and frequency with which such rocks occur has not met with wide recognition.

In his investigation of the very extensive volcanic series of the San Juan Mountains in Colorado, Whitman Cross some twenty years ago observed some striking instances of igneous rocks in the form of dikes and sheets picking up fragments of the country rocks through which they broke their way to the surface and was the first to apply to such occurrences the name flow-breccia.[8] In his description of the rhyolites of the Intermediate Series and of the Potosi Rhyolite Series of the Telluride quadrangle, Cross describes in some detail the occurrence of these flow-breccias and finds them often difficult to distinguish in the field from true breccias and tuffs. For instance, of the rhyolites of the Intermediate Series he says that they consist in part of "apparent tuffs of rather indistinct character, many of which were found to be flow-breccia—that is, a rhyolite flow holding so many fragments of andesite that the fluidal matrix becomes quite inconspicuous and can not be seen with the naked eye.

[8] Whitman Cross: U. S. Geological Survey Folio No. 57, 1899.

The true nature of these rocks was not recognized in the field, and, indeed, the base of the series was not determined for many localities until the specimens were microscopically studied."

Flow structure seems to be especially characteristic of portions of the Potosi Rhyolite Series, and in this case the inclosed fragments are partly andesitic, but mainly rhyolite, similar to that of the massive flow. Of this Cross says: "The fragmental character is most evident near the bottom of the band, and in several sections a massive flow with many inclusions—a flow-breccia—follows without any clearly defined line of separation; in fact, some specimens collected to represent gravelly tuff were found on microscopical examination to be flow-breccia."

Other flow-breccias have later been described by Cross as occurring in the San Juan Mountains. Some of these contain fragments like the fluidal matrix; others like that of the Intermediate Series of the Telluride quadrangle, fragments different from such matrix. This is notably true of a flow-breccia in the Silverton quadrangle, to which the name Eureka rhyolite has been given. Of this rock Cross says:[9] "The second member of the Silverton Series is a rock belonging to the most siliceous of the magmas, which were erupted during this epoch of the San Juan volcanic history. It is so characterized by small included fragments of andesites, of rocks very similar to the rhyolite itself, or occasionally of granite, schist, etcetera, and has so commonly a flow structure that much of the rock may be called a flow-breccia. . . . Normally it is a grayish rock exhibiting many small angular inclusions, averaging much less than half an inch in diameter, of dark, fine-grained andesites or of reddish or grayish rhyolite, and has a prominent fluidal texture in the dense felsitic ground-mass which holds the fragments."

A flow-breccia has also been described by Crawford[10] as occurring on Brittle Silver Mountain, in the Monarch-Tomichi district. Here, again, we have a flow-breccia that contains fragments of porphyry not identical with the material composing the lava flow in which they are inclosed.

A flow-breccia, then, according to the definition established by Cross, may be considered to be a rock having an outward resemblance to a true breccia, of which the cementing material is a fluidal massive lava and the inclosed fragments similar to or different from the fluidal matrix.

Such flow-breccias are, according to the observations of the writer, of very great frequency, not only in the San Juan Mountains, but in the outer lying extension of the San Juan volcanic series to the east and north and also in other parts of Colorado.

In Sagnache County, for instance, in the Bonanza district, is a very marked case of a latite surface flow stretching for a distance of at least 12 miles, in every part of which fragments of inclosed andesite may be observed, in some parts so thick as to closely resemble a true breccia. In the Platora-Summitville district, in Conejos County, some 50 or 60 miles southeast of the San Juan Mountains, occurs a flow-breccia very similar to some of those of the Potosi Series; and in another part of this same district was observed monzonite porphyry with inclosed fragments of monzonite.

Again, in the Bonanza district, there occurs a rock closely resembling a

---

[9] U. S. Geological Survey Folio No. 120, 1905, p. 7.

[10] R. D. Crawford: Colo. Geological Survey Bull. No. 4, 1913, p. 176.

breccia, consisting of amphibolite, that is probably a metamorphosed diorite, inclosed in a matrix of very similar character.

In the Alma district, in the Mosquito Range, an intrusive mass of diorite occurs imbedded in a matrix that is almost identical with the fragments.

In attempting to describe these occurrences, in which the structures designated as flow-breccias are a characteristic feature, the writer has felt the need of a descriptive term that may be used without reference to the exact nature of the inclosed fragments of the enveloping fluidal matrix, and would venture to suggest the term rhyoclastic as suitable for this purpose.

A rhyoclastic rock, then, would be an igneous rock in which occur numerous inclusions of fragments of similar or of different material, so as to resemble more or less closely a true breccia.

Unfortunately, the term flow-breccia has been employed by Iddings in a quite different sense from that originally given by Cross. In his book on Igneous Rocks, Iddings[11] writes as follows: "When exploded fragments of molten magma, large or small, fall together in a still heated condition, as may readily happen within the crater of a volcano or the mouth of a fissure, they may be plastic enough to weld together in a more or less compact, coherent mass. This may subsequently flow like other lava, and is known as flow-breccia."

While such a rock may, of course, very properly be called a flow-breccia, it does not seem to be wise or in conformity with well established custom to change the definition as originally given by Cross. And yet it would be well to recognize the structure to which Iddings has applied this term. This could be done and confusion avoided by designating such rocks as welded flow-breccias.

We have, then, two types of flow-breccias: a rhyoclastic flow-breccia, where foreign fragments are caught up in great abundance in a flowing igneous matrix, and a welded flow-breccia, where fragments of a partially plastic igneous magma are shattered by some explosive act and flow together again by a process of welding.

Presented in full extemporaneously.

Discussion

Prof. Erasmus Haworth expressed a desire for further information on flow-breccias and as to how this breccia is distinguished from other types of breccia.

GEOLOGY OF A PORTION OF THE SANTA YNEZ RIVER DISTRICT, SANTA BARBARA COUNTY, CALIFORNIA

BY W. S. W. KEW [12]

(*Abstract*)

The region under discussion embraces the Santa Ynez Mountains east of the San Marcos Pass, the Santa Ynez River Canyon, and the mountains lying im-

[11] J. P. Iddings: Igneous Rocks, vol. i? 1909, p. 331.

[12] Introduced by A. C. Lawson.

mediately to the north. The following groups and zones are represented: The Franciscan, Knoxville, Chico (?), Tejon, Vaqueros (Turritella inezana zone), Temblor (Turritella ocoyana zone), Monterey shales, Fernando, and Pleistocene terrace deposits. Two thrust-faults are the main structural features north of the Santa Ynez Mountains. An anticline which shows more intense deformation in its eastern part forms the Santa Ynez Mountains.

Read in full from manuscript. Discussion was deferred.

INTERESTING CHANGES IN THE COMPOSITION OF THE SALTON SEA

BY A. E. VINSON[13]

(Abstract)

This paper discussed the change in composition of the waters of the Salton Sea developed by progressive evaporation.

Presented in full extemporaneously. Discussion was deferred.

EXAMPLES OF SUCCESSIVE REPLACEMENT OF EARLIER SULPHIDE MINERALS BY LATER SULPHIDES AT BUTTE, MONTANA

BY J. C. RAY[14]

(Abstract)

The ore deposits at Butte, Montana, belong to the replacement type. They include three distinct sets of ore minerals arranged zonally. These zones grade into each other and the divisions must be made arbitrarily. They are:

First. Silver zone. Silver, lead, and zinc minerals predominating.

Second. Zinc zone. Sphalerite predominating.

Third. Central or copper zone. A complex series of copper minerals.

This paper deals more particularly with successive and selective replacement of earlier sulphides by later sulphides in the copper zone and the inner border of the zinc zone.

The importance of this type of replacement has, perhaps, not been fully appreciated by students of ore deposits, and the present paper presents a few examples of this process which the writer has termed progressive enrichment.

The mineral sequence as determined for the Butte district is as follows:

1. Period.	Quartz-pyrite. Pyrite-quartz.	Replacement of quartz-monzite along fractures.
2. Period.	Sphalerite.	Chalcopyrite. Galena. Silver sulphides.
3. Period.	Tetrahedrite. Enargite. Tennantite.	Chalcopyrite. Bornite ?

[13] Introduced by C. F. Tolman, Jr.

[14] Introduced by C. F. Tolman, Jr.

4. Period.	Bornite. Covellite. Chalcocite.	Chalcopyrite. Bornite.
5. Period.	Chalcocite.	

Those in the second column are the minerals of any one period, while the minerals in the third column are of secondary importance as ores, but of great interest from a scientific point of view.

Presented in full extemporaneously.

DISCUSSION

Then followed general discussion of all papers bearing on ore deposition.

Prof. A. F. ROGERS gave a full summary of the evidence on the temperature of the formation of sericite.

Mr. SIDNEY PAIGE questioned whether sericite is not a low-temperature mineral and the result of weathering.

Professor ROGERS gave reasons for believing that sericite is the result of hydrothermal alteration and not of weathering.

Dr. E. S. BASTIN gave an appreciation of the work being done at Stanford University on ore deposits.

Prof. C. F. TOLMAN, JR., called attention to the complex relation discovered by the metallographic examinations of ores and the care that should be used in interpreting these.

STRUCTURE OF THE SOUTHERN SIERRA NEVADA

BY JOHN P. BULWADA [15]

(*Abstract*)

The rocks of the southern Sierra Nevada may be grouped into two divisions, as are those of the central and northern Sierra: a basement complex consisting of pre-Cretaceous intrusive rocks and metamorphosed stratified formations intensely deformed, and a superjacent series, made up of igneous and sedimentary rocks but little deformed and lying with marked unconformity upon the basement complex.

The structure of the few remnants of stratified rocks in the basement complex of the southern Sierra corresponds to that of the pre-Cretaceous rocks in the more northerly portions of the range; the strata dip steeply and usually strike approximately north-south. The structure of the rocks of the superjacent series in the southern Sierra differs markedly from that in the central and northern Sierra. Instead of lying nearly flat, they have been folded along both the northwestern or San Joaquin Valley side and the southeastern or Mojave Desert border of the range, as well as in the summit region. The structure of the Sierra thus comes to resemble that of the Coast Ranges somewhat as the Sierran range approaches the coastal mountains.

The great fault zone which borders the central and northern Sierra on the east continues along the southeastern face of the southern Sierra to the Coast Ranges.

[15] Introduced by A. C. Lawson.

Read in full from manuscript. Remarks were made by Messrs. R. T. Chamberlin, R. S. Holway, and C. F. Tolman, Jr.

A MEASURE OF ARID EROSION

BY CHARLES KEYES

(Abstract)

The arid regions of western America are particularly noteworthy because of the fact that throughout their extent there have been during late geologic times prodigious extravasation of lavas. These outpourings of basaltic magmas continued, without unusual interruptions, from the early Tertiary period to the present epoch. Being largely extruded over soft deposits of great thickness and wide extent, both lava streams and lava fields resist in a remarkable way all erosive influences. In the erosion and the general lowering of the country the areas covered by the lava-sheets soon develop into plains which now are elevated greater or less distances above the surrounding general plains surface. These plateau plains constitute one of the most characteristic features of arid landscapes.

With the geologic age of the underlying rocks and the time of the lava flowing determined, a measure is provided, within very narrow limits of error, for the time elapsed between the appearance of the effusive cap of the plateau plain, when this level was the general plains surface, and the formation of the present plains surface. There are many such plateau plains on the northern end of the Mexican tableland. In this connection one in particular deserves especial mention. The level of the great Mesa de Maya, in northeastern New Mexico, now 4,000 feet below the crest of the adjoining Rocky Mountains, is 3,000 feet above the next lower plain, the Ocate plateau, which latter is 500 feet above the broad Las Vegas plain, now constituting the general plains surface of the region. Into the surface of the latter the Canadian River intrenches itself to a depth of 2,000 feet.

Under conditions of an arid climate, where water action is almost unknown, the erosive power is believed to be mainly the winds.

Presented by title in the absence of the author.

A POSSIBLE CAUSAL MECHANISM FOR HEAVE FAULT-SLIPPING IN THE CALIFORNIA COAST RANGE REGION

BY HARRY O. WOOD [16]

(Abstract)

The causal mechanism proposed is differential creep of a subcrustal layer, with a maximum movement in the direction of the trend of the Coast Ranges and a minimum transverse to this trend due to lightening of the mountain belts and loading of the valleys and the sea-floor offshore. The principal point in the paper is the hypothesis which explains the causal relation between this transfer of load and the differential creep.

Presented by title in the absence of the author.

---

[16] Introduced by A. C. Lawson.

STRUCTURAL FEATURES OF THE TSIN LING SHAN

BY GEO. D. LOUDERBACK

(Abstract)

This paper includes notes on sections observed; comparison with routes of former expeditions. The inner zone: crystalline complex, development of isoclinal folds; general effects of granitic intrusion. The Mesozoic overlap. The southern zone of thrust. Late Mesozoic or early Tertiary faulting. Late Tertiary or Quaternary faulting. Structural relations of the loess. Résumé of the recognized diastrophic history taken as characteristic of central China, and general comparisons with the diastrophic history of the Pacific States of America. General comparison of results with those of earlier expeditions.

Presented by title in the absence of the author.

CERTAIN STRUCTURAL FEATURES IN THE COAL FIELDS OF NEW MEXICO

BY CHARLES T. KIRK [17]

(Abstract)

In the Number 4 Anthracite mine at Madrid, New Mexico (Upper Mesaverde), there occurs a thrust-fault of northerly strike with the astonishingly steep dip of generally 85 degrees westerly, the upthrow being on the west side. Within a thousand feet of where this fault is best exposed in the workings is another somewhat local normal fault of northwesterly strike with the astonishingly flat dip of generally only 6 degrees southwesterly, the upthrow being on the northeast side. The country flanks on the Ortiz Mountains and is further affected by sills and perhaps other igneous bodies. Surface agencies have so altered the outcrops of these faults—if they ever appeared at the surface—that they may not now be studied there; but workings have progressed sufficiently to warrant an explanation of the former by supposing a radial lift, probably during intrusion, and of the latter by a tangential stretch, probably during cooling of the same or a neighboring magma. The strata and sills dip 14 degrees easterly in both cases, so that the faults act as artesian channels, and both bring up much incombustible gas, presumably carbon dioxide, and some combustible gas, apparently carbon monoxide, both probably from carbonaceous beds below. The first was cut inexpensively by noting that the (igneous) roof rock is underthrust in the face of the entry; the second revealed its hidden nature only by bits of drag.

In the Heaton mine at Gibson (Gallup District), New Mexico, is a fault cutting the Number 5 coal bed (Upper Mesaverde) and offsetting it 24 feet vertically; yet 90 feet above the Number 3 bed, which has been worked out over the entire area of the vertical fault mentioned, shows no trace of a break. While this is suggestive of a disconformity, no surface corroborations of such an hiatus are yet discovered.

The occurrence of the last paragraph is recalled when one examines a break in the Upper Mesaverde coal at Rogers, near Cerillos, New Mexico. The upper

[17] Introduced by C. K. Leith.

bed of the series here runs from the south about 3 feet high, generally under a sandstone roof, to a locality nearly over the Waldo mine, where it is cut away locally to only a few inches. This instance has been cited as evidence that here is the division between Cretaceous and Tertiary in the region discussed.* It would seem desirable, however, that there be found more definite evidence of at least more quantitative importance for designating an oral unconformity than a soft member under a clastic formation deposited apparently under locally turbulent conditions. In a country and at a geologic age where so many unusual geologic features—such as have been cited above—are prevalent, only extremely close scrutiny of every obtainable evidence has brought the writer reliable results.

DEFORMATION OF THE COAST REGION OF BRITISH COLUMBIA

BY CHARLES H. CLAPP

(*Abstract*)

The first period of deformation recorded in the exposed formations of the coast region of British Columbia, by which term is meant that portion of British Columbia which lies to the west of the main crest of the Coast Range, presumably occurred at or near the close of the Paleozoic. Although the character and degree of deformation occurring at that time has been almost entirely obscured by later, more intensive deformation and by batholithic intrusion, there is some evidence that the folding was of an open character, with the principal axes of folding at a considerable angle to the present prevailing northwest-southeast trend of the rocks of the region.

The principal period of deformation, as is true of the entire Pacific Coast region, took place near the close of the Jurassic. This period of deformation can not be dated closely from the known date of the coast region of British Columbia, since the oldest unaffected rocks are of Upper Cretaceous age and rest unconformably on unroofed batholiths intruded during and following the deformation.

Lower Cretaceous rocks are not found, although they have been supposed to occur on Queen Charlotte Islands. It was during this period of deformation that most of the rocks of the region attained their general northwest-southeast trend. The folding occurred in the zone of combined fracture and flow, so the weaker rocks were deformed to closed folds of the similar type, while the more competent rocks were deformed into parallel folds of a more open character. Batholithic intrusion took place during this deformation, producing primary gneisses, although later batholiths appear to have been intruded after most, if not all, dynamic movement had ceased.

Portions of the coast region were profoundly affected by the next period of deformation, which does not appear to have taken place until the close of the Eocene. The rocks were warped into rather broad folds, whose general northeast-southwest axes were determined by the buttresses of older and more competent rocks. Extensive faulting, also, largely of a reversed or overthrust character, took place at this time and in places stocks of subjacent rocks were intruded.

* U. S. Geological Survey Bull. 531-J, 1913, p. 13.

No extensive faulting or folding has occurred since the post-Eocene period of deformation, although uplift and some tilting has taken place. The most conspicuous uplift, presumably during Pliocene times, was followed by at least local depression, and since Glacial times there has been a very general uplift of from 250 to 600 feet.

Presented by title in the absence of the author.

STUDY OF NINETY THOUSAND POUNDS OF MAMMOTH TUSKS FROM LENA RIVER, SIBERIA

BY GEORGE F. KUNZ

Presented by title in the absence of the author.

The Society then adjourned *sine die*.

EXCURSIONS

On Thursday, August 5, an excursion, in charge of A. C. Lawson, of the University of California, was made to Hunter's Point to see a contact of variolitic and ellipsoidal basalt, intrusive in radiolarian cherts of the Franciscan, and incidentally the intrusive relations of serpentinized peridotite to the Franciscan.

On Friday, August 6, an excursion, in charge of A. C. Lawson and E. P. Davis, of the University of California, was made to San Andreas fault and rift, Point Reyes Station, Marin County, to see the most pronounced phenomena of the horizontal slip on the San Andreas fault; also the rift topography.

On Saturday, August 7, an excursion, in charge of R. S. Holway, of the University of California, was made to the Santa Cruz Ocean beaches to see the finely preserved series of old ocean beach terraces which occur up to 1,200 feet above present sealevel. The three major terraces are broad, the maximum width of the lowest terrace being one mile. Fifteen to twenty terraces are found in places between Santa Cruz and Davenport, 12 miles westward.

On Monday, August 9, an excursion, in charge of A. C. Lawson and B. L. Clark, of the University of California, was made from Berkeley to Mount Diablo. This trip enabled the excursionists to see a fairly complete section of the strata involved by the great geosyncline which lies between the valley of the Bay of San Francisco and Mount Diablo. The lowest strata of the section, the Franciscan, are exposed on the two flanks of the geosyncline. Resting on the Franciscan in ascending order are the Knoxville shales, the Oakland conglomerate, and Chico sandstone and shale, extending from Lower to Upper Cretaceous. The Tertiary formations resting on the Chico comprise (1) the Martinez and Tejon, two local divisions of the Eocene; (2) the Monterey (Miocene) group, comprising alternate formations of sandstones and bituminous shales, some of which are cherts; (3) the San Pablo formation, and (4) fresh-water beds of the Orindan formation in the middle of the syncline. Still later than the Orindan, on the western side of the syncline, is a belt of alternating lavas and lacustral and fluviatile deposits, which are best exposed on the hill-tops immediately back of the University of California. These strata are crossed in the line of the route of this excursion.

On Tuesday, August 10, a trip to the Yosemite Valley was begun, under the charge of J. A. Taff, Acting Secretary of the Society, and F. C. Calkins, of the United States Geological Survey. This trip occupied seven days. After examining the park, the members became the guests of the Sierra Club, which had all the conveniences for mountain transportation and subsistence, and conducted the party up Tenaya Canyon via Mirror and Tenaya lakes to the Sierra Club's main camp at Tuolumne Meadows—a day's journey. Opportunity was given for an examination of the unusual glacial effects exposed in the Tuolumne Meadows locality. From this camp excursions were made to study the glacial and other geology in the canyons and high Sierras.

Register of the California Meeting, 1915

Ralph Arnold
Edson S. Bastin
Edward W. Berry
John C. Branner
Rollin T. Chamberlin
Charles H. Clapp
Reginald A. Daly
Arthur L. Day
Joseph S. Diller
Edwin T. Dumble
Harold W. Fairbanks
Erasmus Haworth
Oscar H. Hershey
William H. Hobbs
Charles Keyes
Andrew C. Lawson
W. D. Matthew
John C. Merriam
Henry F. Osborn
Sidney Paige
Horace B. Patton
Charles Schuchert
Elias H. Sellards
William J. Sinclair
W. S. Tangier Smith
Timothy W. Stanton
Ralph W. Stone
Joseph A. Taff
Cyrus F. Tolman, Jr.
Henry W. Turner
Edward O. Ulrich
Charles E. Weaver
Israel C. White
Bailey Willis
John E. Wolff

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 409-418 NOVEMBER 23, 1915
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PROCEEDINGS OF THE SUMMER MEETING OF THE PALEONTOLOGICAL SOCIETY, HELD AT THE UNIVERSITY OF CALIFORNIA AND AT STANFORD UNIVERSITY, AUGUST 3, 4, 5, AND 6, 1915.[1]

CHESTER STOCK, *Secretary pro tem.*

CONTENTS

[1] Manuscript received by the Secretary of the Geological Society of America October 30, 1915.

Session of Tuesday, August 3

The meeting was called to order by Dr. Edward O. Ulrich, the President of the Society, at 2 o'clock, in Bacon Hall, room 206, University of California. Doctor Ulrich then requested Prof. J. C. Merriam, Vice-President, to take the chair. Professor Merriam, after welcoming the visiting paleontologists, pointed out the value of a discussion of correlation problems involving the areas both east and west of the Cordilleras and on both sides of the Pacific Ocean. The subject of the meeting, "General consideration of Paleontologic criteria used in determining time relations," was then declared in order and the following papers were presented:

CRITERIA OF CORRELATION FROM THE POINT OF VIEW OF THE INVERTEBRATE PALEONTOLOGIST

BY EDWARD O. ULRICH

PROBLEM OF CORRELATION BY USE OF VERTEBRATES

BY WILLIAM D. MATTHEW

CORRELATION AND CHRONOLOGY ON THE BASIS OF PALEOGRAPHY

BY CHARLES SCHUCHERT

On account of the absence of Dr. F. H. Knowlton, the reading of his paper, entitled "Correlation based on a study of the history of plants," was postponed to a later meeting.

Discussion of the preceding three Papers

Doctor Matthew stated that the ultimate displacement of strand-lines is satisfactory for wide-spread movements, but in a practical application it is doubtful whether such movements are in unison.

Prof. J. P. Smith stated that in the case of the Triassic rocks of the West correlation has been purely by paleontology.

In correlating the Lower Cretaceous strata, Dr. T. W. Stanton stated that paleontology alone has been used. It was conceded that for practical purposes correlation is by paleontology, but that ultimate correlation depends on diastrophism.

Professor Schuchert briefly reviewed Suess' conception of the great overlap in the Cretaceous and his application of this principle to the Devonian, and considered the Pacific province in this connection. He called attention to the fact that the middle of a period is characterized by the most cosmopolitan fauna.

Professor Osborn called attention to the importance of fossils as compared with diastrophic movements when used for correlation purposes, and emphasized the stability of protoplasm through the past as contrasted with our standards of permanence in the inorganic world.

Professor Willis called attention to the insufficiency of our knowledge concerning diastrophism. He contrasted the gradual changes in the Mississippi basin with the sudden changes on the Pacific coast, and questioned the universality of movements. The Atlantic and the Pacific are separate dynamic basins which are discordant in their movements. It is necessary to work out the paleogeography in as great detail as possible.

Doctor Ulrich remarked that in considering diastrophism we should note especially those movements felt over broad areas. He believed in the correlation of submergence in one region with emergence in another.

Professor Merriam in summarizing stated that the present discussion was a necessary preliminary to any consideration of correlation between the Pacific and Atlantic basins. He noted that the consensus of opinion seemed to be that organic criteria furnish the tools actually used in practically all wide-range correlation. Attention was directed to the importance of the history of life as a basis or scale for use in time measurement or classification.

The meeting then adjourned.

Session of Wednesday, August 4

The meeting was called to order by Prof. J. P. Smith at 2.30 o'clock, in room 320, Department of Geology, Stanford University. Prof. J. C. Merriam was then called to the chair. The symposium, "Correlation of the Triassic," formed the topic for this meeting, and four following papers on this subject were presented:

RELATIONS OF THE INVERTEBRATE FAUNAS OF THE AMERICAN TRIASSIC TO THOSE OF ASIA AND EUROPE

BY JAMES PERRIN SMITH

Discussion

In answer to a query by Professor Merriam as to the number of species occurring in the Triassic of California, Professor Smith replied that a conservative estimate would place the number at about 400. He stated that the number of interregional faunas were three in the Lower, two in the Middle, and four in the Upper Triassic. These are separated by local faunas. In Europe definite faunal zones can be recognized, and between these are beds not characteristically fossiliferous, or in some cases non-fossiliferous.

In reply to Professor Merriam's query as to whether these interregional faunas were more or less common in the Triassic than in later periods, Professor Smith replied that they were much more common in the Triassic.

Professor Schuchert emphasized the cosmopolitan range of ammonites, their extensive migration, and stated that there was nothing comparable among the other groups of invertebrates.

Professor Smith stated that the ammonites were apparently exceedingly sensitive to changes in their diet. They appear to be represented about coral reefs and are not found in black shales.

Doctor Ulrich pointed out various aspects of the migration problem. He stated that species may pass around rather than across basins, and that forms do not always choose the shortest way across.

After noting the proportions of ammonites, pelecypods, brachiopods, and other invertebrates in the Triassic faunas, Professor Schuchert remarked that with the exception of the ammonites the types are all shallow-water forms. Ammonites were powerful swimmers and probably did not float. During the development of geosynclines the ammonites lived in relatively shallow waters.

Prof. J. C. Jones pointed out that in discussing the migration of these forms it is necessary to consider also the course of oceanic currents.

In answer to Professor Merriam's query whether the number of interregional zones denoted a great length of time, Professor Smith replied that it certainly implied a number of physiographic changes in the Triassic. He stated further that he did not believe that climatic changes exerted a great influence on the general evolution of these forms.

Professor SCHUCHERT expressed his appreciation of Professor Smith's work in elucidating the Triassic problems of North America.

TRIASSIC DEPOSITS OF JAPAN

BY H. YABE

DISCUSSION

Professor SMITH stated that the Middle Triassic is represented in Japan. In commenting on the fauna, he noted the differences exhibited by the ammonites and the similarity of the other forms when contrasted with North American types. He designated the differences as provincial.

CORRELATION BETWEEN THE TERRESTRIAL TRIASSIC FORMS OF WESTERN NORTH AMERICA AND EUROPE

BY RICHARD S. LULL

Read by Charles Schuchert.

DISCUSSION

Professor MERRIAM noted the inherent difficulties in correlating continental with marine formations, since land vertebrates occur, as a rule, where there are no marine deposits.

Professor SMITH remarked that a case in point is shown on the border between Idaho and Utah, where the land and marine Triassic are 15 miles apart and yet it is impossible to correlate across.

COMPARISON OF MARINE VERTEBRATES OF WESTERN NORTH AMERICA WITH THOSE OF OTHER TRIASSIC AREAS

BY JOHN C. MERRIAM

The meeting then adjourned.

DINNER

On Wednesday evening the members of the Society joined with the Geological Society in a dinner given at the Engineers' Club, in San Francisco.

SESSION OF THURSDAY, AUGUST 5

This meeting of the Society was called to order by Dr. Timothy W. Stanton at 2.30 o'clock, in Bacon Hall, room 206, University of California. The symposium, "Correlation of the Cretaceous," formed the topic of this meeting and the following papers were presented:

CORRELATION BETWEEN THE CRETACEOUS OF THE PACIFIC AREA AND THAT OF OTHER REGIONS OF THE WORLD

BY TIMOTHY W. STANTON

CORRELATION OF THE CRETACEOUS INVERTEBRATE FAUNAS OF CALIFORNIA

BY TIMOTHY W. STANTON

CORRELATION BETWEEN INVERTEBRATE FAUNAS OF CALIFORNIA AND THOSE OF MEXICO

BY EARL L. PACKARD

COMPARISON OF THE CRETACEOUS FAUNAS OF JAPAN WITH THOSE OF WESTERN UNITED STATES

BY H. YABE

COMPARISON OF THE CRETACEOUS FLORAS OF CALIFORNIA WITH THOSE OF OTHER CRETACEOUS AREAS

BY F. H. KNOWLTON

Read by John C. Merriam.

DISCUSSION OF THE PRECEDING FIVE PAPERS

In reply to Professor Schuchert's query as to the cause of the discordance between the floras and the faunas of the Knoxville when used as indicators of age of this formation, Doctor STANTON stated that the faunal evidence was not strong.

Professor SMITH noted that the Knoxville and Mariposa are never found in contact. The persistence of striated Aucellæ later than the Mariposa is not especially significant. It indicates that the time interval was not great.

Doctor STANTON remarked that paleobotanists make no distinctions between the Upper Knoxville and Horsetown floras, while there is a distinct difference in the faunas.

Professor SCHUCHERT stated that if there was a great movement at the end of the Jurassic there must be a marked unconformity and the disturbance must be reflected in the faunas.

Doctor ULRICH stated that there was undoubtedly considerable land during the Jurassic-Cretaceous interval. Since the age is determined by the marine faunas, and since the last of the Jurassic flora would leave its impression on the Cretaceous flora, there seems to be no agreement between the evidence derived from these sources. It was suggested that the standards may not agree;

that possibly an older portion of the Cretaceous is represented here with no equivalent in the European standard.

Professor SCHUCHERT stated that there is no marked change in the flora of the Jurassic, and that the change occurs in the Lower Cretaceous. On the other hand, the marine faunas change rapidly and at the end of the periods.

Professor MERRIAM said that the Cretaceous offers one of the best examples in the use of the migration of strand-lines for correlation purposes. Before an adequate time classification can be established it is necessary to know more of the causes of life change and of diastrophic change. More is known of life changes than of diastrophic movements.

Professor OSBORN remarked that the lines drawn by Cuvier and a number of other early workers were based on paleontologic evidence. The chief objection to the use of diastrophism for correlation purposes is that its effects have not been world-wide. The continent of Africa has remained approximately the same for a considerable length of time.

Doctor ULRICH stated that the systems were originally based on lithology, and it was afterward recognized that they could be determined by their faunal content. He cited the Silurian and Devonian as examples. The idea of world-wide diastrophism depends on the meaning of the term. It refers to any movement which will affect the strand-line.

Professor SCHUCHERT emphasized the world-wide influence of diastrophic movement, and referred to it as due to periodic shrinking of the earth's crust. The influence of diastrophism is exerted over both marine and continental deposits.

Doctor MATTHEW stated that he believed theoretically in diastrophism as an aid in correlation, but doubted its value in practical application. He recognized the obvious evidences of world-wide diastrophism, as in the Cretaceous.

The meeting then adjourned.

SESSION OF FRIDAY, AUGUST 6

The meeting was called to order by Prof. Henry F. Osborn at 10 o'clock, in Bacon Hall, room 206, University of California. The symposium, "Correlation between the Miocene of the Pacific region and that of other areas of the world," was the topic of this session, and the morning was devoted to the reading of the following papers:

INTRODUCTORY REMARKS ON CORRELATION OF MIOCENE

BY HENRY FAIRFIELD OSBORN

CORRELATION OF THE LOWER MIOCENE OF CALIFORNIA

BY RALPH ARNOLD

REVIEW OF THE MIOCENE AND OLIGOCENE FAUNAS OF CALIFORNIA

BY B. L. CLARK

MIOCENE OF THE WASHINGTON-OREGON PROVINCE AND ITS RELATION TO THAT OF CALIFORNIA AND OTHER MIOCENE AREAS

BY CHARLES E. WEAVER

VERTEBRATE FAUNAS OF THE PACIFIC COAST REGION

BY JOHN C. MERRIAM

The meeting was then adjourned until the afternoon.

The meeting was again called to order by Professor Osborn at 2 o'clock. The symposium on the "Correlation of the Miocene" was continued and the following papers were read:

CORRELATION BETWEEN THE MIDDLE AND LATE TERTIARY OF THE SOUTH ATLANTIC COAST OF THE UNITED STATES WITH THAT OF THE PACIFIC COAST

BY E. H. SELLARDS

RELATION OF THE MIOCENE MAMMALIAN FAUNAS OF WESTERN UNITED STATES TO THOSE OF EUROPE AND ASIA

BY WILLIAM D. MATTHEW

CORRELATION OF THE MIOCENE FLORAS OF WESTERN UNITED STATES WITH THOSE OF OTHER MIOCENE AREAS

BY F. H. KNOWLTON

Read by John C. Merriam.

FLORA OF FLORISSANT

BY T. D. A. COCKERELL

Discussion of the papers dealing with the correlation of the Miocene was deferred. Prof. J. C. Merriam was called to the chair. The remainder of the afternoon was devoted to the reading of the following papers of general interest:

FAUNAL GEOGRAPHY OF THE EOCENE OF CALIFORNIA

BY R. E. DICKERSON

RECENT WORK ON THE DINOSAURS OF THE CRETACEOUS

BY HENRY FAIRFIELD OSBORN

HISTORY OF THE APLODONTIA GROUP

BY W. P. TAYLOR

SOME PROBLEMS ENCOUNTERED IN THE STUDY OF FOSSIL BIRDS OF THE WEST COAST

BY L. H. MILLER

A number of important papers were not reached in the program, as the Society adjourned to take part in the excursions on the following day.

Resolution of Thanks

Prof. Henry F. Osborn offered a resolution instructing the Secretary to tender to the officers of the American Association for the Advancement of Science, to the President of the University of California, and to the President of Stanford University the thanks of the members of the Paleontological Society and an appreciation of the courtesies extended to the Society at this meeting.

The meeting then adjourned.

Excursions

Following the meeting a number of the members of the Society participated in excursions to some of the principal localities of paleontologic interest in California.

On Saturday, August 7, under the direction of Prof. John C. Merriam, the San Pablo Bay syncline was visited. A section, including faunas from the Chico-Cretaceous to the Rodeo-Pleistocene, was examined by the party.

Under the leadership of Prof. A. C. Lawson and Dr. B. L. Clark, the section near Walnut Creek was examined on Monday, August 9, and on the following day Mount Diablo was visited. The members of the party were able to examine a section ranging from the Franciscan-Jurassic to the Pleistocene and offering much of structural and paleontologic interest.

The Ricardo Pliocene beds exposed on the Mohave Desert were visited by several members of the Society on Thursday, August 12, with Dr. J. P. Buwalda as leader.

Following the excursion to Ricardo the famous Pleistocene asphalt deposits of Rancho La Brea were visited, under the leadership of Mr. Frank S. Daggett and Professor Merriam, on Friday, August 13. On the same day the party visited the Museum of History, Science, and Art, in Los Angeles.

Under the leadership of Dr. Ralph Arnold, the splendid marine Pleistocene sections exposed at San Pedro and Long Beach, near Los Angeles, were examined on Saturday, August 14. On the excursions in and around Los Angeles the visiting members were most hospitably entertained, through the courtesy of the Museum of History, Science, and Art and the Chamber of Commerce of Los Angeles.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 419-446 NOVEMBER 24, 1915
PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

I. ON THE RELATIONSHIP OF THE EOCENE LEMUR *NOTHARCTUS* TO THE ADAPIDÆ AND TO OTHER PRIMATES[1]

II. ON THE CLASSIFICATION AND PHYLOGENY OF THE LEMUROIDEA

BY WILLIAM K. GREGORY

(Presented before the Paleontological Society December 31, 1914, and, in abstract, August 4, 1915)

CONTENTS

I. ON THE RELATIONSHIP OF THE EOCENE LEMUR *Notharctus* TO THE ADAPIDÆ AND TO OTHER PRIMATES[2]

RESULTS OBTAINED BY OTHER INVESTIGATORS

The genus *Notharctus* was founded by Leidy in 1870 upon a small fossil jaw which had been found in the Eocene formation near Fort Bridger, Wyoming. Leidy was not able to refer the animal to any existing order of mammals. He noted its resemblances to carnivorous mammals on the one hand and to certain supposed Eocene pachyderms on the other.

[1] Manuscript received by the Secretary of the Geological Society August 19, 1915.
[2] This paper and the following one contain an outline of observations and conclusions which will be fully presented in a Memoir of the American Museum of Natural History.

Marsh, who described a similar jaw fragment the next year, 1871, also noted its resemblances to the supposed suilline pachyderm *Hyopsodus*. In October, 1872, however, Marsh described some better specimens, which included parts of the limb bones. He remarked that the principal parts of the skeleton of these animals were formed much as in some of the Lemurs, especially the limb bones, and he referred the animals to the order Quadrumana. He also gave the correct dental formula. The subsequent systematic history of the group was developed by Cope, Marsh, Osborn, Wortman, and Matthew in a long series of papers, extending from 1871 to the present time. Through their labors three valid genera—*Pelycodus*, *Notharctus*, and *Telmalestes*—including perhaps a dozen or more nominal and valid species, have been recognized, constituting the family Limnotheridæ of Marsh, or Notharctidæ of Osborn.

The problem of the relationship of this family to other Eocene families, namely, to the Hyopsodontidæ, to the Adapidæ of Europe, and to the modern Lemurs, has had a confusing history. Marsh, as it now seems, correctly placed the group as being more or less related to the modern Lemurs. Cope was long deceived by a false association of Creodont claws with teeth belonging to *Pelycodus*, and on this misconception he based his suborder Mesodonta (1876). This error was corrected both by Schlosser (1887, page 22) and by Matthew. Cope also held that the genus *Notharctus* and its allies were related to the European Eocene genus *Adapis*, and he referred them all to the family Adapidæ (1885).

Osborn, in 1902, revised the genera and species of American Eocene Primates, defined the family Notharctidæ, and traced the history of the family from the Lower Eocene species of *Pelycodus* to the Upper Middle Eocene species of *Telmalestes*. Up to this time these animals were known chiefly from the dentition, and as Professor Osborn did not regard such material as adequate, he left unsettled the general problem of the relationships of this family, provisionally retaining them in Cope's group Mesodonta.

Wortman, in 1904, endeavored to show that the Hyopsodontidæ, which had been supposed to be related to the Notharctidæ, were not Primates at all, but Insectivores. He regarded Cope's Mesodonta as an unnatural assemblage. He placed *Notharctus* with the European genus *Adapis* in the Adapidæ, but he regarded this group as not at all nearly related to the modern Lemurs; he thought rather that the Adapidæ stood near to the beginnings of the higher Primates, especially the New World monkeys. Accordingly he placed *Notharctus*, along with *Adapis*, in the same division with the monkeys both of the New and the Old World, the great apes and man, and to this assemblage he gave the name Neopithecini, or modernized Primates. This opinion, therefore, would be highly important if true, for, if confirmed, it would mean that the Adapidæ represent an early evolution stage of the group that includes man and the higher apes.

Stehlin, in 1908, in his monographic revision of the European genus *Adapis*, which ranges from the Lower to the Upper Eocene of France, concluded from a comparison of the dentitions that the American *Notharctus* and its allies were not nearly related to *Adapis*, but that the two formed divergent contemporary families in Europe and America, which were not more nearly related to each other than to other families of Primates. Stehlin showed that the Adapidæ in the fundamental architecture of the skull were related to the modern Lemuridæ.

Schlosser, in Zittel's Grundzüge der Paläontologie (1911), referred *Notharctus* and its allies to the Adapidæ and suggested that the European genera might be derived from the more primitive Notharctid genus *Pelycodus*.

As long as *Notharctus* and its allies were known chiefly from the dentition and scattered limb bones, and as long as the architectural plan of the skull was but poorly known, there was room for these wide differences of opinion regarding the relationships of the Notharctidæ and the Adapidæ with each other and with the higher Primates.

OBSERVATIONS OF THE WRITER

In 1903 and subsequent years, however, American Museum expeditions under Mr. Walter Granger, working in the Middle Eocene formations of Wyoming, discovered a series of specimens which has afforded an adequate knowledge of the skull, vertebræ, and limbs of *Notharctus*. This material was generously placed in my hands by Doctor Matthew, with the consent of Professor Osborn, and it has afforded much new evidence regarding the relationship of the Notharctidæ with the Adapidæ, with the Lemurs, and with other groups.

I purpose, therefore, to present very briefly some of the evidence which has led me first to adopt the view of Schlosser, that the Notharctidæ and Adapidæ are closely related to each other and to the Lemurs, and, secondly, to modify largely the view of Wortman regarding their several relationships with the Lemurs and with the higher Primates.

The American genera *Notharctus* and *Telmalestes* agree with the European genera *Adapis* and *Leptadapis*, not only in the general form of the skull as a whole, but also in the form of the orbit, malar, sagittal and lambdoidal crests, lower jaw, and dental formula. Very important is the close agreement between *Adapis* and *Notharctus* in the form and relations of the lacrymal. In both genera the lacrymal was largely within the orbit, instead of being widely extended on the face, as it is in Lemurs, and the lacrymal foramen was marginal, instead of preorbital; and this condition is, I believe, the primitive one for Primates in general, the existing Lemurs having lost this and other primitive lemuroid characters. The generic differences are obvious and may be passed over.

In the architecture of the skull *Adapis* and *Notharctus* reveal differences which are chiefly quantitative, or allometric. In a skull of *Notharctus* in the American Museum (number 11477), the basicranial region has been skilfully freed from the matrix by Mr. Anderson. It exhibits the following important characters: (1) the pterygoid plate of the alisphenoid is continued down outside the bulla; (2) the bulla represents an expansion of the periotic; (3) the auditory prominence or cochlea bears on its outer surface a bony canal for the internal carotid artery; (4) this canal runs forward to the anterior end of the bulla, and there it enters the posterior part of the basisphenoid; (5) the entrance to the carotid canal, or posterior carotid foramen, is at the postero-external corner of the bulla; (6) immediately external to the posterior carotid foramen is the stylomastoid foramen, for the seventh nerve.

In *Adapis*, as figured by Stehlin (1912), the basicranial region is fundamentally similar to that of *Notharctus*. Here the pterygoid plate of the alisphenoid likewise extends outside the bulla, which is again only an expanded portion of the periotic; the cochlea has the same carotid canal, which also runs forward to the anterior end of the tympanic chamber; the stylomastoid foramen is in the same position. Stehlin found preserved in some specimens the delicate tympanic annulus which, as in *Notharctus* and all other true lemuriform lemuroids, was inside the expanded bulla.

The dentition, however, offers divergent characters. The upper incisors of *Adapis* are more chisel-like than those of *Notharctus*, the premolars are more compressed, the molars are trituberculate, the postero-internal cusps of the molars are formed by the upgrowth of the basal cingulum, and there is no median external cusp, or mesostyle.

In *Notharctus*, on the other hand, the posterior premolars are wider transversely, the posterointernal cusp of the molars is formed by a splitting or division of the protocone, and there is a progressively developed mesostyle.

The different modes of forming the posterointernal cusp of the upper molars are correlated with equal differences in the entoconid in the lower molars. By fitting the upper and lower teeth together I find that in the case of *Notharctus* the constriction between the two inner cusps marks the spot where the entoconid of the lower molar sweeps across the internal ridge of the upper molar. In *Notharctus*, as in many Perissodactyls, the progressive development of the tetartocone, or posterointernal division of the protocone, is correlated with the progressive development of the entoconid of the lower molars. The progressive development of the mesostyle is also correlated with a partly transverse excursion of the mandible and with the V-like modification of the para- and metacones.

In the Adapidæ, on the other hand, the entoconids, for some reason, remained small; there was consequently no correlated development of the tetartocone, and the posterior cingulum was thus free to grow up in a normal manner into a true hypocone, which fits into the valley of the trigonid. Also, there being less transverse movement of the mandible, the para- and metacones did not become V-shaped and the mesostyle failed to develop. But, although these differences in the dentition are very marked in the later members of the Adapinæ and Notharctinæ, they are less pronounced if we compare Stehlin's *Protoadapis* with our American *Pelycodus*. The oldest forms of *Pelycodus*, which have recently been described by Doctor Matthew,[3] have extremely primitive tritubercular upper molars, without any posterointernal cusp, and they have a pattern which, according to accepted principles of dental evolution, is structurally ancestral to the two divergent lines seen in the Notharctinæ and Adapinæ.

Stehlin (1912), noting the marked differences in the dentition between *Adapis* and *Notharctus*, but without investigating the functional significance of these differences, concluded that the Adapidæ and the Notharctidæ were rather widely separated families, not more nearly related to each other than to other groups of lemuroids; but if Doctor Stehlin had realized that these observed differences were all correlated with a divergent habit of swinging the mandible, and that the more primitive Notharctids of the Lower Eocene appear to be structurally ancestral, both to the Adapidæ and Notharctidæ, and especially if he had had a well-preserved skull of *Notharctus*, and could have seen the fundamental similarity throughout, I think it probable that he would have been led to the conclusion that the two groups are rather nearly related.

In *Adapis* we see the same dental formula as in the Notharctinæ, but the ramus is now stout and the region of the angle is much expanded, paralleling in this respect such advanced lemuroids as the Indrisinæ. In fact, the differences in the lower jaw between *Notharctus* and *Adapis* are not as great as those between *Lepilemur* of the Lemurinæ and *Indris* of

[3] Bull. Amer. Mus. Nat. Hist., vol. xxxiv, 1915, pp. 429-483.

the Indrisinæ. With the expansion of the angle, the areas of insertion of the pterygoid muscles and of the masseter and temporalis are greatly expanded. We accordingly find that *Adapis* also has the malar and the sagittal and lambdoidal crests highly developed, and that in the dentition this superior crushing power is shown in the expanded talonids of the lower molars and in the expanded protocones of the upper molars. In short, the skulls and dentitions of *Adapis* and *Notharctus* are fundamentally similar in architectural plan, but differ in adaptive details.

The limbs of *Adapis* are also fundamentally similar to those of *Notharctus*, *Adapis* being more robust. It is noteworthy that the astragalus of *Adapis* agrees with that of *Notharctus* in having a narrow vertically extended trochlea, whereas in all the Anthropoidea the trochlea is wide and has more distinct keels.

I would therefore define the family Adapidæ and the included subfamilies Notharctinæ and Adapinæ as on page 433, below.

Coming now to the structural relationships of the Notharctidæ to modern Primates, I can only emphasize what I have previously stated (1913), that in my judgment there is no justification for associating the Notharctinæ with the South American monkeys, as Wortman (1904) has done in placing both *Adapis* and *Notharctus*, along with *Tarsius*, in his major group Neopithecini. The Notharctinæ are certainly in a lemuroid rather than a simian stage of evolution, and they differ from modern Lemurs chiefly in being more primitive and in having avoided both the peculiar lemurid specialization of the lower incisors and canines and the secondary elongation of the lacrymal on the face.

The skull of *Notharctus* is lemur-like in general form. The face is long: the postorbital bar reaches the malar: the malar is essentially similar to that of Lemurs: the orbit is not shut off from the temporal fossa by a transverse partition. But in many ways the skull of *Notharctus* is far more primitive than that of existing Lemurs and approaches the skull of other primitive Eocene mammals: thus the brain-case is relatively small and is surmounted by well-developed sagittal and lambdoidal crests: the jaw is stout: the dental formula is $I\frac{2}{2}$, $C\frac{1}{1}$, $P\frac{4}{4}$, $M\frac{3}{3}$, which differs from the primitive Placental formula of $\frac{3.}{3.}\ \frac{1}{1.}\ \frac{4.}{4.}\ \frac{3.}{3.}$ only in the loss of one upper and one lower incisor. The base of the cranium is fundamentally similar to that of the Lemuridæ.

The existing genus *Lepilemur*, which in many characters is perhaps the most primitive of the Lemuridæ, is far more advanced than *Notharctus* in the expansion of its brain-case, in the loss of the sagittal crest, in the weakening of the lower jaw, and especially in the characteristic lemurid specialization of the incisors, canines, and anterior premolars—a specialization which *Notharctus* had not assumed.

The lower jaw of the earlier species of *Notharctus* has two important primitive characters in common with that of modern Lemurs: First, the two halves are suturally separate at the symphysis, whereas in the Anthropoidea, including the New World monkeys, or Platyrrhinæ, and the Old World monkeys, apes and man, or Catarrhinæ, the opposite halves are fused at an early stage of development: secondly, the angle forms a long backwardly projecting process for the insertion of the internal pterygoid muscle, whereas in the Anthropoidea the angle is much expanded. The lower jaw of *Notharctus* is also more primitive than that of the existing Lemurs in retaining erect canines and incisors.

The upper incisors are of a very primitive compressed type, which could give rise, with slight modifications, to the upper incisors of the existing *Microcebus* of the Lemuridæ, and in another way they resemble the incisors of *Adapis*.

The vertebral column is, on the whole, rather close to that of existing Lemurs, considerably different from that of existing New World Primates and widely different from that of Old World Primates.

For example, the lumbar centra are elongate, with depressed ends, as in Lemurs, while in the Anthropoidea the centra are short and wide and the ends are vertically thicker. Again, the wide parapophyses of the lumbars are similar to those of Lemurs.

The pelvis is decidedly Lemur-like in the lyrate form of the ilia, in the prominence of the process for the rectus femoris muscle, and in the non-expansion of the ischia. The remaining limb bones and the hands and feet are strikingly like those of *Lemur,* the chief differences being that the metapodials and the humerus are decidedly short—a primitive character.

CONCLUSIONS

In conclusion, the type of skeleton which is represented in *Notharctus* appears to be considerably more primitive than that seen in any later Primate; it has been transmitted, with minor changes, chiefly of proportions, to modern Lemurs, while very distinct traces of this skeletal pattern are retained in varying degrees by the Hapalidæ and Cebidæ. From the skeletal pattern of the Old World Primates, however, it is separated by a wide structural hiatus.

II. On the Classification and Phylogeny of the Lemuroidea

On the Basicranial Region of the Lemuroidea

As the characters of the base of the cranium are of great systematic and phylogenetic importance in the Primates, as well as in all other mammals, I may begin by describing in a general way the principal types of auditory bullæ in the Lemuroidea and the principal relations of the internal carotid artery and its branches to the osseous parts of the cranium in that group.

The structure of the auditory bullæ and surrounding parts has been very carefully studied in the recent Primates by Winge, Leche, Forsyth Major, Van Kampen, and others, whose researches afford adequate data for the interpretation of this region in such extinct Primates as *Notharctus*, *Necrolemur*, and *Anaptomorphus*. In the more primitive form of the auditory region the tympanic membrane is stretched on a ringlike tympanic bone or ectotympanic, and this lies well within the bulla, or tympanic chamber, so as to be completely concealed by the ventral wall of the bulla, as seen from below; the bulla itself in all Primates appears to be formed as an expanded shell of the periotic. The mastoid region is sometimes inflated. With minor variations, this relation of the ring-like tympanic to the inclosing bulla is found in all known members of the Lemurinæ, Megaladapinæ, Chirogaleinæ, Indrisinæ, Archæolemurinæ, and Chiromyidæ, all of which are found in Madagascar. This series of lemuroid families and subfamilies will be referred to below as the *Lemuriformes*. The material of *Adapis*, figured by Stehlin (1912), and the American Museum material of *Notharctus* afford proof that in these genera the structure and relations of the auditory bulla and of the ecto-tympanic conformed to the plan seen in *Lemur* and *Propithecus*, and this fact, in conjunction with other evidence, shows that the Notharctinæ and the Adapinæ, together constituting the family Adapidæ, should be referred to the series Lemuriformes.

In the more specialized form of auditory region the ectotympanic bone is not hidden beneath the bulla, but forms its external portion and projects externally in a tubular osseous auricular meatus. The bullæ in these forms are much inflated and extended anterointernally toward the mid-line. This series includes, first, the Oriental *Tarsius* and its extinct Lower Eocene American relatives, *Anaptomorphus*, *Hemiacodon*, and their allies, all referred here to the Tarsiidæ; and, secondly, the Upper European Eocene genera *Necrolemur* and *Microchœrus*, forming the family Microchœridæ. This series will be referred to below as the *Tarsiiformes*.

In the members of the family Lorisidæ, which includes all the existing non-Malagasy lemuroids except *Tarsius,* namely, the Galagos and Pottos of Africa and the Lorises of the Far East, the auditory region agrees with that of the Tarsiiformes in that the ectotympanic lies outside the bulla, of which it forms the outer margin. In the Lorisidæ, however, the ectotympanic does not form a protruding tubular auditory meatus, but merely a circular opening into the bulla; in these forms the mastoid is much inflated and its sinus extends widely into the inflated medial wall of the bulla, a character foreshadowed in *Necrolemur* of the Tarsiiformes. The Lorisidæ in many respects mingle the characters of the true Lemuriformes with those of the Tarsiiformes and are here referred to an intermediate series which may be named Lorisiformes.

The complex relations of the branches of the internal and external carotid arteries to the auditory region and to other parts of the cranium have been explored in the Primates, especially by Tandler (1899), Winge (1895), and Leche (1896), the work of Tandler being the most comprehensive. Van Kampen (1905) has partly applied their results in his work on the tympanic region of mammals. Wortman (1903) attempted to apply this line of investigation to the study of fossil Primates, but as he was equipped with the imperfect data furnished by Huxley and Mivart, rather than with the fuller and more correct results of Tandler, Zuckerkandl, and others, his interpretation of the conditions in recent and fossil Primates is partly erroneous. Stehlin (1912) has made a thorough study of the basicranial region of *Lemur* and *Adapis* with special reference to the course of the internal carotid.

Tandler's researches are especially important as furnishing a rational explanation of the complex and varied arrangements of the carotid arteries and their branches throughout the mammalia. The internal and external carotid arteries are regarded by embryologists as having been derived phylogenetically from the afferent vessels of the branchial arches of lower vertebrates. In mammals some of the minor branches belonging to adjacent arches tend to anastomose with each other, and when this happens, according to Tandler's theory, the terminal branches of the more anterior arches are captured, as it were, by the main trunks of the more posterior arches. In this way some of the minor carotid branches in the orbit, which appear to have been supplied originally by the first visceral arch, are found in certain adult mammals to be supplied by the main vessel of the second visceral arch, which is the stapedial artery. Again, the minor branches of the stapedial artery are often captured by the main trunk of the third visceral arch, which is the external carotid artery, and as a result of this capture the stapedial artery itself is often absent in the adult, although present in the embryo (as in man). According to this theory, the recent Insectivores retain an arrangement of the carotid branches which is more primitive than that which is characteristic of the Lemuriformes, as described below, while these in turn are more primitive than the Tarsiiformes and the higher Primates.

In *Erinaceus*, according to the researches of Hyrtl, Tandler, and others, the internal carotid enters the bulla from the rear, through a foramen that is incompletely separated from the stylomastoid foramen. Inside the bulla the artery divides into two main branches, named the *arteria promentorii* and the *art. stapedia*. The art. promentorii, which is homologous with the internal carotid of man, bends around over the cochlea, or auditory prominence, and, passing forward and inward, pierces the side of the basisphenoid, as in Marsupials, *Centetes* and *Lemur*: entering the cerebral chamber lateral to the sella turcica, it joins the main cerebral artery. The stapedial branch is of large size, and after piercing the stapes runs forward in a groove in the roof of the tympanic cavity, issuing into the temporal fossa through a notch, or foramen, in the tympanic process of the alisphenoid, posteroexternal to the foramen ovale; the carotid notch or foramen transmits an important branch named the "ramus inferior," which runs forward to the orbit and gives rise to several minor branches. The other branch of the stapedial artery ("ramus superior") comes off from the ramus inferior in the anterior part of the tympanic fossa; it passes backward and upward through the petrosal. In *Tupaia*, representing the suborder Menotyphla of the order Insectivora, Hyrtl's figures show that the internal carotid likewise divides into two main branches—the art. promentorii and art. stapedia—which run in bony canals in the tympanic cavity: the ramus inferior is large and issues from the tympanic cavity anteriorly, as in *Erinaceus*.

In all the recent Lemuriformes the internal carotid differs from that of the insectivores chiefly in that the ramus inferior of the stapedial artery is always wanting, and consequently there is no carotid foramen in the tympanic region of the alisphenoid—apparently, according to Tandler's view, because its terminal branches have been captured by the external carotid.

The internal carotid in typical lemurs enters the bulla on its postero-external border medial to and below the stylomastoid foramen.[4] This posterior carotid foramen leads into a short carotid canal, which runs

[4] Doctor Wortman (1903, page 167) errs in locating the carotid foramen of *Lemur* on the postero-internal border of the bulla. The foramen at that point (marked *cc* in his figure 101, page 166), according to Van Kampen (1905, page 658) and other authorities, is a part of the foramen lacerum posterius; it leads directly into the cranial chamber and plainly gives exit to a cranial nerve, probably the eleventh.

over the auditory prominence, or cochlea: the canal divides into two branches for the arteria promentorii and the art. stapedia respectively. The arteria stapedia traverses the stapes and then runs upward through the periotic, this branch being homologous with the ramus superior of Insectivores. The arteria promentorii runs forward in the outer wall of the anterointernal extension of the bulla, pierces the basisphenoid, and emerges into the cerebral chamber lateral to the sella turcica, as in Insectivores.

In *Notharctus,* as shown in an American Museum specimen, and in *Adapis,* as shown in Stehlin's material, the foramina and canals for the arteria promentorii and the art. stapedia were identical in position with those in *Lemur* and *Propithecus* and quite different from those of the Tarsiiformes. In modern Lemuriformes, and very likely in *Notharctus* and *Adapis,* the arteria promentorii was small and the major part of the blood supply of the cerebral arteries was furnished by the vertebral arteries through the ramus communicans posterior. In the Tarsiiformes, on the other hand, as well as in the whole suborder Anthropoidea, the vessel which is supposed to be homologous with the arteria promentorii is enlarged, forming the typical "internal carotid" and furnishing a large part of the blood supply of the cerebral arteries. Tandler's observations and conclusions suggest that the latter condition has been derived from the former.

Another distinction between the Lemuriformes and the Tarsiiformes is that in the former the stapedial artery and its ramus superior are always well developed, while in the latter they are typically reduced or wanting.

These facts and considerations afford further evidence for referring *Notharctus* and *Adapis* to the Lemuriformes rather than to the "Neopithecini" of Wortman (1903, pages 172-174), which is an unnatural assemblage composed of the Adapidæ and all the families of the Anthropoidea.

While the typical Lemuriformes (including the Lemurinæ, the Indrisidæ, and the Chiromyidæ) have the main branch of the internal carotid passing over the cochlea and through the tympanic cavity, a puzzling exception to this rule is furnished by the mouse lemurs and other dwarf lemurs of the subfamily Chirogaleinæ. In these genera the observations of Mivart, Winge, Tandler, and Van Kampen have established the fact that the main branch of the internal carotid does not pass through the tympanic cavity at all, but enters the skull through a pair of large foramina lacera media[5] immediately anterointernal to the

[5] Foramen lacerum anterius of German authors.

bullæ. Van Kampen (1905, page 661), from the observations of Zuckerkandl and Wincza, suggested that this condition is secondary, and my observations on the skull of the Chirogaleinæ also lead me to suspect that this subfamily has been derived from more normal lemurs.

The Lorisidæ (a family which has been referred to above as the Lorisiformes) resemble the Chirogaleinæ in the fact that the main branch of the internal carotid passes through the widely open foramen lacerum medium, but there is also a very small branch that enters the tympanic cavity from the inner side. The observations of Tandler and Winge leave it doubtful whether this small branch represents both the arteria promentorii and the arteria stapedia or only the latter (Van Kampen, 1905, pages 671, 672).

Passing to the Tarsiiformes, the foramina in the basicranial region of *Necrolemur* are shown in three good skulls, belonging respectively to the British Museum, the Princeton University Museum, and the Museum of Comparative Zoölogy of Harvard University, which I have studied with great care. There is a foramen on the inner face of the bulla that appears to be the main posterior carotid foramen. There are no visible foramina in the position of the foramina lacera media of the Nycticebidæ, and if these were present they must have been covered over by the greatly expanded bullæ, this indicating that the carotid pierced the bulla and traversed the tympanic cavity. In front of the greatly inflated bulla and on the outer anterior face of the enwrapped pterygoid wing of the alisphenoid are two foramina which, by comparison with *Tarsius*, appear to be the for. ovale and for. rotundum (respectively for the ramus mandibularis and ramus maxillaris trigemini). Internal to the ala temporalis is the foramen (ostium) tubæ Eustachii. A postglenoid foramen is present. On the whole, in the position of the foramina, especially that for the carotid, *Necrolemur* is nearer to *Tarsius* than to any of the Nycticebidæ.

The famous skull described by Cope as "*Anaptomorphus*" *homunculus*[6] has recently been further developed from the matrix by Mr. A. E. Anderson, under my direction, and thus the interior of the bulla has been revealed. The basicranial region, as a whole, is remarkably similar to that of *Tarsius*, save that the trochlea, or auditory prominence, is much smaller. The bulla was greatly inflated, as in *Tarsius* and *Necrolemur*, and its anterointernal extension likewise completely covered over the region where the foramen lacerum medium is located in the Nycticebidæ. The internal carotid must surely have traversed the tympanic chamber, but its exact course is doubtful. In *Tarsius* it pierces the middle of the

[6] *Tetonius* Matthew.

bulla on the lower surface, then passes directly upward (craniad) through the margin of the septum of the cavum bullæ, passing into the cranial cavity at the apex of the enlarged cochlea (Van Kampen, 1905, page 676). In the only known skull of "*Anaptomorphus*" *homunculus* the whole lower wall of the bulla is broken away, so the place of entry of the carotid into the cavum bullæ is not indicated. To the small cochlea is attached a remnant of a long septum, which may have carried the carotid canal.

The chief conclusions which may provisionally be drawn regarding the course of the main branch of the internal carotid in the Lemuroidea are as follows:

(1) That most of the Lemuriformes retain a primitive lemuroid condition, in that the arteria promentorii, or main branch of the internal carotid, in passing through the bulla, runs forward in a bony tube along the outer side of the cochlea, or auditory prominence, and pierces the basisphenoid. These forms have no "foramen lacerum medium," in the ordinary sense of the term, since the point where the carotid pierces the basisphenoid is concealed from below by the bulla. This condition is characteristic of the Notharctinæ, Adapinæ, Lemurinæ, Indrisinæ, Archæolemurinæ, and *Chiromys*.

(2) In the Chirogaleinæ the main branch of the internal carotid does not pass through the bulla at all, but enters the brain-case in front of the bulla through the large foramen lacerum medium. This condition appears to be a later specialization.

(3) Of the Tarsiiformes, the Upper Eocene *Necrolemur* had no foramen lacerum medium, and the main branch of the internal carotid apparently entered the bulla through a carotid foramen on the inner or medial surface of the bulla. Whether the arteria promentorii ran through a tube over the auditory prominence is not known. In *Tarsius* the carotid foramen is enlarged and shifted to the ventral surface of the bulla, and the carotid canal, or tube, only touches the cochlea at its apex. In "*Anaptomorphus*" the carotid probably pierced the bulla either as in *Necrolemur* or as in *Tarsius*, but its course inside the bulla is doubtful.

(4) In the Lorisiformes (Lorisidæ) the main branch of the internal carotid did not pierce the bulla at all, but entered the brain-case through the widely open foramen lacerum medium, a condition which is probably secondary, as in Chirogaleinæ.

Thus the true Lemuriformes, with the exception of the Chirogaleinæ, are distinguished by retaining an apparently primitive arrangement of the carotid foramina and canals; *Necrolemur* and the *Tarsiidæ*, including "*Anaptomorphus*" *homunculus*, are characterized by a more advanced arrangement leading to that of the higher Primates, while the Chirogaleinæ of the Lemuriformes and the Lorisidæ of the Lorisiformes have independently acquired an aberrant arrangement by which the main branch of the internal carotid avoids the bulla entirely and enters through a foramen lacerum medium.

A CLASSIFICATION OF THE LEMUROIDEA

Order PRIMATES

Suborder LEMUROIDEA

Series LEMURIFORMES

1. Malar touching lacrymal.
2. Orbits widely opening into temporal fossæ.
3. Lacrymal foramen primitively within orbit, often secondarily in front of orbit. Lacrymal often extended in front of orbit.
4. Nasals often retracted, rostrum more or less truncate, rarely (Chirogaleinæ) produced.
5. Auditory bullæ usually of moderate size.
6. Ectotympanic inclosed within bulla, forming a ring or horseshoe.
7. Stapedial branch of internal carotid artery typically large.
8. Main branch of internal carotid typically of small size, running in carotid canal over the cochlea and piercing the basisphenoid. Exceptionally entering in front of bulla (Chirogaleinæ).
9. Placenta diffuse, adeciduous.
10. Digit IV of manus the longest.
11. Digit II of manus sometimes more or less reduced.

Family Adapidæ

Dental formula: $I\frac{2}{2}$, $C\frac{1}{1}$, $P\frac{4}{4}$, $M\frac{3}{3}$.

Medial upper and lower incisors broad-edged and spatulate; medial lower incisors more or less erect (that is, not markedly procumbent).

Lower canines caniniform; lower p_2 not caniniform, not opposing upper canine.

Lacrymal not expanded on face, but lying within the orbit; lacrymal foramen marginal.

Brain-case but little expanded.

Sagittal and lambdoidal crests high.

Fundamental architecture of skull identical in the two subfamilies.

Bullæ and entocarotid foramina essentially as in Lemuridæ.
Trochlea of astragalus narrow.
Metacarpals and metatarsals short.

Subfamily Notharctinæ

Lower and Middle Eocene of North America.
Posterointernal cusp of m^1, m^2, progressively derived from anterointernal cusp: m^1—m^3 acquiring a mesostyle (in *Notharctus* and *Telmalestes*): m_1—m_3 with entoconids progressive.
Genera: *Pelycodus, Notharctus, Telmalestes.*

Subfamily Adapinæ

Chiefly Middle and Upper Eocene of Europe (rare in upper part of Lower Eocene).
Posterointernal cups of m^1, m^2, progressively derived from the cingulum; m^1—m^3 without mesostyle: m_1—m_3 with entoconids retarded, talonids enlarged.
Forehead very narrow.
Angle of mandible much expanded.
Genera: *Protoadapis, Adapis, Leptadapis, ? Pronycticebus.*

Family Lemuridæ

Pleistocene and Recent of Madagascar.
Dental formula: $I\,\frac{2-0}{2},\ C\frac{1}{1},\ P\frac{3}{3},\ M\frac{3}{3}.$
Lower incisors styliform, procumbent; upper incisors reduced or wanting.
Lower canines resembling the incisors.
P_2 more or less caniniform, opposing upper canine.
Lacrymal extended on face; lacrymal foramen in front of orbit.
Brain-case usually expanded.
Sagittal and lambdoidal crest absent or reduced.
Angle of mandible typically slender.
Upper molars more or less tritubercular, rarely with mesostyle.
M_3 with third lobe (hypoconulid).

Subfamily Lemurinæ

Size moderate.
Foramen lacerum medium roofed over.
Posterior nares opening near or behind m^2.
Genera: *Lemur, Lepilemur, Mixocebus.*

Subfamily Chirogaleinæ

Size usually small.

Foramen lacerum medium ("carotid foramen") open (except *Myoxicebus*).

Palate extended to or behind m^3.

Brain-case wide; no sagittal crest.

Genera: *Microcebus, Cheirogale, Altililemur* (*Opolemur*), *Myoxicebus* (*Hapalemur*).

Subfamily Megaladapinæ

Size very large.

Foramen lacerum medium roofed over.

Palate extended behind m^3.

Skull excessively elongate.

Brain-case small, much reduced in width, with sagittal crest.

M^3 large.

Genus: *Megaladapis*.

Family Indrisidæ

Pleistocene and Recent of Madagascar.

Dental formula: $I\frac{2}{1}, C\frac{1}{1}, P\frac{2}{2-3}, M\frac{3}{3}$.

Lower incisors styliform, procumbent; upper incisors usually persistent, sometimes large.

Lower canines resembling the incisors.

Upper canines fairly large.

P_2 compressed opposing upper canine.

Lacrymal less extended on face; lacrymal foramen either just in front of orbit (most Indrisinæ) or marginal (*Palæopropithecus,* Archæolemurinæ).

Brain-case expanded (except *Palæopropithecus*).

Angle of mandible much expanded; symphysis much prolonged and sloping.

Upper molars large, quadritubercular; m^3 small; m_3 with third lobe reduced or absent.

Bullæ typically much expanded and completely inclosing tympanic annulus (except *Palæopropithecus*).

Subfamily Indrisinæ

Medial upper incisors and lower canines small or of moderate size.

Two lower premolars.

Outer cusps of m^1, m^2 often V-shaped.
Skull short to long.
Bullæ normal (except in *Palæopropithecus*).
Genera: *Avahi* (*Lichanotus*), *Mesopropithecus*, *Propithecus*, *Indris*, *Palæopropithecus*.

Subfamily Archæolemurinæ

Medial upper incisors and lower canines enlarged, diprodont, with wide, chisel-like edges, with enamel thicker on anterior face.
Three lower premolars; premolars with laterally compressed bladelike edges.
Molars more or less bilophodont.
Orbits directed forward.
A sagittal crest.
Bullæ normal.
Genera: *Archæolemur* (*Nesopithecus*), *Hadropithecus*.

Family Chiromyidæ (Daubentoniidæ)

Recent of Madagascar.
Dental formula: $I\frac{1}{0}$, $C\frac{0}{1}$, $P\frac{1}{0}$, $M\frac{3}{3}$.
Medial upper incisors and lower canines (?) much enlarged, compressed, diprotodont, with thick enamel on anterior border.
Upper canine, p^{1-3} and p_{1-3} absent, leaving a wide diastema.
Upper molars small; cusps degenerate; surface of crown wrinkled.
M_3 with little or no third lobe.
Lacrymal very little extended on face; lacrymal foramen slightly in front of crista posterior of orbit.
Brain-case expanded; no sagittal crest.
Bullæ and course of internal carotid as in Lemuridæ and Indrisidæ.
Angle of mandible much reduced.
Genera: *Chiromys* (*Daubentonia*).

Series LORISIFORMES

1. Malar more or less separated from lacrymal by maxillary.
2. Orbits enlarged, widely opening into temporal fossæ.
3. Lacrymal foramen in front of orbit.
4. Nasals and premaxillaries more or less produced into a tubular rostrum.
5. Auditory bullæ of moderate to large size.

6. Ectotympanic enlarged, external to bulla, forming its outer wall and sometimes continued externally into a tubular meatus.
7. Stapedial branch of internal carotid reduced.
8. Main branch of internal carotid entering brain-case in front of bulla.
9. Placenta diffuse adeciduous (so far as known).
10. Digit IV of manus usually the longest.
11. Digit II of manus more or less reduced.

Family Lorisidæ Gray

Dental formula: $I\frac{2}{2}$, $C\frac{1}{1}$, $P\frac{3}{3}$, $M\frac{3}{3}$.

Anterior pair of upper incisors more or less separated, of medium to minute size.

Lateral upper incisors placed more or less laterally to median pair.

Upper canines more or less dagger-shaped; much larger than incisors (near anterior end of tooth row).

Lower canines compressed, sharply procumbent, and incisiform.

Pm_2 more or less enlarged and caniniform.

Pm^2 varying in form, often enlarged; Pm^4 bicuspid or tricuspid.

M^1, M^2 tritubercular with cingulum-hypocone; no mesostyle.

Lower molars with paracone reduced or absent.

Mastoids much inflated, broadly continuous with bulla. (Mastoid sinus in wide communication with medial sinus of bulla).

Occiput more or less flattened.

Subfamily Lorisinæ

Recent: Southeastern Asia and West Africa.

Climbing arboreal animals with short calcaneum and navicular, hind legs slender and not much longer than fore legs, short lumbar parapophyses, and short tail. Femur with vestigial third trochanter.

Spines of twelfth and thirteenth dorsal vertebræ directed backward.

Spines of cervical and first dorsal vertebræ elongate.

Skull strongly brachycephalic, with much widened occiput.

Orbits directed forward.

Postorbital process of malar wide.

Zygomata stout; proximal end of zygomatic branch of squamosal continuous with external auditory meatus.

Posterior nares usually behind m_3.

Pm^4 small, bicuspid, with one external cusp; hypocone reduced or absent.

Genera: *Perodicticus, Artocebus, Nycticebus, Loris.*

Subfamily Galaginæ

Recent: Africa.

Leaping arboreal animals with elongate calcaneum and navicular, long and stout hind legs, elongate lumbar parapophyses, and long tail. Femur with small third trochanter.

Spines of twelfth and thirteenth dorsal vertebræ directed forward.

Spines of cervical and first dorsal vertebræ short.

Skull mesocephalic.

Orbits directed more outward.

Postorbital process of malar slender.

Zygomata slender; proximal end of zygomatic branch of squamosal wholly in front of external auditory meatus.

Posterior nares usually behind m^2.

Pm^4 submolariform or tricuspid, with two external cusps; hypocone present.

Genera: *Galago*, *Hemigalago*.

Series TARSIIFORMES

1. Malar widely separated from lacrymal by maxillary.
2. Orbits more or less partitioned off from temporal fossæ.
3. Lacrymal foramen in front of orbit.
4. Rostrum very narrow.
5. Auditory bullæ of very large size, much extended anterointernally.
6. Ectotympanic enlarged, external to bulla, forming its outer wall and continued externally into a tubular meatus.
7. Stapedial branch of internal carotid reduced or wanting.
8. Main branch of internal carotid traversing bulla from below.
9. Placenta discoidal, deciduous (Tarsiidæ).
10. Digit III of manus the longest.
11. Digit II of manus not reduced (*Tarsius*).

Family Microchœridæ (Lydekker)

Upper Eocene (? Lower Oligocene) Europe.

Dental formula: $I\frac{2}{1(?)}, C\frac{1}{1(?)}, P\frac{3}{3(4)}, M\frac{3}{3}$.

Anterior pair of upper incisors well separated, of medium size.

Lateral upper incisors directly behind median pair.

Lower incisors vestigial or absent.

Upper canines varying in size; wholly posterior to incisors.

Lower canines more (*Microchærus*) or less (*Necrolemur*) enlarged.

Pm_2 small.

Pm^4 bi- or tricuspid, with high external cusp, two internal cusps, and heavy internal cingulum.

M^1, M^2 quadrilateral with four main cusps, large proto- and metaconules, and an accessory conule between the protocone and the metaconule; mesostyle present or absent.

M^3 much smaller than m^2, with oblique ectoloph.

Lower molars m_2, m_3 with paraconid absent.

Mastoids much inflated; mastoid inflation demarcated from bulla by a constriction. (Mastoid sinus perhaps less widely opening into bulla.)

Genera: *Microchærus*, *Necrolemur*.

Family Tarsiidæ

Lower, Middle, and Upper Eocene, North America; Recent, East Indies.

Dental formula: $I\frac{2}{2-0(?)}$, $C\frac{1}{1}$, $P\frac{3-2}{3-2}$, $M\frac{3}{3}$.

Anterior pair of upper incisors in contact, enlarged, with vertically extended crowns (*Tarsius*).

Lateral upper incisors minute, posteroexternal to median pair.

Lower incisors, varying in size, with crowns more erect than in Lorisidæ; one or both pairs sometimes wanting.[7]

Upper canines varying in size, wholly posterior to incisors.

Lower canines sometimes enlarged, vertical or semi-procumbent.

Pm_2 small or absent; pm_4 bicuspid.

Pm^2 minute to absent; pm^3, pm^4 bicuspid.

M^1, M^2 tritubercular, with small proto- and metaconules; mesostyle rarely present; hypocone small to absent.

M^3 tritubercular.

Lower molars tuberculo-sectorial, with small, high trigonid and low talonid. Paraconid present typically well developed.

Mastoids not or but little inflated; occiput well rounded.

Placenta discoidal, deciduous (*Tarsius*).

Genera: *Tetonius*, *Shoshonius*, *Anaptomorphus*, Lower Eocene; *Omomys*, *Hemiacodon*, *Washakius*, Middle Eocene; *Uintanius*, Upper Eocene; *Tarsius*, Recent.

---

[7] In certain Lower Eocene forms recently described by Doctor Matthew, op. cit.

PHYLOGENETIC SUMMARY

Nearly all known genera of recent and fossil lemuroids have been studied by the writer with special reference to the basicranial region, dentition, and limbs. It is proposed to divide the suborder Lemuroidea into three major groups or series—the Lemuriformes, the Lorisiformes, and the Tarsiiformes.

Of the Lemuriformes, by far the most primitive is the subfamily Notharctinæ of the family Adapidæ. This subfamily first appears as small insectivorous forms of the genus *Pelycodus* in the Lower Eocene of North America. These have the primitive dental formula of $I\frac{2}{2}, C\frac{1}{1}, P\frac{4}{4}, M\frac{3}{3}$ and simple trituberculer molars. The next stage, *Notharctus*, with quadritubercular molar teeth, is well known in the skull and most parts of the skeleton. The subfamily terminates in the relatively large and progressive genus *Telmalestes* of the Upper Bridger formation. Except for certain details of the molars, the Notharctinæ appear to be structurally ancestral to all the higher Lemuriformes.

In Europe the true Adapinæ are said to appear in the upper levels of the Lower Eocene, but are more abundant in the Middle and Upper Eocene. The Adapinæ are closely related to the earliest Notharctinæ, but follow a different trend of evolution of the molars. The best known genus, *Adapis*, is evidently a specialized side branch; but *Pronycticebus* Grandidier, which, in the writer's judgment, should be referred to the Adapinæ, has the expected characters of the basicranium, dentition, and general skull characters for an ancestor of the lemurs of Madagascar.

The latter constitute all the existing branches of the Lemuriformes and include three families—the Lemuridæ, the Indrisidæ, and the Chiromyidæ. These three families seem to have sprung from a common stock which entered Madagascar perhaps in Oligocene times. The earliest true lemurs probably had a fairly short face and large orbits, a wide basicranium and expanded bullæ; the upper molars may have been like those of *Pronycticebus*, namely, tritubercular, with a prominent cingulum-hypocone; the lower incisors and canines were partly procumbent, pm^1 and pm_1 were small or absent, the jaw was fairly short and deep with a large angle. *Cheirogaleus* of the mouse lemurs has retained most of these primitive characters.

The varied descendants of this relatively high type exhibit diverse combinations of retrogressive and progressive changes.

In *Megaladapis*, for example, there was an extremely rapid increase in size of body and in the length both of the face and of the brain-case, with a relative reduction in size of the orbits and of the volume of the brain: in *Microcebus*, on the contrary, there may have been a dwarfing of body size, a great widening of the brain, a reduction of the face, and an enlargement of the orbits. In many lines the lower jaw grew long and weak, the angle slender: the lower incisors and canines became small, procumbent and compressed: the muzzle was often widened: the upper incisors were reduced: the opposite tooth rows straightened. The molars were diversely modified, some becoming blunt-cusped with low, round cingulum, others becoming sharp-cusped with cuspidate cingulum. The limbs and extremities, which were primitively short, as in *Lepilemur*, either grew long and slender, as in *Microcebus*, which has the tarsus variously elongate, or stout and relatively short, as in the hind limb of *Megaladapis*. The writer is convinced that changes in the direction of evolution involving reversal of proportions, such as large orbits changing into small orbits, expanded bullæ becoming deflated, and the like, have been frequent in the history of the Lemuroidea.

The Indrisine lemurs, or Indrisidæ, constitute a very well marked Malagasy group which may have been derived from a form like *Pronycticebus* of the Adapinæ by the expansion of the orbits and brain-case, very marked shortening of the face, great deepening of the lower jaw and its angle, and crowding out of two premolars above and below on each side, namely, pm^1, pm^2 and pm_1, pm_2; at the same time the upper molars became elongate anteroposteriorly and the cingulum grew up into a large hypocone in adaptation to leaf- and fruit-eating habits. The basicranium, including the bullæ and the course of the internal carotid artery, were fundamentally similar to those of the Adapidæ and Lemuridæ, and the same is true of the backbone, limbs, placentation, and brain. This primitively central and relatively high type is most nearly realized in the existing genus *Avahis*, which has, however, further expanded the brain and orbits. A retrogressive series leading in a general way through *Mesopropithecus* and *Indris* ends in the highly aberrant and misnamed *Palæpropithecus*—a gross and swinelike animal, with a thick muzzle, small eyes, deflated bullæ, and a low brain-case. About the only feature in which *Palæpropithecus* is not degraded is the extreme depth of its lower jaw, in which it surpasses all the other Indrisinæ.

In the opposite direction a progressive series, in which only the terminal members are known, has led from the primitive Indrisine to the apelike *Nesopithecus* (*Archæolemur*) and the still more advanced *Hadropithecus*. These forms, by reason of their large brain-case, forwardly directed orbits, and macaque-like molar teeth, have given rise to the preposterous hypothesis that they indicate a special affinity between the

Indrisidæ and the Anthropoidea; but in all their palæotelic characters, especially of the basicranium, the Archæolemurinæ are truly Indrisine, as Elliot Smith has also observed in their brains.

From some early member of the Archæolemurinæ sprang the aberrant *Chiromys* (*Daubentonia*). This genus exhibits a rodent-like modification of the Indrisine type. Its lower front teeth are probably not incisors, but procumbent canines. Its grub-eating habits are reflected in the degenerate character of the cheek teeth.

The second grand division of the Lemuroidea, as here classified, is named the Lorisiformes, comprising the existing Lorisinæ of Asia and Africa and the Galaginæ of Africa. The members of the Lorisiformes combine the characters of the Lemuriformes and of the Tarsiiformes in a manner suggesting extensive parallelism with these groups. All the Lorisiformes resemble the Lemuriformes in the lemur-like modification of the incisors and canines. All show special resemblances with the mouse lemurs in the manner in which the internal carotid artery enters the brain-case, and some further parallel the mouse lemurs in the lengthening of the tarsus. *Nycticebus* of the Lorisiformes is known to have the placenta diffuse and adeciduous as in true Lemurs. On the other hand, the Lorisiformes parallel the Tarsiiformes in the fact that the ectotympanic, or tympanic annulus, instead of being completely covered over by the bulla, as in the Lemuriformes, forms its outer margin, as in the Tarsiiformes. The Galagos further parallel *Necrolemur* of the Tarsiiformes in the form of the occiput and in the expansion of the mastoid region. The correct phylogenetic evaluation of these conflicting resemblances to the Lemuriform and Tarsiiform groups is still doubtful, but I incline to the opinion that the Lorisiformes are, on the whole, more nearly allied to the Lemuriformes: that they may have come off from some such an Adapid as *Pronycticebus*, as suggested by Grandidier, and that the lengthening of the tarsus, exposure of the ectotympanic, and inflation of the mastoid has occurred independently in the Lorisiformes and Tarsiiformes.

Tarsiiformes.—The third and last great group of the Lemuroidea includes not only the existing *Tarsius*, but also the American Lower, Middle, and Upper Eocene "Anaptomorphidæ" and the European Upper Eocene *Microchœrus* and *Necrolemur*.

Even in the Lower Eocene of North America there were genera with large orbits, very narrow muzzle, and wide, round brain-case, which appear extremely modernized for such ancient types. The skull structure of these Anaptomorphidæ is best known from a famous specimen named by Cope *Anaptomorphus homunculus*. Further development of the basicranial region of this specimen has served to emphasize its resemblance to *Tarsius*, especially in the formation of the bulla and in the pattern of the cheek teeth. It is, however, far more primitive than *Tarsius* in having a much smaller cochlea, or auditory prominence, a less expanded brain-case, and smaller orbits. Its Middle Eocene relative *Omomys* is extremely like *Tarsius* in the cheek teeth, as noted by Wortman, and, in the opinion of Doctor Matthew and the writer, it is so difficult to separate the Anaptomorphidæ and the Tarsiidæ as distinct families that we prefer to unite them in a single family—Tarsiidæ.

The Lower Eocene members of the Tarsiiformes were thus rather widely different from the contemporary Lemuriformes of the family Notharctinæ. From the characters of the jaw and dentition in the earliest Notharctinæ it seems right to infer that the general architecture of the skull was not dissimilar to that of *Notharctus*. This differs widely from "*Anaptomorphus*" in having a relatively narrow, unexpanded brain-case, a far larger face, and smaller orbits. These features may have been less pronounced in the earlier Notharctinæ, while the opposite Tarsiiform characters may have been less pronounced in some of the other Lower Eocene genera of the *Anaptomorphus* group; but still the contrast between the representatives of the Lemuriformes and Tarsiiformes must have been sufficiently great in the Lower Eocene to warrant us in looking for the common stem form of the Lemuroidea in the Paleocene or even earlier.

Microchœridæ.—A study of several excellently preserved skulls of *Necrolemur* shows that the basicranium closely resembles that of Tarsius in many respects, especially the mode of formation of the bullæ, character of the glenoid, position of the cranial and carotid foramina; so that, in view of further evidence offered by the facial region and dentition, reference of *Necrolemur* to the Tarsiiformes seems well warranted. On the other hand, *Necrolemur* has more complex sexitubercular upper molars than any of the *Anaptomorphus-Tarsius* group, and its nearest affinities are undoubtedly with *Microchœrus*, as suggested by Forster Cooper; but neither of these genera have anything to do with the Hyopsodontidæ, with which earlier authors placed *Microchœrus*.

The relationships of the Tarsiiform series on the one hand to the Microsyopsidæ and on the other to the Anthropoidea seem at present highly doubtful.

Bibliography

C. Forster Cooper: *Microchœrus erinaceus* (Wood). Annals and Magazine of Natural History (8), Volume VI, 1910, pages 39–43, Plate III.

E. D. Cope: On a new vertebrate genus from the northern part of the Tertiary Basin of Green River. Proceedings of the American Philosophical Society, Volume XII, 1872, page 554. [*Anaptomorphus æmulus.*]

———: Third account of new vertebrata from the Bridger Eocene of Wyoming Territory. Proceedings of the American Philosophical Society, Volume XII, pages 469–472. (Palæontological Bulletin, Number 3, August 7, 1872.) [*Tomitherium rostratum.*]

———: On the extinct vertebrata of the Eocene of Wyoming, observed by the expedition of 1872, with notes on the geology. U. S. Geological Survey of the Territories for 1872, 6th Annual Report (Hayden), pages 545–649. [Tomitherium.]

———: Systematic catalogue of vertebrata of the Eocene of New Mexico, collected in 1874. Report to the Engineer Department. Department of the U. S. Army (Wheeler), 1875, pages 5–37. [Pelycodus, page 13.]

———: On some supposed Lemurine forms of the Eocene Period. Proceedings of the Academy of Natural Sciences of Philadelphia, 1876, pages 88–89. [Mesodonta proposed.]

———: The vertebrata of the Tertiary formations of the West. Book I. Report of the U. S. Geological Survey of the Territories (Hayden), Volume III, 1884. [Tomitherium, Pelycodus, Anaptomorphus.]

———: The Lemuroidea and the Insectivora of the Eocene Period of North America. American Naturalist, Volume XIX, 1885, pages 457–471.

D. J. Cunningham: Text-book of Anatomy. 1902. [Myology, carotid artery, etc.]

Georges Cuvier et M. Laurillard: Anatomie Comparée Recueil de Planches de Myologie. 1849.

A. H. G. Doran: Morphology of the mammalian *Ossicula auditus*. Transactions of the Linnæan Society (2), Volume I, Zoology, 1879, pages 371–497, plates 58–64.

C. Earle: On the affinities of Tarsius; a contribution to the phylogeny of the Primates. American Naturalist, Volume XXXI, pages 569–575, July, 1897; pages 680–689, August, 1897. [Phylogenetic evaluation of characters of the placentation in Lemurs and Tarsius.]

A. Milne Edwards and A. Grandidier: Histoire naturelle des Mammifères in: Histoire Physique Naturelle et Politique de Madagascar, Volume VI, 1875. [386 pages and 122 plates on anatomy, etc., of Indrisidae.]

D. G. Elliot: A review of the Primates. Monographs of the American Museum of Natural History, Volumes I–III, 1912.

H. Filhol: Recherches sur les Phosphorites du Quercy, Étude des Fossiles Qu'on y Rencontre et Spécialement des Mammifères. 1877. See also Ann. d. sci. geol., tome vii, 1876, pages 1–220; tome viii, 1877, pages 1–340; article 1, pages 1–561.

G. GRANDIDIER: Recherces sur les Lémuriens Disparus et en particulier sur ceux qui vivaient à Madagascar. Extrait des Nouvelles Archives du Muséum. 4e series, Tome VII, 1905, pages 1–142.

W. K. GREGORY: The orders of mammals. Bulletin of the American Museum of Natural History, Volume XXVII, 1910, pages 269–292, 321–322. [Relationships of Tupaiidæ to Primates.]

———: Relationship of the Tupaiidæ and of Eocene Lemurs, especially Notharctus. Proceedings of the Geological Society of America, Volume XXIV, 1913, pages 247–252.

———: Exhibition of a fossil skeleton of *Notharctus rostratus*, an American Eocene Lemur, with remarks on the phylogeny of the Primates. Report of the British Association for the Advancement of Science, 1913, pages 529–530. [Classification of the Primates.]

A. A. W. HUBRECHT: Descent of the Primates. 1897.

J. HYRTL: Vergleichend-anatomische Untersuchungen über das innere Gehörorgan des Menschen und der Säugethiere. Prag, 1845.

KEIBEL and MALL: Human Embryology, Volume II, 1912. [Development of carotid artery.]

WILLIAM LECHE: Untersuchungen ueber das Zahnsystem lebender und fossiler Halbaffen. Separat-Abdruck aus: Festschrift für Carl Gegenbaur, 1896, ss. 127–166.

J. LEIDY: [Descriptions of *Palæosyops paludosus*, *Microsus cuspidatus*, and *Notharctus tenebrosus*.] Proceedings of the Academy of Natural Sciences of Philadelphia, pages 113–114. October, 1870.

R. LYDEKKER: Catalogue of the fossil Mammalia in the British Museum (Natural History), Part V. 8vo. 1887. [Family Microchœridæ established for the reception of *Microchœrus erinaceus*, regarded as "apparently allied to the Erinaceidæ."]

MAJOR C. I. FORSYTH: Über die Malagassischen Lemuriden-Gattungen Microcebus Opolemur und Chirogale. Novitates Zoologicæ, Volume I, number 1, ss. 2–39, taf. I, II. January, 1894.

———: On Lemur mongoz and Lemur rubiventer. Proceedings of the Zoological Society, pages 248–268. March 19, 1901.

———: On some characters of the skull in the Lemurs and Monkeys. Proceedings of the Zoological Society of London, Volume I, number ix, 1901, pages 129–153, Plates XI–XIII.

O. C. MARSH: Notice of some new fossil mammals from the Tertiary formation. American Journal of Science (3), Volume II, 1871, pages 35–44. [*Limnotherium tyrannus*, page 43.]

———: Discovery of fossil Quadrumana in the Eocene of Wyoming. American Journal of Science (3), Volume IV, pages 405–406. October 8, 1872. [Limnotherium referred to Quadrumana.]

———: Notice of new Tertiary mammals. IV. American Journal of Science (3), Volume IX, 1875, pages 239–250. [Limnotheridæ proposed, page 239.]

W. D. MATTHEW and WALTER GRANGER: A revision of the Lower Eocene Wasatch and Wind River faunas. Part II. Order Condylarthra, Family

Hyopsodontidæ. By W. D. Matthew. Bulletin of the American Museum of Natural History, Volume XXXIV, pages 311–328. May 29, 1915. Part III. Entelonychia, Primates. By W. D. Matthew. Ibid., Volume XXXIV, pages 429–483. September, 1915.

W. D. Matthew: Climate and evolution. Annals of the New York Academy of Sciences, Volume XXIV, 1915, pages 171–318. [Primates, page 214.]

St. G. Mivart: Notes on the crania and dentition of the Lemuridæ. Proceedings of the Zoological Society of London, 1864, pages 611–648.

———: Contributions towards a more complete knowledge of the axial skeleton in the Primates. Proceedings of the Zoological Society, 1865, pages 545–592.

———: Additional notes on the osteology of the Lemuridæ. Proceedings of the Zoological Society, pages 960–975. December 12, 1867. [*Cheirogaleus furcifer*, skull, tarsus.]

———: On Lepilemur and Cheirogaleus, and on the zoological rank of the Lemuroidea. Proceedings of the Zoological Society, 1873, pages 484–510.

H. F. Osborn: American Eocene Primates and the supposed rodent family Mixodectidæ. Bulletin of the American Museum of Natural History, Volume XVI, article xvii, 1902, pages 169–214.

Max Schlosser: Die Affen, Lemuren, Chiropteren, Insectivoren, Marsupialier, Creodonten und Carnivoren des Europäischen Tertiärs, und deren Beziehungen zu ihren lebenden und fossilien aussereuropäischen Verwandten. Theil—II. Beiträge Palæont. Oesterreich-Ungarns und des Orients (Mojsisovics und Neumayr), VII Bd., 1888, ss. 1–162.

———: Beitrag zur Osteologie und systematischen Stellung der Gattung Necrolemur, sowie zur Stammesgeschichte der Primaten überhaupt. Neues Jahrbuch für Mineralogie, Geologie und Paläontologie. Festband (ss. 197–226), 1907.

———: 5. Klasse Mammalia Säugetiere. Grundzüge der Paläontologie . . . von Karl A. von Zittel. Neu bearbeitet von F. Broili, E. Koken, M. Schlosser. II Abt. Vertebrata. 1911. [Primates, pages 544–562.]

G. Elliot Smith: On the form of the brain in the extinct Lemurs of Madagascar, with some remarks on the affinities of the Indrisinæ. Transactions of the Zoological Society of London, Volume XVIII, Part II, Number 1, 1908, pages 163–177.

Herbert F. Standing: On recently discovered subfossil Primates from Madagascar. Transactions of the Zoological Society of London, Volume XVIII, Part II, Number I, 1908, pages 59–162.

H. G. Stehlin: Die Säugetiere des schweizerischen Eocaens., VII Teil, erst Hälfte Adapis. Abhandl. d. schweiz. palæont. Gesellsch., Volume XXXVIII, 1912, pages 1165–1298.

J. Tandler: Zur vergleichenden Anatomie der Kopfarterien bei den Mammalia. Denkschr. kais. Akad. der Wiss., Math.-nat. Cl., LXVII, Wien. 1899.

———: Zur vergleichenden Anatomie der Kopfarterien bei den Mammalia. Anat. Hefte, herausg. von Merkel und Bonnet, II. 59. 1901.

J. Tandler: Zur Entwicklungsgeschichte der Kopfarterien bei den Mammalia. Morph. Jahrb., XXX, H. 1 u. 2. 1902.

P. N. van Kampen: Die Tympanalgegend des Saugetierschädels. Morphol. Jahrb. Bd. XXXIV, Heft 3 u. 4, ss. 321-722. 1905.

H. Winge: Jordfundne og nulevende Aber (Premates) fra Lagoa Santa, Minas Geraes, Brasilien. E. Museo Lundii. Kjobenhavn. 1895.

J. L. Wortman: Studies of Eocene mammalia in the Marsh collection. Peabody Museum. Part II. Primates. American Journal of Science, Volumes XV–XVII, 1903–1904.

E. Zuckerkandl: Zur Anatomie von Chiromys madagascariensis. Denkschr. kais. Akad. Wiss., Math.-nat. Cl., LXVIII, Wien, 1899, pages 89–200, plates 1–10.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 447-476, PLS. 25-27 DECEMBER 4, 1915

PROBLEM OF THE TEXAS TERTIARY SANDS [1]

BY E. T. DUMBLE

(Read before the Society August 5, 1915)

CONTENTS

INTRODUCTION

In connection with the Gulf Tertiary deposits, which stretch entirely across the Coastal Plain of Texas, there is a narrow belt within which the outcrops of several distinct sandy formations are exposed. The shoreward margin of this belt averages about 100 miles from the present Gulf coast. The belt is sometimes less than 10 miles in width, very rarely widens to more than 20 miles, and reaches its broadest exposures of about 40 miles only on the Nueces and Rio Grande.

There are five of these sands. They are very similar in composition and appearance, fossils are comparatively rare in them, and it is often difficult to distinguish the one from the other, especially where the sands of one division overlap and are in direct contact with another.

These sands, in descending order, are:

[1] Manuscript received by the Secretary of the Society October 13, 1915.

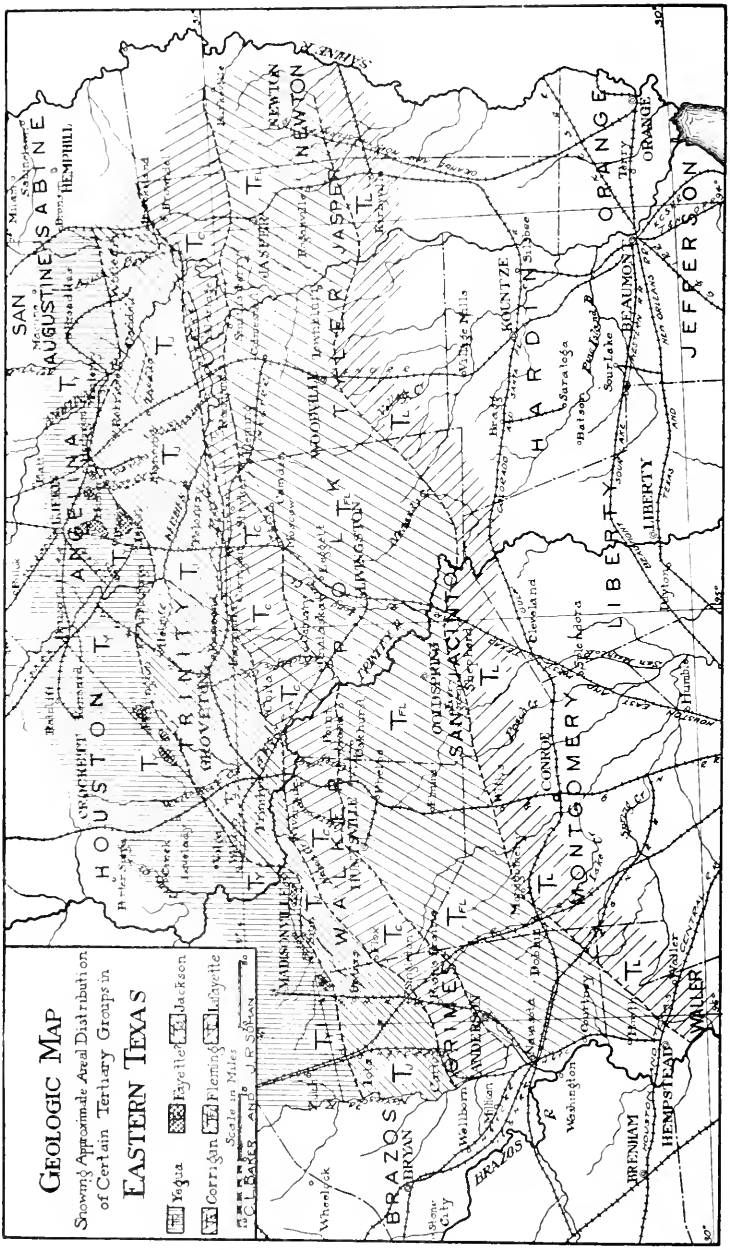


FIGURE 1.—Geologic Map of eastern Texas

Lapara (Dumble),[2] carrying in the Nueces section vertebrates determined by Cope to be of Blanco Pliocene age.

Oakville (Dumble),[3] with vertebrate fossils determined by Cope to be of Loup Fork Miocene age. Plant remains unstudied.

Catahoula (Veatch),[4] continuation of beds in Louisiana and carrying plant remains. Oligocene.

Wellborn (Kennedy),[5] with marine invertebrates which Harris referred to the Lower Claiborne, and were, therefore, correlated by Kennedy with the Fayette, but which Vaughan[6] now considers Lower Jackson. Middle or Upper Eocene.

Fayette (Dumble)[7], with marine invertebrates determined by Harris and referred to Lower Claiborne. Plant remains unstudied. Middle Eocene.

So far as known, there is no place within the belt where all of these sands are present, unless it be on the Colorado River.

On the Rio Grande the Fayette is overlain by the Frio, and this by the Oakville. There is no evidence of the Catahoula.

On the Sabine, while the Oakville may be present as such above the Catahoula, no evidence has yet been found of either the Wellborn or Fayette beneath it.

In the region between, other conditions prevail, and this has led to such confusion that it seems best to bring together what has been done in order to clear away, as far as possible, the misunderstandings that have arisen and open the road for the final solution of the problem.

Review of previous Work

Hilgard,[8] who made a geological reconnaissance of Louisiana in 1869, visited some localities in east Texas, where he found the extension of his Grand Gulf beds. These he described and referred to that age.

Loughridge[9] reports that this belt of sandstone, beginning on the Sabine, in the lower part of Sabine County, outcrops on the Trinity near Trinity station, near Chapel Hill and Burton, at La Grange Bluff, at Hellgate Ferry near Cuero, and then forms a line of hills, via Oakville, southwestward through Duval County to the Rio Grande at Rio Grande

[2] Journal of Geology, Sept., 1894, p. 559.
[3] Journal of Geology, Sept., 1894, p. 556.
[4] U. S. Geological Survey Prof. Paper 46, p. 42.
[5] Fourth Ann. Rept. Geol. Surv. Texas, p. 45.
[6] U. S. Geological Survey Water-supply Paper No. 335, p. 72.
[7] Journal of Geology, Sept., 1894, p. 552.
[8] Am. Jour. Sci., 2d ser., vol. 48, 1869, pp. 337-338.
[9] Cotton Production, Tenth Census, p. 21.

City. He describes the rock as coarse-grained or conglomerate, with white siliceous clay as a cementing material. He notes the lack of fossils and states that it has been referred to the Grand Gulf, of probably Miocene age, for stratigraphic reasons.

Outside of the Sabine, Trinity River, and Burton outcrops, all of the localities mentioned by Loughridge are occupied by exposures of the Oakville or Lapara sands of the present classification.

Penrose,[10] who studied these sands by boat trips down the Colorado, Brazos, and Rio Grande, used the name Fayette to designate the entire series of deposits lying "between the uppermost fossiliferous strata of the marine Tertiary and the post-Tertiary." In this he followed the example of Hilgard, and he, furthermore, correlated his Fayette with the Grand Gulf of that author. The Fayette of Penrose did not include the Orange sand or Reynosa (Lafayette).

On the Colorado, which was first traversed by Penrose and made the basis and type of this division, his Fayette begins near the county line between Bastrop and Fayette counties, where the last fossiliferous beds were found in White Marl Bluff. Its base consists of dark clays with lignites, as seen on Barton Creek, followed by light-colored, sulphur-coated clays and sands, forming bluffs on the river and becoming more clayey toward the top, and his description closes with the bluff of somewhat similar materials south of La Grange.

On the Brazos, similarly, the Fayette beds, as described by Penrose, begin below Mosely Ferry, where the last Eocene fossils were found, and have at the base gray sands and chocolate clays with lignite beds, followed by light-colored sands and clays to the Houston and Texas Central crossing near Hempstead.

Carrying out the same basis of division, the description of the Fayette of the Rio Grande begins with the clays overlying the last fossil-bearing beds of the Eocene near Roma, and includes the sands at the base of the section near Reynosa. Doctor Penrose, however, recognized the close resemblance of the light-colored clays and sands, with *Ostrea alabamiensis* var. *contracta* (*O. georgiana ?* of Penrose report), occurring north of Roma, to those of the Fayette section.[11]

A year or two later it was found that the body of dark-colored clays with lignite, which formed the base of the Fayette division of Penrose, carried a marine invertebrate fauna in their exposures in branches of the Yegua. As these fossils proved to be of Lower Claiborne age, these clays

---

[10] First Ann. Rept. Geol. Surv. Texas, p. 17 et seq.

[11] First Ann. Rept. Geol. Surv. Texas, p. 56. These are included in the Fayette beds of our present classification. Geol. S. W. Texas. Trans. A. I. M. E., vol. 33, p. 969.

were separated from his Fayette and added to his Marine beds under the name of Yegua clays.[12]

During 1892-1893 Harris studied the great mass of Tertiary invertebrate material that had been collected by various members of the Texas Survey and prepared a report on it[13] that would have been of greatest value to all workers in Tertiary geology. Unfortunately a wave of economy struck the State administration about that time, and, together with the other papers which were to make up the Fifth Annual Report, its publication was held up. Fortunately he had made a very complete catalogue of species and localities, and this is preserved at the University of Texas.

The collections made by Penrose and Dumble from the Fayette sands, exposed on the Rio Grande between Zapata (Carrizo) and the northern line of Starr County, were studied and the following forms determined:[14]

Ostrea alabamiensis var. *contracta* Con.
Anomia ephippioides Gabb
Pecten sp. a
Leda opulenta
Venericardia planicosta Lam.
Crassatella protexta
Cytherea sp. a
Cytherea bastropensis Har.
Tellina sp.
Tellina mooreana
Semele linosa
Volutilithes sp.
Volutilithes petrosa
Pseudoliva vetusta
Pseudoliva vetusta var. *pica*
Pseudoliva vetusta var. *fusiformis*
Levifusus trabeatoides
Cornulina armigera
Turritella nasuta
Turritella nasuta var. *houstonia*
Natica sp. b
Natica sp. c
Natica recurva var. *dumblei*
Lacinea alveata
Conus sauridens

No fossils except oysters were found in the upper portion of the section lying between the Starr County line and Roma, and it was in this stretch that all of the larger oysters were found. The lower beds, between Zapata and the Starr County line, which furnished all the other species of fossils, carried only medium-sized oysters, although they were identified as belonging to same species.

The abundance of invertebrate fossils in this region is in striking contrast to the conditions on the Colorado, where only plant remains have been observed.

The section on the Nueces River showed the Fayette sands overlying the Yegua clays and overlain by a body of dark-colored calcareous clays, which were called the Frio clays.

---

[12] Brown: Coal and lignite, p. 148.
[13] Harris: Manuscript record of Tertiary fossils.
[14] Harris: Manuscript record of Tertiary fossils.

Dumble's collections from the sands in the Nueces River section, embracing five localities near Lipan Creek, below Campbellton, yielded:

Ostrea alabamiensis var. *contracta*	*Corbula aldrichi*
Modiola texana	*Corbula* sp. a
Venericardia planicosta	*Hialella* sp.
Cytherea bastropensis	*Turritella nasuta*
Cytherea sp. a	*Pseudoliva vetusta*
Tellina scandula	*Cornulina armigera*
Mactra sp.	*Terebra houstonia*
Corbula alabamiensis	*Levifusus trabeatoides*

Harris, on the basis of these collections, referred these sands to the Lower Claiborne.

The Frio furnished very few fossils, and those gave no hint of any later age than that of the Lower Claiborne.

Overlying these Frio clays was an extensive body of sandstones, to which the name Oakville[15] was given. On tracing, these appeared to be the same sands that occur at Rio Grande City and in La Grange Bluff. Vertebrate fossils found at various places determined their age as Loup Fork Miocene.

Overlying the Miocene Oakville sands on the Nueces we found another series of similar sands with vertebrate fossils. These were determined by Cope as Pliocene and as of the same horizon as the Blanco beds of the Staked Plains region. These were called Lapara. These were followed by greenish gray clays which carried Pliocene fossils, but were later than the Lapara. These were called the Lagarto.

The name Fayette sands was then restricted to those sands and clays of the original typical sections, which, with their light colors, sulphur coatings, quartzite bands, petrified and opalized wood, were most prominent in the earlier descriptions of Penrose and which had become most closely associated with this name in the minds of those working on the Texas Survey.

We have, therefore, in southwest Texas three sands which, while similar in character, are clearly differentiated by their fossils as Eocene, Miocene, and Pliocene in age.

Where we find the Oakville sands overlapping and resting upon the Fayette, or find the Lapara in direct contact with the Oakville, as is often the case, it is sometimes difficult, because of their similarity, to separate them, unless fossils are present, and such conditions may interfere with their being accurately mapped as separate formations.

The typical sands at Grand Gulf, to which Wailes' name of Grand Gulf

[15] Journal of Geology, 1894, p. 552 et seq.

sands is now restricted (just as we have restricted the name Fayette sands to those of the typical Colorado and Rio Grande sections), are of Oligocene age, and therefore are not represented by either the Fayette, the Oakville, or the Lapara sands. It is true that there are points of resemblance in these sands to those of the Grand Gulf, especially in the quartzitic beds and the opaline cement, besides which the Fayette, in places, carries some plant remains.

In the Nueces section the Oakville includes a body of brown sands at its base in which no fossils were found, and it was recognized that further study might necessitate a separation of this from the upper fossiliferous beds;[16] but, so far as is now known, there is nothing to indicate its connection with the Grand Gulf or Catahoula or to remove it from the Miocene.

The physical conditions on the Rio Grande and Nueces appear to extend eastward to the San Antonio River. East of that stream the Frio gradually becomes thinner, and is almost, if not entirely, lacking on the Colorado. Both the Fayette and Oakville show a greater admixture of clay, and the invertebrate fossils so abundant on the Rio Grande seem entirely wanting and are replaced by fossil plants.

East of the Colorado the difference is even more marked.

In 1891 a few imperfect casts of fossils were found at what was supposed to be the base of the Fayette sands,[17] near Sunnyside, in Lee County. Later better specimens were found, and Harris determined them as follows:

Ceronia singleyi — *Pleurotoma moorei* var. g

Paphia

Kennedy, in his East Texas sections,[18] describes the sands in the vicinity of Corrigan and Rockland. In a railroad cut 4 miles north of Corrigan he collected the following forms from the base of these sands:[19]

Dentalium microstriatum var. *dumblei*

Venericardia planicosta

Cytherea texacola var. *tornadonis*

Corbula alabamiensis

Calyptraphorus velatus

Pleurotoma quassalis

Turbonella sp.

Levifusus trabeatoides

Cancellaria penrosei

These sands carried opalized wood similar to that of the Fayette west of the Brazos and showed similar quartzitic masses. They were referred to the Fayette.

[16] Dumble: Geol. S. W. Tex. Trans. A. I. M. E., vol. 33, p. 976.

[17] Third Ann. Rept. Geol. Surv. Texas, p. xxiii.

[18] Kennedy: Third Ann. Rept. Geol. Surv. Texas, p. 115.

[19] Harris: Manuscript record Tertiary fossils.

The clays overlying these Corrigan sands he called the Fleming beds.

In his work in Grimes and Brazos counties, Kennedy[20] found two series of sands, the lower of which he called the Wellborn sands and correlated with the Fayette sands. He made the other the basal member of his Navasota beds. Fossils were found at Williams quarry, in the Stephenson league, east of Wellborn, near the base of the Wellborn sands. They were as follows:[21]

Yoldia claibornensis	*Corbula alabamiensis*
Venericardia planicosta	*Turritella* sp.
Cytherea bastropensis	*Cancellaria penrosei*
Siliqua simondsi	*Pleurotoma quassalis*
Mactra sp. a	*Cylichna kellogii*

No fossils were found in the Navasota sands.

In the section along the International & Great Northern Railway the sands between Riverside and Huntsville were supposed, on account of lithologic resemblance and the number of palmetto leaves they carried, to represent the Oakville sands, and the overlying clays between Huntsville and Willis were, on stratigraphic and lithologic ground, correlated with the Lagarto. The clays underlying the Oakville at Riverside were thought to be Frio.[22]

In 1895 Kennedy, in an article on "The Eocene Tertiary of Texas east of the Brazos River,"[23] correlates his Fleming beds south of Corrigan and around Woodville, Tyler County, with the Frio clays of west Texas and the underlying "Corrigan" sands, including those at Stryker, Corrigan, Lovelady, and Wellborn, with the Fayette. Speaking of the plant remains of these sands, he says:[24]

"Palm wood is plentiful, while the stems and leaves of the palmetto, rushes, and marsh-grass may be found in some localities in abundance, showing that when these beds were being deposited the marshy tracts of the Yegua clays to the northward were still the home of such growths. None of these are indigenous to the Fayette sands and exist there only in the form of drift material cast up by the sea. Near the top of the Fayette (Corrigan) sands we find trunks and limbs of trees of large size, many of them even now showing diametric measurements of over 3 feet; and although some show a length of 25 or 30 feet, the greater portion of the logs do not exceed 10 or 12 feet in length. Occasionally a stump with the larger roots attached may be found, but this is exceedingly rare. A peculiarity regarding these trees is that they

[20] Kennedy: Fourth Ann. Rept. Geol. Surv. Texas, pp. 9-46.
Eocene-Tertiary. Phil. Acad. Nat. Sci., 1895, p. 95 et seq.

[21] Harris: Manuscript record Tertiary fossils.

[22] Dumble: Notes on Texas Tertiaries. Texas Acad. Sci., 1894, p. 25.

[23] Trans. Phil. Acad. Nat. Sci., 1895, pp. 84-160.

[24] Op. cit., p. 159.

are every one in the form of wood opal or in an opalized condition, vitreous and clear when broken, breaking with sharp cutting edges, and retaining every mark and line of growth as it appeared in the tree. The outside of these woods is generally a dull white, showing a process of decay. This form of wood is peculiar to the Fayette (Corrigan) sands and occurs nowhere else within the Texas regions."

Dumble,[25] describing the section along the Texas & New Orleans Railway between Beaumont and Rockland, refers the clay beds around Woodville, described by Kennedy[26] as Fleming, to the Lagarto on account of their stratigraphic position and lithologic resemblance. The contact of these Lagarto clays with the underlying Oakville was described as crossing the line of road 2½ miles south of Rockland. The Lapara was not recognized in this section.

Veatch, in connection with his investigations of the water resources of Louisiana and Arkansas, studied the geology of a portion of eastern Texas. Examining the beds[27] 4 miles north of Corrigan, he found, in addition to the fossils collected by Kennedy, a number of others which made necessary the reference of this portion of the beds to the Jackson. These included:[28]

Levifusus branneri	*Mazzalina* var. *oweni*

Just below Robinsons Ferry, on the Sabine River, he found the Jackson clays well exposed. Two other fossiliferous beds are noted farther down the river. He also mentions Jackson fossils near Caddell and large bones (probably Zeuglodon) east of the Sabine, on Caney Creek.[29]

The sands immediately overlying the Jackson, beginning just south of Piney Creek and extending south of Corrigan to Moscow, he refers to the Catahoula, which, as shown by the geologic map accompanying his report, also includes the sands at Rockland.

He states that, in order to furnish a name not likely to be misunderstood,[30] the name Catahoula formation is used as a synonym for the "typical Grand Gulf," or the "Grand Gulf proper," which immediately overlies the Vicksburg and is of Oligocene age. East of the Mississippi the sands apparently grade into the Chatahoochee group of sands and clays.

He also describes the Fleming clays of Kennedy which overlie his Catahoula, and since no marine fossils were found in them except near

---

[25] Dumble: Disc. Lucas Well. Trans. A. I. M. E., 1901, vol. 31, p. 1031.
[26] Kennedy: Third Ann. Rept. Geol. Surv. Texas, p. 62.
[27] Veatch: U. S. Geological Survey Prof. Paper No. 16, p. 39
[28] Harris: Geol. Surv. Louisiana, 1902, p. 25.
[29] Veatch: Geol. Surv. Louisiana, 1902, p. 130.
[30] Veatch: U. S. Geological Survey Prof. Paper No. 16, p. 12.

Burkeville, Newton County, "where a brackish-water Oligocene fauna has been found," he correlates the Fleming beds, as well as most of the Corrigan sands, with the Oligocene.

This discovery of Jackson fossils by Veatch seemed to cast a doubt on Harris' earlier correlation of the Corrigan sands with the Fayette and an effort was made to get the facts. It was found that there was a body of sand crossing the line of road south of Burke[31] about where the Fayette should be, but that there was no distinct exposure on the railroad along which Kennedy made his section. Other detached exposures were found east and west of the line, one of the principal ones being at the town of Homer. These sands and white clays overlie the Yegua and are very like the Fayette, and while no fossils were found, we were reasonably certain that they did represent the true Fayette in this region and these exposures were supposed to represent the outcropping edges of the main body of sands. The clays in the valley of the Neches apparently overlying these sands were therefore thought to be Frio.

Harris follows Veatch in referring the "Grand Gulf beds proper" and the Frio clays, as he terms Kennedy's Fleming beds, to the Oligocene.[32]

Deussen embodies the result of his examination of this region in his report, "Geology and Underground Water-supply of Southeastern Texas." [33]

From this report and the geologic map accompanying it, it would appear that he limits the Jackson proper to a narrow lens of calcareous fossiliferous clays containing large limestone concretions which extend from the Sabine River to Burke, on the Houston, East & West Texas Railway. The surrounding sandier beds he calls the Catahoula, using the name in a much broader sense than Veatch gave it, to include everything (except the small belt of Jackson clays already referred to) between the Yegua clays and the Fleming clays from the Sabine River to the Colorado. This is modified, however, in a footnote[34] stating that later studies indicate that the Catahoula sandstone, described in his report as a stratigraphic unit, really comprises two formations of similar lithologic character, the one at the base being of Jackson age, whereas the upper sandstone is of Oligocene age. The lower of these sandstones includes the Wellborn sands of Kennedy.

With regard to the age of the Wellborn beds, Deussen says:[35]

"Vaughan is of the opinion that the horizon represented by the hard fos-

---

[31] Dumble: Science, vol. 16, 1902, p. 670.
[32] Harris: Geol. Surv. Louisiana, 1902, p. 28.
[33] U. S. Geological Survey Water-supply Paper No. 335.
[34] Op. cit., p. 70.
[35] Op. cit., p. 72.

siliferous sandstone on the Robert Stephenson league is probably very low in the Jackson; and, if this be so, the beds between Wellborn and Millican would represent in part the time equivalents of the Jackson formation along the Sabine."

His use of the Catahoula makes it cover the locality 4 miles north of Corrigan, at which Veatch found his Jackson fossils.

The inference is, therefore, that he considers all of the beds from the top of the Yegua to the base of his upper or Oligocene sandstone as referable to the Jackson.

The report describing the Fleming clays refers them to the Miocene. In connection with this, Matson gives Dall's determination of the Burkeville fossils and his reference of them to the Pliocene.

Deussen, under the name Dewitt, includes the Oakville, Lapara, and Lagarto of Dumble, and shows them overlying the Fleming clay. A footnote suggests that on the Sabine the Dewitt is represented by the Fleming clay.

Recent Examinations

In connection with the investigation of the oil fields of the coast region, which has been carried on under the direction of the writer, there has been occasion to study these sands at various places, and some of the information obtained and heretofore unpublished has a direct bearing on this subject.

During 1904 Hager endeavored to trace the lower contact of the Oakville beds from the Nueces to the Sabine, his identifications of it being based largely on the lithology of the beds.

On the San Antonio River he found the contact about 3 miles south of Helena; on the Guadalupe near the mouth of Barton Creek, 10 miles southeast of Gonzales; near Flatonia on the Galveston, Harrisburg & San Antonio Railway; 3 miles north of La Grange; on the Brazos 5 miles west of Navasota; at Riverside on the Trinity; three-quarters of a mile south of Corrigan; 1 mile south of Rockland, and on the Sabine about 1 mile north of Burr's Ferry, northeast of Burkeville.

West of the Guadalupe he notes the presence of the Frio immediately underlying the Oakville, but thinning toward the northeast. He mentions its absence on the Colorado and eastward of that stream, all of the contacts observed being described as with the Fayette or Eocene sands.

He thus describes the Oakville beds east of the Brazos:

"On the Brazos the Oakville beds may best be described as cemented sands. They consist of fine white sands, with some clay, firmly cemented into a white mass by calcareous material. They contain some gravel, silicified wood, and numerous rolled Cretaceous fossils. Often they form thin-bedded, jointed, iron-stained calcareous sandstones.

"Toward the east their character gradually but materially changes. They become more ferruginous, and their cemented condition is less marked. The sand occurs more often in a loose condition. Small black land prairies occur. The amount of gravel constantly increases.

"The calcareous clays which overlie these on the Brazos undergo similar changes. They become more sandy, gradually lose their lime in balls and pockets, until at Colmesneil they retain only thin, platelike concretions. The ferruginous matter in the form of plates and concretions increases and the beds assume a red color, interspersed with black land prairies. Heavy sands are interbedded with the clays.

"The most marked difference between the Oakville beds of this region and those of the Colorado seem to be the entire absence of the coarse-grained, cross-bedded sandstones, such as occur at La Grange Bluff. The Grimes County sandstones, in general, are finer of grain, harder, more calcareous, contain fewer Cretaceous fossils, are nearly always thin-bedded and flaggy, and seem to occupy a place of lesser importance as a whole than those of the Colorado."

The strong unconformity between his Oakville and Fayette (?) is brought out in connection with the contacts observed on Rocky Creek north of Anderson.

"The Eocene member consists of 30 feet of massive, grayish yellow, coarse-grained sandstone, quartzitic throughout, but the silicification has not proceeded to the extent of rendering the entire stratum blue and vitreous. Opalized wood is present.

"Upon the eroded flanks of this Eocene hill lie the Oakville beds. They are here represented by a coarse, brown calcareous sand, stratified and semi-indurated in places, containing numerous fragments derived from the underlying Eocene quartzite, together with flint and jasper pebbles. At the line of contact the sand is much mixed with clay and lignitized wood.

"Throughout this region there are occasional Eocene outliers, at times several miles from the main contact."

He also notes that the dips of the older sandstones are considerably greater than that of the Oakville.

Kennedy, Garrett, and Dumble made several trips across these sands between the Colorado and Nueces rivers for the express purpose of ascertaining whether or not beds intermediate in age between the Frio and Oakville could be found. In every case where the contact was found the Oakville rested either on the Frio or the Fayette, and no indications of other beds were observed. Many localities were found where marine invertebrate fossils were abundant and well preserved, but they were nearly all in Yegua territory. The principal, if not only, find in the Fayette was a reef of *Ostrea alabamiensis* var. *contracta* Con. This locality was east of the San Antonio River, on Marcelina Creek, some 5 miles north of Falls City, and it marks the extreme eastern limit of this form, so far as now known. The last exposure of clays which we could refer to the Frio was found just east of the San Antonio River, east of which the Oakville overlap concealed it, so far as our sections show. No marine forms were found in it.

In 1912 and 1913 Baker and Suman spent several months in the Tertiary belt between the Brazos and Sabine rivers, the greater part of this investigation being of the post-Yegua deposits, although the beds underlying the Yegua were given sufficient attention to determine their boundaries. Large collections of fossils were made, which have not yet had critical study except in special cases. Their reports and notes are very full and satisfactory, but, owing to the heavily timbered character of the country and the scattered exposures, they were unable to fully clear up the situation. The maps prepared by them show their interpretation of the surficial extent of the Marine, Yegua, Jackson, Corrigan, and Fleming from near the Sabine River to the Navasota. They differ somewhat from the published map and report of Deussen, both in their classification of the beds and their boundaries.

The following descriptions are based principally on a study of their reports, maps, and collections and on personal conferences with them. The work of Kennedy and the writer in the same area has also been used.

Descriptions of Formations of East Texas

LOWER CLAIBORNE

Yegua.—The lignitic clays and sands of the Yegua are exposed over an extensive area between the Brazos and the Sabine.

The clays are laminated, thinly stratified, and massive in structure, and chocolate, dark blue, brown, and gray in color. The cone-in-cone structure, noted on Atascosa Creek in the Nueces section, is also found in the basal beds of this area. The sands and sandy clays, which are sometimes micaceous, are brownish drab, buff, and gray. They range from laminated to massive and are often cross-bedded. Laminated clays and sandy clays, sometimes leaf-bearing, frequently occur as lenses, pockets, and nodules in the sands, even when the latter are cross-bedded. Similarly, lenses of sand are found in the laminated, jointed clays.

In the lower portion of the beds the clays seem to predominate. The middle portion seems to carry the most lignitic matter, and the sands prevail in the upper beds.

Both clays and sands weather to light colors, mostly yellow or dirty white, and some of the sandy clays show typical badland weathering. The topographic expression is generally flat.

In the upper beds, referred to this formation by Baker and Suman, some of the sands have a porcelaneous cement, others limonitic, and still others contain streaks and balls of white clay having the appearance of porcelain.

Lignitic material is abundant, disseminated through the beds in fragmentary form, as carbonaceous coatings, and in lenticular beds; but few, if any, deposits of workable lignite are known to occur in the Yegua east of the line of the International & Great Northern Railway.

Gypsum is very abundant. In the lower portion of the beds, where it predominates, it occurs as large masses of selenite of irregular form. Elsewhere it occurs as crystals of selenite, sometimes of large size, or as fragments intermingled with the sands and clays. In some localities these gypsum fragments constitute a considerable percentage of the sand bed. Saliferous strata also occur.

The cannon-ball concretions of the Rio Grande are found here in abundance. While some of these are of spherical shape, as on that stream, many of the clay-ironstone concretions are in the form of flattened masses, some of them 2 to 3 feet in diameter. They are usually altered to limonite, and these limonite concretions and impregnations are characteristic of the beds. Occasionally the limonitic concretions have streaks of calc-spar through them, but true calcareous concretions are apparently absent. Silicified wood is plentiful as logs of large size and as fragments scattered through the formation from bottom to top, but none of it is opalized.

Marine invertebrate fossils occur occasionally as poorly preserved casts in connection with pockets or concretions of greensand marls. Fossil plants are found abundantly at many places.

The Yegua belt has an average width of 12 miles. Its greatest width, 22 miles, is found along the Neches River, while on the Sabine it narrows to 3 miles. In dip it varies from 40 feet to the mile to more than 100 and has a thickness of 400 to 800 feet.

Fayette.—The fossils on which the correlation of Kennedy's Wellborn beds with the Fayette was based were collected from the lowest beds of the sands. The more recent work of Deussen and Vaughan seems to indicate that this may prove to be Jackson. In this event, we know of no Fayette east of the Brazos, unless it be such remnantal areas of sand and clay as those between Blix and Huntington.

On the west side of Jacks Bayou, just east of Blix, in Angelina County, there is a ridge of evenly bedded medium or fine-grained sandstone of

FIGURE 1. YEGUA ON TRINITY RIVER ABOVE WESTMORELAND BLUFF
Photograph by C. L. Baker

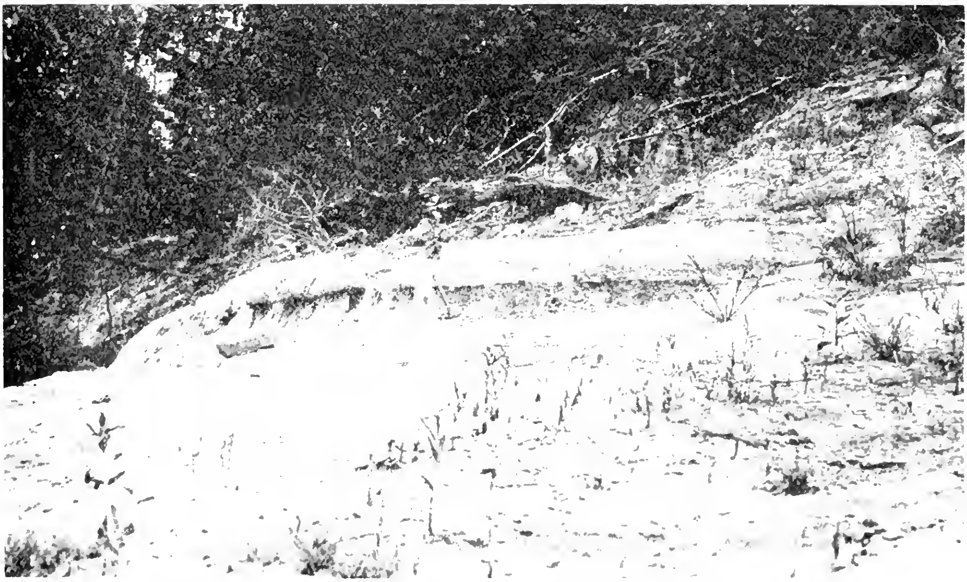


FIGURE 2. VOLCANIC ASH IN JACKSON, WHITE ROCK CREEK, TRINITY COUNTY
Photograph by C. L. Baker

YEGUA FORMATION AND VOLCANIC ASH

light gray color. The ridge is 20 feet in height, and a well 50 feet deep found only the same sand. A smaller ridge of similar sands trends eastward, crossing the line of the Houston, East & West Texas Railway north of Burke, where there is another hill similar to that at Jacks Bayou and composed of similar fine-grained massive or medium-bedded sands. In this area a silicified tree trunk was found. It was not opalized. South of this a third area of these light gray sands stretches almost to the line of the Jackson contact.

The town of Homer is underlain by a light bluish gray, cross-bedded sandstone. North of the town this changes to even-bedded, medium-grained sandstone, which is quarried for local use. It is overlain to the south by light cream-colored clay, thin-bedded to massive, and showing cross-bedding in places. Finally, there is a small hill of similar fine-grained sand, hardened to quartzite, just south of Huntington.

Similar remnantal bodies of fine-grained sandstones are found as detached hills or ridges overlying the Yegua in interstream areas and north of all recognized Jackson as far west as the northwest corner of Grimes County. An outcrop of very similar sand was also found overlying the Cooks Mountain beds of the Marine as far north as Alto, in Cherokee County.

These sands differ from any of those found in the Yegua, Jackson, or Catahoula, both in material and structure. From their location it would seem improbable that they can be outliers of the Catahoula, and they are so different from the underlying Yegua that they can hardly belong with it.

The evidence seems clear that their stratigraphic position is between the Yegua and the Jackson, and if this be true they probably represent some part of the Fayette-Frio time of the Rio Grande section.

Frio.—No evidence was found between the Brazos and Sabine of the existence between the Yegua and Jackson of any beds representing the Frio. If they were deposited in Claiborne time succeeding the Fayette, they were completely eroded.

UPPER CLAIBORNE

Nowhere in the Texas coastal area have any beds yet been found the fossils of which would suggest a reference to the Upper Claiborne, and it seems probable that this period was one of elevation and erosion in this region.

JACKSON

Robinsons Ferry is on the Sabine River, about 6 miles south of Columbus, Louisiana. A quarter of a mile below the ferry Deussen found an outcrop of shales carrying such Yegua forms as *Pleurotoma terebriformis*, *Marginella semen*, and *Corbula oniscus*.[36] Half a mile below this Veatch found a blue fossiliferous clay, which yielded "a rather extensive Jackson fauna, including *Umbrella planulata* and many large *Capulus americanus*."[37] Outcrops of overlying beds seen down the river seem to be principally of clays and sandy clays. North of Anthonys Ferry these clays are succeeded by the Grand Gulf or Catahoula sandstone, giving the Jackson outcrop a width of between 3 and 4 miles on the Sabine.

According to Baker and Suman, the northern limit of the Jackson, on the line of the Santa Fe, is not clear, but is probably near Rush or between Rush and Bronson. The Jackson-Catahoula contact is just south of Brookeland. No fossils were found in this section.

From the valley of Ayish Bayou westward the base of the Jackson was more easily determined by reason of the occurrence of a series of dark clays with greensand and calcareous concretions carrying fossils. The line thus given crosses the St. Louis & Southwestern Railway north of White City, the Angelina River 2 miles north of Caddell, follows the line of the St. Louis & Southwestern Railway from Monterey to Donovan, and crosses the Texas & New Orleans Railway just south of Prestridge and the Houston, East & West Texas Railway in the vicinity of Diboll. In the area east of the railway the general section of the Jackson from a number of sections and traverses of Baker and Suman shows:

At the base are greenish clays and sandy clays with some sand and greensand, which are iron-stained. These weather dark brown and carry calcareous concretions. The concretions contain more or less sand and greensand, are geodic in places, and they carry Jackson invertebrate fossils and remains of plants. These are overlain by grayish brown, sandy clays with seams of sulphur, which are followed by buff, sandy clays with plant fragments, and gray drab clays with gypsum and sulphur. Excellent exposures of these beds are found around the town of Caddell, San Augustine County, and that name is proposed for this stage.

Overlying these there is a series of lignitic or carbonaceous chocolate clays and sands, with which are interbedded light-brown sandstones with a porcelaneous cement, and coarse-grained gray sandstones which are sometimes quartzitic. In the vicinity of the Angelina River and elsewhere thin beds of lignite are found.

The upper beds are of light greenish sands and carbonaceous sandy clays stained with limonite and weathering into badland forms, capped by dark-brown, sandy carbonaceous shales with plant fragments, selenite,

---

[36] U. S. Geological Survey Water-supply Paper No. 335, plate iv.

[37] Geol. Surv. Louisiana, 1902, pp. 131-132.

and sulphur seams. For this upper stage the name Manning is proposed from the station of that name on the St. Louis & Santa Fe Railway, where they are well exposed.

In this area the Jackson belt has a width of 8 to 14 miles and a probable thickness of 400 to 500 feet. East of Corrigan a well beginning in the base of the Catahoula passed through the Jackson and Yegua beds and reached the fossiliferous Marine beds at 1,200 feet. This would give the Jackson a thickness of about 600 feet in this locality. The beds are not only thicker than on the Sabine, but they become more and more sandy toward the west.

West of the Houston, East & West Texas Railway we find the Caddell clays with fossiliferous calcareous concretions on Tar Kiln Creek some 5 miles southwest of Diboll, at which place well preserved fossils were collected, and it outcrops again about 12 miles northeast of Groveton, on the Groveton, Lufkin & Northern Railway. This was as far west as we could trace it.

Fossils are of more frequent occurrence in this terrane than in any other in east Texas except the Marine beds. Those near the base occur in connection with the calcareous concretions. Sometimes the shells are present in the concretions or weathered out from them, but more often the shell material has been leached out, leaving only the imprint.

From the Tar Kiln Creek, 4 miles southwest of Diboll, the following forms were identified:

Ostrea frag. like *contracta*
Arca sp. ?
Venericardia planicosta Lam.
Venericardia rotunda Lea.
Pectunculus idoneus Con.
Pectunculus sp. ?
Crassatella texana Heilp. ?
Crassatella flexura
Corbula alabamiensis Lea.
Corbula oniscus ?
Cytherea tornadonis Har. ?
Tellina mooreana
Tellina sp.
Turricula sp.
Bulinella kellogii Gabb
Turritella nasuta Gabb
Turritella houstonia Har.
Solarium alveatum Con.
Solarium huppertzi Har.
Volutilithes petrosus
Cassidaria sp.
Calyptrea sp.
Dentalium dumblei Har.
Flabellum wailesii Con.

In the yellow, sandy concretions are many large *Pinna*, *Pholodomya*, *Echinoderms*, small *Haminea grandis*, etcetera.

In connection with these beds north of Manning a fragment of a vertebra was found, which is probably Zeuglodon.

At a somewhat higher horizon the brown sands carry a number of fossils in the form of casts. This appears to be the special horizon of *Haminea grandis*.

In the Manning beds many lamellibranchs are found in the limonitic shales, and in the overlying light-gray sands there are pockets of fossils which are mostly casts, but occasionally have the shells preserved. Similar occurrences were found in the carbonaceous shales and sands at the top of the section.

No specimens of *Levifusus branneri* were found, but in the upper carbonaceous sands of the Manning stage there are imprints and casts of a large gasteropod that may possibly be referred to that species.

A marked increase in the sandiness of the Jackson is shown in the Groveton section.

The sandy clay with limestone concretions, found 12 miles north of Groveton, grades upward through carbonaceous shaly clays into a succession of gray and brown sands and lignitic sands carrying silicified wood, some limestone concretions, clay balls, fragments of volcanic tuff, and many plant impressions. Wells drilled at Groveton to depths of 400 to 600 feet show principally sands or sandy strata, with a few clay beds and streaks of lignitic material. South of Groveton carbonaceous sands are found with imprints of invertebrates similar to those at the top of section north of Corrigan.

Going northward the Caddell clay of this section is underlain by sandy carbonaceous shales and sands, with silicified logs, massive, rather fine-grained, sandstones and lignitic clays and sands seemingly of Jackson facies. These extend to the vicinity of Apple Springs, beyond which the Yegua badland sandy clays and gypsiferous clays with clay ironstone concretions make their appearance. It would appear, therefore, that this section gives us a member of the Jackson lower than any seen east of the Neches or of a series of beds intermediate in age between the Yegua and Jackson, most probably the former.

West of Groveton the change is decided. No further traces of the Caddell sandy clay with limestone concretions are found, but the lignitic sands and clays underlying it seem to be immediately overlain by the carbonaceous sands of the Manning beds, as shown in section north of Corrigan. Volcanic ash comes in as definite beds and is well shown in the section along the International & Great Northern Railway.

Between Calhoun's ferry, near the Houston-Trinity County line and the bend north of Riverside, the Trinity River gives many good sections of the Jackson. At the base are lignitic clays carrying plant remains and sands with lignites. These are overlain by light-yellow, gray, and brown sands, with sulphur, and by carbonaceous shales, sulphur-stained, followed by other lignitic clays, sands, and lignites. There are beds of volcanic ash as much as 10 feet in thickness in the upper portion, and

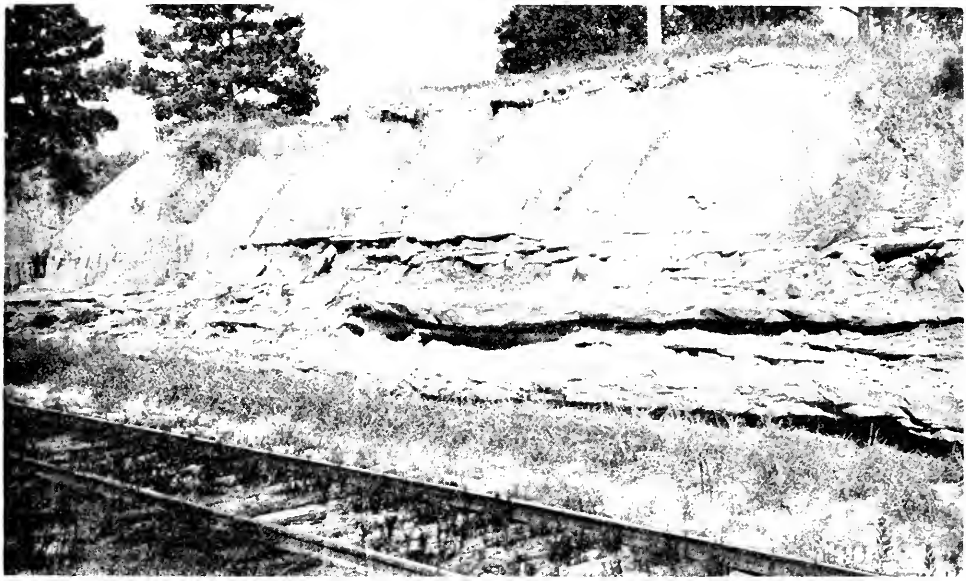


FIGURE 1.—CORRIGAN SANDS NEAR RIVERSIDE
Photograph by C. L. Baker

FIGURE 2.—FLEMING CLAYS, SMITHS FERRY, NECHES RIVER
Photograph by J. R. Suman

CORRIGAN SANDS AND FLEMING CLAYS

these carry plant fragments. The volcanic ash beds give a good working horizon, as they are fairly continuous west of Groveton.

Sections in Walker and Grimes counties are very similar to that on the Trinity. At one locality, near the line between these two counties, a bed of laminated chocolate clays was found, in which there were balls and masses of Grahamite 8 to 10 inches in diameter.

Fossils were found in colonies in sandstones near the base of the Jackson series at a number of localities west of the International & Great Northern Railway, and the upper carbonaceous clays of the Manning stage also furnished a few fossil-bearing localities similar to those further east. At one locality, 2½ miles west of Bedias, Suman reports the sandstone packed with fossil casts apparently identical with those from 2 miles north of Corrigan. The fossils collected from these have not yet been studied.

Unfortunately, the work was suspended before the exact connection of these beds and the Wellborn of Kennedy was determined. The probability, however, is that they are the same, and that Vaughan's reference of the Wellborn to the Jackson is correct. In this case the name Wellborn, instead of being a synonym for Fayette, would characterize the basal beds of Jackson age in Texas.

The Jackson is distinguished by the fact that in it the clay ironstone and limonitic concretions of the underlying Yegua are replaced by calcareous concretions and by a greater proportion of sands and sandstones. Some of the Jackson sands are very hard, even quartzitic, but are always light gray in color and are fossiliferous in places. Volcanic ash beds are also characteristic. The top of the Jackson is placed where the chocolate laminated clays and carbonaceous sands give place to coarse "rice" sands or sandstones and yellowish green, structureless clays and claystones.

CORRIGAN

The name Catahoula has been proposed by Veatch for the sands overlying the Jackson and underlying the Fleming, but expressly limited its use to such as were of true Grand Gulf age. Deussen used the name in a much wider sense to include a large part of the Jackson as well. It is here proposed to use Kennedy's older term Corrigan sands for the group of deposits lying between the known Jackson and the Fleming, which, while forming the only mapable unit, probably includes beds of later age than the Catahoula of Veatch, which name should be retained for that portion of the Corrigan to which it strictly applies.

The Corrigan comprises coarse "rice"[38] sands and sandstones at the base, overlain by finer sands and by yellowish green clay and claystones with plant remains. The clays and claystones carry pyritic nodules and streaks of lignite and weather yellow to cream color. The sands are coarse to fine-grained and may be friable, cemented with opaline or porcelaneous matter, or hardened to a dense gray-blue quartzite. There are local unconformities between the sands and clays and the sands often carry clay balls and are occasionally cross-bedded. Volcanic ash is rare in them. They are noted for the abundance of fossil palms, and the fossil wood which occurs in them is often opalized.

On the Santa Fe, in Jasper County, the contact of the Corrigan and Jackson is found just south of Brookeland, and it passes under the Fleming about 5 miles north of the Jasper. Many excellent exposures are found along the Angelina and the Neches rivers west of this. On the Texas & New Orleans Railroad the outcrop, as determined by Baker and Suman, has a width of 5 miles, with Rockland as its center. In the Corrigan section, which begins one mile north of Corrigan and extends southward to Moscow, we find these materials typically displayed, and in connection with them local conglomerates occur, with pebbles of jasper, flint, and quartz up to an inch in diameter. Palm leaves are abundant also.

In the exposures of the Trinity River region, while the basal beds are the same as those to the eastward, there appears to be at the top a transitional zone, in which sands of the Corrigan are interbedded with calcareous clays similar to those of the overlying Fleming. On this account the limit is not as well defined as further east, and the upper line is drawn where the sands with porcelaneous cement cease and the clays weather entirely dark brown or black, instead of showing the characteristic yellow weathering of the Corrigan clays.

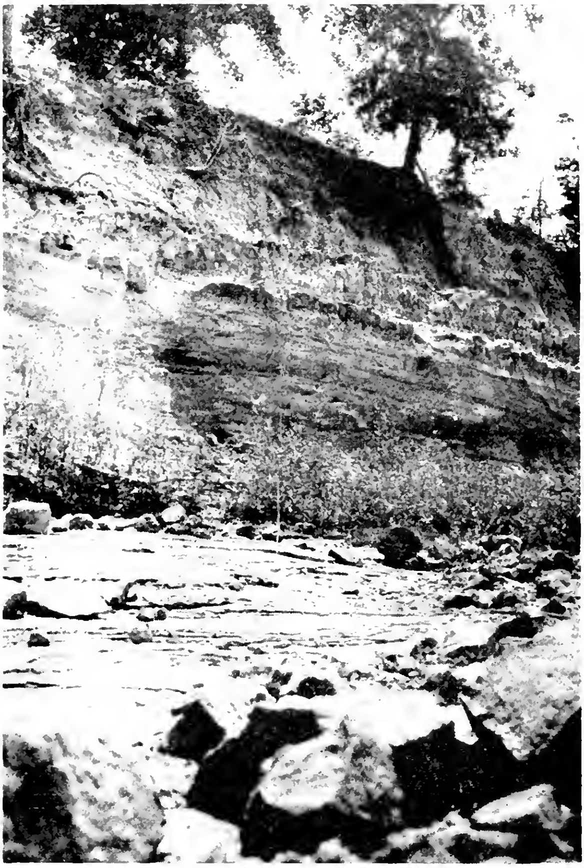
These upper beds maintain their character and thickness as far west as the Navasota River. While they appear to be later than the Catahoula proper, they are definitely connected with it by the character of the sands and clays of which they are composed.

For this portion of the Corrigan the name Onalaska is proposed, from the name of a town in Polk County which is located on them. Excellent exposures may be found on Kickapoo Creek east of the town and on Harmon Creek northeast of Huntsville.

On the Trinity & Brazos Valley Railway, in Grimes County, the Jackson-Corrigan contact was found about 2½ miles south of Singleton and the Corrigan-Fleming contact just north of Richards.

Although two or three fragments of bone were found in the sands, no

[38] So called because of the resemblance of the grains to those of rice.



CONTACT OF JACKSON AND CORRIGAN FORMATIONS

View on Trinity River near Trinity. Photograph by C. L. Baker determinable fossils except plant remains have been secured from these beds, and while good collections were made we have as yet no definite information as to the exact age indicated by them.

Stratigraphically, this group is post-Jackson. Lithologically, the base corresponds closely with the typical Grand Gulf, while the top is very similar to the Oakville beds of the Nueces section, and up to the present, in the absence of determinable fossils other than plants and on account of the apparent stratigraphic connections, it has seemed to the writer that the group represented a remnantal area of Catahoula overlain or surrounded by the Oakville. Baker and Suman did not find any basis for such a division of these beds, but regarded the observed unconformities as local only, and, in view of the age of the fossils found in beds overlying the Corrigan, it may be that this opinion is no longer tenable as a whole. It now seems probable that the Corrigan represents some portion or all of the Oligocene above the Vicksburg (which is wanting in this area), and that while the base may be Grand Gulf the upper portion is probably later.

FLEMING

South of the Corrigan sands and overlying them there occurs a broad belt of clays and sands, with quantities of calcareous concretions, which were called by Kennedy the Fleming clays. They occupy a belt from 15 to 25 miles in width and are followed by the deposits referred to the Lafayette or Reynosa. Since no clear basis for the division of these beds was found, the name Fleming as used here includes all sediments between the Corrigan sands and the Lafayette between the Sabine and Navasota rivers, and these were mapped as a unit, although they probably comprise deposits of both Miocene and Pliocene age.

Burkeville is near the base of the Fleming clays as exposed in the region near the Sabine River. Baker describes the deposits here as follows:

"In color the Fleming is most generally a light shade of grayish or yellowish green, often weathering brown on the surface. The surface, when dry, is cracked like ordinary plastic clay. The material is fine clay and clayey sand, with small whitish limestone concretions. However, there are, at Burkeville, larger grayish brown, very fine-grained limestone concretions with dendritic markings of manganese dioxide, concretions of fine- to medium-grained sandstones, of large size and rough, irregular outline; and the fossiliferous breccia or beach limestone conglomerate known only from one-half mile east of Burkeville and south of Little Cow Creek, where fragmentary bones of land mammals and brackish water mollusks were found. In many places the small white concretions are arranged in thin beds parallel to the imperfect lines of stratification. The fine sands are also locally finely laminated and crossbedded."

Kennedy's original section[39] shows at base calcareous clays overlain by other clays and by gray stratified sands, with fossil palm-wood in quantities and with pebbles of quartz, jasper, flint, etcetera. Higher beds found on the Texas & New Orleans Railway south of Rockland are sandy clays of various colors, with interbedded sands, and the upper beds of calcareous clays were found near Woodville, south of which the Fleming is overlain by the Lafayette.

The Trinity River section similarly shows at the base green-brown clays with calcareous nodules. At Red Bluff there are greenish gray clays with calcareous nodules and cross-bedded sands in which bone fragments are found. The exposure of these beds has here a maximum thickness of 15 feet. In the middle of the exposure there is a layer of oolitic shoreline limestone conglomerate a foot in thickness containing a few jasper and quartz pebbles of small size and an occasional bone fragment.

Similar beds are found a short distance below at Johnson's bluff, where they also include fresh-water mollusks. These deposits extend along the river to a point south of Drews Landing, near Smithfield. Here an outcrop of Fleming, 10 feet in thickness, shows friable fine-grained gray sandstone in lenticles at the base, with 5 feet of greenish gray, russet-brown, mottled clay with small, white calcareous nodules overlying it. Fragments of bone were found in this. The Fleming is here overlain by the Port Hudson, with the usual layer of Lafayette-derived pebbles at the base.

A mile below Drews Landing, in a section of 5 feet of light-gray Fleming clay with calcareous nodules, a portion of the remains of a mastodon was found.

Cold Springs, west of the river, is in the midst of an important outcrop of the Fleming. In this region the Fleming brown and gray clay has a considerable portion of brown, buff, and white sand. Locally there are large boulders of grayish brown, soft sandstone, some of which are 10 to 12 feet in length. There is also a fine-grained, hard, brown claystone and numerous calcareous nodules. Crystals of selenite are found locally. Pure white sand, with only a minor amount of clay, is also found. Fossils of mammals were found in the region extending from 2 miles north to 2 miles west of Cold Springs. The bones, with the exception of a mastodon's skull (*Trilophodon*), are fragmentary and are scattered through the clays. *Planorbis* was also found at this locality.

Baker describes the Fleming of the Navasota region as follows:

---

[39] Third Ann. Rept. Geol. Surv. Texas, pp. 117-121.

"The lowermost Fleming is exposed in a cut on the International & Great Northern Railway 3 miles north of Anderson, where there is 5 feet of green sandy clay very poorly laminated, carrying calcareous cemented nodules of sandstones. From Anderson to Navasota the railroad passes over Fleming, which is here composed mainly of clays, but locally of gray and brown sands and sandstones. Seven miles northeast of Navasota and half a mile east of Becker flat-topped mesas capped by sandstones and very arenaceous limestone begin and continue nearly all the way to Navasota. These are entirely south and east of the track and rise to 100 feet above the track level. The Fleming in this vicinity consists of the following materials:

"1. Sands of all textures from the finest up to coarse grit or fine conglomerate.

"2. Brown and dirty green clays with calcareous nodules.

"3. Very arenaceous, thin, irregular-bedded, and concretionary limestone.

"4. Clay ball conglomerate in a coarse sand matrix.

"All of these materials are either channel or littoral deposits. Mammalian bones are found in a layer of coarse grit or fine conglomerate. They are fragmentary, sometimes water-worn, and are associated with rolled Cretaceous fossils. Petrified wood, differing from that of the older formations in being less consolidated, lighter in weight, and duller in luster, was found with the bones and shells. Fresh-water shells (unios) are found in abundance in the clays between 3 and 4 miles north of Navasota in shallow gulleys just east of the right of way. The bones are found in the deeper gulleys to the east of the second mile-post."

South of Navasota the Fleming continues to 1½ miles south of Crooks, where the Lafayette begins, the uppermost Fleming being made up of dirty green clays with white calcareous nodules. West of this it continues southward and is exposed at the Houston & Texas Central Railroad crossing of Clear Creek, just east of Hempstead, where it has the appearance of the Lagarto of the Nueces section and, like it, carries manganese as fragments of wad.

The invertebrate fossils collected at the Burkeville locality were submitted to Dr. W. H. Dall, who had already had other collections from the same locality, the result of the study of which is given by Matson.[40] Ten species are listed from Burkeville, and Matson states that the character of the fauna led Doctor Dall to refer it to the Pliocene. This is the only locality at which this fauna has been found on the surface. In a well at Terry, 66 miles south of Burkeville, however, at a depth of 3,000 feet, the same forms were found in abundance, and in a second well, a mile or more south of the first, they continued to the bottom of the drill-hole, which was a little more than 1,000 feet below the surface. Doctor Dall determined the following forms from these wells:

[40] U. S. Geological Survey Water-supply Paper No. 335, pp. 72-73.

Ostrea virginica Gm. (fragments)
Rangia cuneata var. *solida* Dall
Unio sp. (fragments)
Potamides matsoni Dall
Potamides suavis Dall
Potamides sp. (fragments)
Pyrgulopsis ? satilla Dall
Neritina sparsilineata Dall

In connection with the invertebrate fossils at the Burkeville locality, Baker collected some mammalian fossils which were studied by Doctor Matthew. He reports as determinable:

Tibia of a young rhinoceros, with the proportions of Teleoceras.

Upper molar of a horse, either Protohippus or a long-crowned Merychippus.

He states that both these specimens indicate late Miocene or possibly early Pliocene age, the horse tooth being pretty certain evidence.

It is therefore evident that in the vicinity of Burkeville the base of the Fleming is not earlier than late Miocene nor younger than early Pliocene.

In the Neches River section, at the base of the Fleming, a bone was found by Baker which was determined by Doctor Matthew as "part of the upper end of cannon-bone of a Camelid, compared Procamelus. This might be Middle Miocene or Pliocene, so far as comparison of known species of Camelidæ goes."

Collections of vertebrates were secured from the Cold Springs horizon, which is above the center of the series of deposits in the Trinity drainage here referred to the Fleming, and from the Navasota horizon, which is near the base of the section on the Brazos River. These were sent to Dr. W. D. Matthew, who reports as follows:

344. Two miles west of Cold Springs.

"*Trilophodon* sp., parts of lower jaws and separate molars, mostly well preserved.

The best specimen shows a large part of the lower jaw with m_{1-3}, and the molars of the opposite side. Part of the symphysis is preserved, and apparently a little of the alveolus for the lower tusk. Symphysis is moderately long, slender; not decurved. The species is a very small and primitive one in most respects, but the retarding of the posterior teeth so that m_3 does not come into use until m_1 is worn out and dropped is suggestive of Upper Miocene species, such as *T. euhypodon*. The small size and primitive construction of the teeth are more suggestive of Middle Miocene.

Indicated age, probably Middle Miocene.

"*Peccary*, gen. indet., jaw fragment, m_3.

This might be anything from *Perchœrus* (Oligocene) to *Prosthennops* (Upper Miocene). It is small and primitive, so far as the tooth goes, but this is not conclusive, as the progressive characters of this phylum are in the front teeth. I can not identify it with certainty as belonging to any known genus or species.

Indicated age, Oligocene to Upper Miocene.

"*Merychippus* sp., upper and lower teeth.

A rather small and moderately progressive species; it might be Upper or late Middle Miocene.

"? *Alticamelus*, distal ends tibia and metapodial.

Indicated age, Middle Miocene to Lower Pliocene.

"Crocodile and Tortoise fragments.

345. Pointblank road, north of Cold Springs.

"Cervid, cf. *Dromomeryx*, horn fragment, calcaneum.

"Camelid, gen. indet., jaw fragments, proximal phalanx.

"Rhinoceros, cf. *Aphelops*, several fragments limb bones, calcaneum.

"Large Rhinoceros, cf. *Teleoceras* or large *Aphelops*, fragments of limb bones.

"Proboscidean, cf. *Trilophodon*, unciform.

Indicated age of the above specimens, Middle Miocene to Lower Pliocene.

345. One and one-fourth miles north of Cold Springs.

"*Hystricops* sp., upper jaw with m^1; lower molar.

This is more primitive than the one known species of this genus, which is Upper Miocene and Pliocene. It is intermediate between it and the supposed ancestral type, the *Steneofiber* group of the Upper Oligocene and Lower Miocene.

Indicated age, probably Middle Miocene.

"*Blastomeryx* sp., last lower molar.

This is apparently distinct from any known species, decidedly more progressive than those of the Lower Miocene, less so than the Upper Miocene species *B. wellsi*, more perhaps than the Middle Miocene species *B. gemmifer*.

Indicated age, late Middle Miocene or Upper Miocene.

"? *Oreodont*, gen. indet., upper canine and premolar.

Indicated age, Miocene or Lower Pliocene.

"Carnivore, indet., scapholunar and head of metatarsal.

"Proboscidean, cf. *Trilophodon*, fragments of teeth.

Indicated age, Middle Miocene to Pliocene.

"Trionychid fragments.

"Garpike scales.

"? Snake vertebra.

"*Merychippus* sp., cf. *seversus*, upper and lower teeth and fragmentary foot bones; part of right lower jaw, p_4-m_2.

This is a Middle Miocene stage, although small and primitive Merychippi do survive into the Upper Miocene and Lower Pliocene. No trace of any of the distinctively Upper Miocene horses among these fragments.

Indicated age, Middle Miocene.

351. Two miles north of Cold Springs.

"Cervid (? *Dromomeryx*) radius.

"Trionychid plate.

Indicated age, *Dromomeryx* is Middle Miocene to Lower Pliocene, but this evidence is very slight.

352. Red Bluff, Trinity River.

"*Protohippine* horse, lower tooth.

Indicated age, Middle Miocene to Pliocene; nothing more definite.

349. Two and one-fourth miles north of Navasota.

"*Merychippus*, small species, cf. *M. seversus*, but probably not identical, upper molar and fragments of foot bones.

Indicated age, Middle Miocene, but Upper Miocene or Lower Pliocene is not excluded.

"Rhinoceros, cf. *Aphelops*, fragments of teeth, head of radius.

Indicated age, Miocene.'

"Camelid, cf. *Protolabis* or *Procamelus*, fragment lower molar, astragalus, navicular, unciform, fragments of foot bones, ? symphysis of jaw.

Indicated age, Miocene or Pliocene.

"Testudo, large species, carapace fragments.

"Crocodilian, fragments of skull.

"General conclusions: Fauna of Navasota and Cold Springs localities appears to be the same. It is certainly not earlier than Middle Miocene of Osborn's correlation, nor younger than Lower Pliocene. Absence of all characteristically Upper Miocene or Lower Pliocene mammals points to Middle Miocene as the proper correlation. But there are two points which should be considered as making for a possible later date than the comparison indicates: (1) Our land faunas are mostly derived from the north and northwest, and older types may have lingered longer along the Atlantic and Gulf coasts than in the northwest, thus making the fauna seem older than it is; (2) Knowlton regards the Mascall on plant evidence as Upper Miocene. This, if accepted, would set our whole scale of continental Neocene horizons a little higher than does Osborn's correlation. If you give much weight to these considerations, they might serve to set the correlation up to Upper Miocene. The fauna is quite decidedly older than the Blanco.

"A parallel case occurs in Mexico, where Freudenberg has described a mammal fauna of Pleistocene age, but largely of Pliocene type, as compared with our Plains succession."

So far as reported, no vertebrate fossils have been found in the Fleming which are referable to the Blanco or other later Pliocene horizon.

The horizon from which the Navasota fossils were taken and that of the Burkeville fossils are similarly related to the Corrigan-Fleming contact and are near the base of the Fleming beds. The Cold Springs horizon is much higher and is in the upper half of the Fleming. It would, therefore, appear that the base and even the middle of the Fleming west of the Neches is older than the base of the Fleming east of that stream.

West of the Colorado the Neocene beds are composed principally of sands with smaller proportions of clay, while east of the Brazos these conditions are reversed.

The fossils found in the Oakville of the Nueces sections, as determined by Cope—*Protohippus medius, P. perditus, P. placidus*, and *Aphelops meridianus*—indicate a higher horizon than that of Navasota or Cold Springs. Not enough material is at hand to decide its exact relationship to the Burkeville. Based on comparison of vertebrate remains, they may be of similar age; but if the invertebrates are to govern, the Burkeville is more nearly the age of the Lapara, in which case Hager's reference of the sands at Burrs Ferry, on the Sabine, to the Oakville may be true.

Since the fossils obtained from the Fleming beds show that they cover Middle and Upper Miocene and Lower Pliocene time, they must include the eastern time-representatives of the Oakville and Lapara beds, although lithologically the Fleming is dissimilar to the Oakville and Lapara. The Fleming resembles the Lagarto and, while no Middle Pliocene fossils have been found in it, it is possible that the Lagarto may also be represented in the upper portion of these beds as exposed around Woodville and at Hempstead. This would make the Fleming the representative, east of the Brazos River, of the entire Neocene series west of that stream below the Lafayette.

The apparent beds of passage between the upper part of the Corrigan and lower beds of the Fleming may signify comparatively continuous sedimentation in the vicinity of the Trinity River from the Grand Gulf to the Lafayette, while to the east and west of that locality land conditions persisted longer, the older beds were more slowly submerged, and we have the Upper Miocene or Pliocene at the base of the Neocene beds at the eastern extremity and Loup Fork at the western.

The entire sedimentation represents conditions in the west comparable to those of the Staked Plains area and a comparatively arid climate, while on the east they represent moister conditions, favorable to the formation of marshes at or near the mouths of outflowing rivers.

Summary

The outcrops on the Sabine show only one sand – the Corrigan. Whether the Corrigan at this point embraces anything more than the Catahoula is not fully known; but the Oakville sands may be represented, as indicated by Hager, between the Catahoula and the overlying Burkeville stage of the Fleming.

In the area between the Sabine and Trinity the Fayette, if it occurs at all, is represented by remnantal patches.

In the Trinity River section the Fayette and Frio appear to be wanting; but in the Jackson the clays which were predominant on the Sabine have largely given place to sand, so that we have here the Jackson sands overlain by the Corrigan, which, apparently, graduates into the Fleming through a series of interbedded clays and sands. The Oakville is probably represented on the Trinity by some part of the Fleming clays.

On the Navasota the Jackson sands (Wellborn?-Manning) are followed by the Corrigan, and the basal portion of the succeeding Fleming is composed largely of sands, so that we have three formations in which sand is predominant succeeding one another. The presence of Fayette in this section has not been proven, nor has the Oakville certainly been differentiated from the Fleming.

In our earlier work it was considered that the occurrence of opalized wood was characteristic of the Fayette only. East of the Brazos, where the Fayette is lacking, it is found in the Corrigan beds only. If it be representative of the Corrigan rather than of the Fayette, it would change the reference of our beds near Nails Creek, in Lee County, and near Ledbetter, from Fayette to Corrigan.

On the Colorado the section as previously understood will require revision. No determinable fossils other than plants have been found east of White Marl Bluff, and it will require more detailed work than has yet been done to decide the exact correlation of the various beds occurring here.

White Marl Bluff, just west of the Bastrop-Fayette line, carries a fauna which is distinctly that of the Marine beds. The Yegua, beginning at the county line and continuing to near West Point, shows the characteristic dark clays, sands, and lignites of that substage, with their limonite concretions. These beds are followed, in the two exposures noted by Penrose as "Chalk bluffs," by the typical light-colored sands and clays of his Fayette beds. Some of the hard, gray sandstones connected with these are seen just south of West Point. A series of darker colored lignitic sands and clays, which are exposed from the vicinity of Rabbs Creek eastward to the base of Palm Bluff, some three miles from La Grange, may represent the Jackson in this section. It includes the heavy lignite beds at Mantons Bluff. Overlying these, in Palm Bluff, there is a series of sands and clays and quartzites, with opalized wood and palmetto, which we have heretofore included in the Fayette, but which is lithologically similar to the Catahoula of the eastern section. There is a strong unconformity between the massive coarse sands of this stage and the overlying thin-bedded sand and clays, which are also palmetto bearing and which we have heretofore classed as belonging to the Oakville. These thin-bedded sands and clays are overlain unconformably a mile west of La Grange by limy clays with calcareous concretions carrying fragments of bone. The section of Town Bluff, or Monument Bluff, one mile east of La Grange, has already been given.

On the Rio Grande the only sands recognized are the Fayette and Oakville. The fossils of the former, to the southern line of Starr County, are certainly Lower Claiborne. The brown or buff sand between this point and the base of the Frio clays apparently contains no fossils except the large oyster, which Harris has determined as *O. alabamienses* var. *contracta* of Conrad, but which was earlier called *Ostrea georgiana*. This oyster is also common in smaller form in the beds as far up the river as Carrizo, and the buff sands in which it occurs are found interstratified with the other fossiliferous sediments.

Of the few Frio fossils found by us there were none characteristic of beds later than the Lower Claiborne; but this was also the case with what is now regarded as the Jackson, and there is a possibility that when full collections are made from the Frio it may also be classed as Jackson, in which case we will probably have a band of Jackson entirely across the State, showing principally clays on the Sabine and Rio Grande and sands between.

Our knowledge of the Oakville sands on the Rio Grande is not such as will permit more definite statements regarding them than have already been made.

Possible Equivalency

The following table summarizes the possible equivalency of the various sections:

	Rio Grande:	*West Texas:*		*East Texas:*	*Sabine River:*
Pliocene:					
Upper	Reynosa	Reynosa		Lafayette	Lafayette
Middle		Lagarto		Woodville	Woodville
Lower		Lapara		Burkeville	Burkeville
Miocene:			Fleming:		
Upper	Oakville	Oakville			Oakville ?
Middle				Cold Springs	
Lower	Wanting	Wanting		Wanting	
Oligocene:					
Upper		Corrigan ?	Corrigan:	Onalaska	
				Catahoula	Catahoula
Lower	Wanting	Wanting		Wanting	
Eocene:		Manning ?		Manning	
Upper	Frio ?		Jackson:	Caddell	Caddell
		Wellborn ?		Wellborn	
Middle					
U. Claiborne	Wanting	Wanting		Wanting	
L. Claiborne	Frio ?				
	Fayette	Fayette		Fayette ?	
	Yegua	Yegua		Yegua	Yegua
	Marine	Marine		Marine	Marine

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 26, PP. 477-483 DECEMBER 4, 1915

A STRATIGRAPHIC DISTURBANCE THROUGH THE OHIO VALLEY, RUNNING FROM THE APPALACHIAN PLATEAU IN PENNSYLVANIA, TO THE OZARK MOUNTAINS IN MISSOURI[1]

BY JAMES H. GARDNER

(Presented before the Society December 29, 1914)

CONTENTS

RELATIONS AND EXTENT OF THE ZONE OF DISTURBANCE

The writer in recent years has done considerable geologic work in connection with a study of the oil pools that lie along the extension of the Campton anticline and the Rough Creek uplift, in Kentucky. The result of these observations, added to the work previously done by others, has served to show that there is a zone of disturbance in the Paleozoic rocks which completely crosses the State in an east-west direction. To the west it connects with the Shawneetown fault and Bald Hill uplift, which is shown by F. W. DeWolf on the State geologic map of Illinois as completely crossing southern Illinois into Missouri. To the east it connects with the Warfield-Chestnut Ridge zone of folding, which I. C. White has, with a slight interruption, mapped across the State of West Virginia into Pennsylvania, showing the position of it on his State geologic map. From the south line of Pennsylvania, on northward to a point west of Clearfield, this same fold is vouched for by R. R. Hice, State Geologist of Pennsylvania.

The distance now known to be traversed by this structure is approximately 560 miles. From Pennsylvania southward it is one of several

[1] Manuscript received by the Secretary of the Geological Society May 11, 1915.

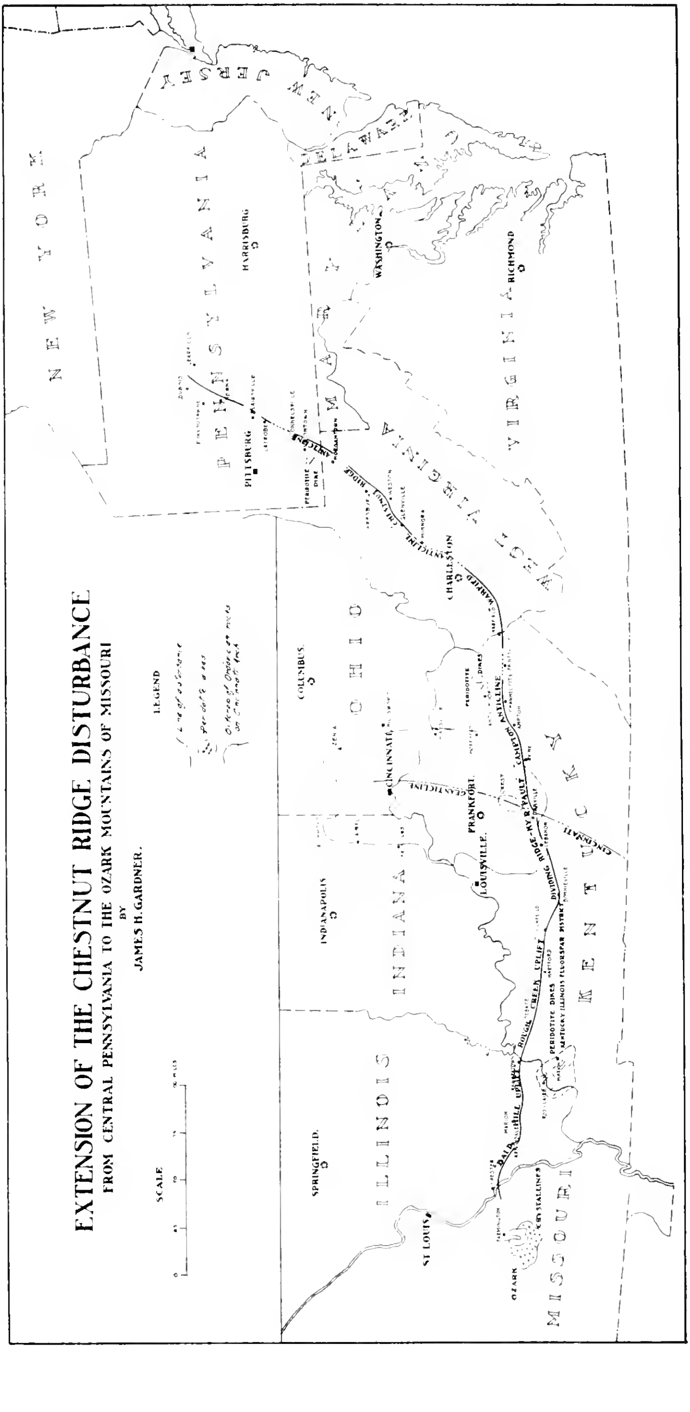


FIGURE 1.—*Map showing Extension of the Chestnut Ridge Disturbance*

anticlines produced by Appalachian folding, but in the Big Sandy Valley along the border line of West Virginia and Kentucky it swings westward along the Ohio Valley, crossing near the crest of the Cincinnati arch and continuing across Kentucky and Illinois to the Ozark uplift. Surely, it shows some sort of structural relationship between Appalachian structure and these other large uplifts to the west.

Nature of the Structure in the Disturbance Zone

The structure varies in its nature from point to point along this zone, depending on whether or not faulting occurs in connection with the folding. In Pennsylvania, West Virginia, and for some distance into Kentucky it has been mapped as a low anticline, accompanied locally by displacements of slight magnitude. But through central Kentucky and westward to and through Illinois faulting is the predominant feature, though at places it is a fairly regular anticline. In Ohio County, Kentucky, it consists of a fault zone with parallel anticlinal folding on the south side. Where faulted, the upthrow side is the south side or southeast side, depending on the direction of strike and showing a thrust from the south or southeast. It bears out consistently the fact that the thrust was away from the direction of the seashore, just as is true of all Appalachian structure. Where folded without faulting, the steeper side of the anticline is on the north or northwest, depending on the curve of the strike line.

The writer regrets that he is not in a position to make a more complete study of this most interesting subject. What is given here, along with the accompanying map, is to serve as a basis for more detailed investigations by others. Facts as now known warrant a closer study of the relations of the Ozark Mountains and Cincinnati geanticline to Appalachian folding. The writer does not have the data before him nor the time at his command to go into a detailed description of this long line of disturbance that appears to tie the three regions together. He does not attempt to say just what it means. Offhand it suggests that Appalachian folding was accompanied by strong folding at the same time on the Cincinnati arch and in the Ozark Mountains, this line being a relief of the stresses that were set up across the intermediate areas.

Mapping of the Line of Weakness

Very little need be vouched for by the writer in connection with the authenticity of the map presented here which shows the position of this line of weakness. Knowledge regarding it in Kentucky has not heretofore been assembled, though Orton, Munn, Miller, Campbell, and Glenn have mapped respective portions of it. The Rough Creek uplift, mapped by Orton; the Campton anticline, mapped by Munn; the Kentucky River fault zone, mapped by Campbell, and its extension, mapped by Miller, as well as the Sebree structure of Glenn, are all but sections of it in Kentucky. The writer's work on the Hartford Quadrangle and former studies in the region of Dividing Ridge and eastward has brought to light the missing links in this long chain which has been unconsciously lined up by several well known geologists. From central Pennsylvania to eastern Missouri is a long way for such a structure to continue and not have been previously known in the geology of North America; but such appears to be the case. At least the writer has seen no literature regarding it as a unit nor has he heard it discussed.

On the accompanying map a solid line is drawn where the structure is known to be evident, and at points where it has not been mapped or is not known to the writer it is shown by broken dashes. It will be seen at a glance that the broken line constitutes a very small percentage of the line of extension. At a point northeast of Charleston, West Virginia; at another near Paintsville, Kentucky, and a third just north of Connellsville, Pennsylvania, the folding is either obscure or has not been mapped. At a point near Lebanon, Kentucky, the writer has not seen the structure nor has it been mapped; but its presence here in the form of a strong fault is vouched for by F. J. Fohs, formerly a member of the Kentucky Geological Survey. It is at once evident that the points where its presence is obscure are so small as to be negligible.

Intrusive Materials

In three known localities near the line of this disturbance there are intrusions of peridotite; all three of these districts are well known: one is in Fayette and Greene counties, Pennsylvania, described by R. R. Hice in the biennial report, 1910-1912, of the State Geological Survey of Pennsylvania; one is in Elliott County, Kentucky, discovered by A. R. Crandall and described by J. S. Diller in Bulletin Number 38 of the United States Geological Survey; the third is the Kentucky-Illinois fluorspar district, first described by Ulrich and Smith in Professional Paper Number 36 of the United States Geological Survey.

These intrusions of periodotite are all remarkable in that they are in isolated districts remote from all other intrusions of igneous rocks. The fact that all three of these localities lie near a line of regional disturbance throws a new light on their occurrence. That the pressure initiating this line of stratigraphic yielding affected the rocks to remote depths is certainly strongly suggested by the presence of these igneous intrusions.

There are no known dikes that cut through the surface rocks on the Cincinnati geanticline, either on the Kentucky or Tennessee arches, but there are numerous lead and zinc bearing veins, composed of calcite, barite, and fluorite, that do cut across the Ordovician rocks of these domes. Similar veins in the Kentucky-Illinois fluorspar district are related to the dikes of peridotite, where they cut walls of limestone and are accompanied by faulting. The depths to which the mineral veins continue on the Cincinnati geanticline are not known; the Chinn vein of calcite and fluorite on the Kentucky River, in Mercer County, Kentucky, passes down into the lowest rocks exposed in Kentucky, the same being the Camp Nelson beds of the Ordovician system. These veins completely fill wide fissures in limetone, and to what extent they have been eroded may never be known; but, in view of the facts brought to light in this paper, the writer suggests the strong probability that beneath these mineral-bearing veins there are intrusions of igneous rock; that the veins were formed from hot ascending solutions and vapors passing upward to the surface along crevices which the intrusions formed, but only partially filled. In the case of the mineral veins of the Kentucky-Illinois district, the dikes came near, if not entirely to, the land surface as it existed at the time of the intrusion; but the peridotite in Fayette County, Pennsylvania, according to Hice, did not reach the surface. It is found cutting across the Pittsburgh coal bed, where it was discovered in mine workings, but dies out in the Pennsylvanian rocks that overlie the coal. The dikes of Elliott County, Kentucky, are found on the surface cutting across rocks of the Coal Measures, but whether or not they reached the surface as it existed at the time of the intrusion is not known. There are no mineral veins associated with the intrusions, either in Fayette County, Pennsylvania, or in Elliott County, Kentucky, for the reason probably that they cut sandstone and shale instead of limestone and did not offer the proper conditions for precipitation and metasomatic replacement, such as existed in the Kentucky-Illinois district or on the central Kentucky and Nashville arches of the Cincinnati uplift, where the veins have walls of limestone.

Broad geologic Features

A. R. Crandall recognized the importance of considering the broad geologic features in connection with the dikes of Elliott County and pointed out the fact that they are near an east-west anticline which is merely a section of the structure discussed in this paper. In the paper by Diller above cited, Crandall is quoted partially as follows:

"The most striking modifications of the general dip by transverse flexure is found along a belt which extends from the Big Sandy River, south of Louisa, in Lawrence County, to a point opposite to and but a few miles east of the dikes. The dip along this belt is to the northward from a ridge of conglomerate rock which elsewhere falls below the drainage along the border of the coal field. It is along this slope that the oil and gas developments of Lawrence and Martin counties are found. The prominent geological basin centering at Willard is formed by the junction of the northward dip with the general southeast dip, increased by local depression. Willard is about six miles in a direct line northeast of the dike. The dike is found near the juncture of two lines of flexure: one parallel with the axis of uplift of the Coal Measures and the other a transverse or secondary undulation of considerable local prominence. Whether or not these conditions throw light on the occurrence of the igneous rock far from any region of great disturbance, they form an interesting, if not necessary, background to any general view of the dike and its surroundings."

Although not prominent on the surface and having only a very slight topographic expression, this long line of folding and faulting is deep seated in its character. There was evidently a yielding of the plastic under-mass at the time of origin, so that the semi-fluid material far beneath the sedimentary series was folded in conformity with the overlying structure. At points of special weakness, where faulting was prominent, the pressure against the igneous mass was sufficient to force dikes entirely across the sedimentary rocks to the surface. But at other points the intrusive material penetrated only to such distances into the overlying rocks as the pressure, viscosity, and resistance would permit. Where the dikes found their way to the surface between walls of limestone, as in the Kentucky-Illinois fluorspar district, ideal conditions existed for the formation of mineral veins. In the sandstone and shale rocks of the Coal Measures in eastern Kentucky and in Pennsylvania no veins are found, and in at least one of the two districts the intrusion did not reach the surface. So it seems reasonable to suppose that on the central Kentucky and Nashville domes of the Cincinnati geanticline dikes may have penetrated into the Cambrian and basal Ordovician systems, the pressure behind the intrusions being relieved before the igneous rock reached the surface, but crevices were formed on upward to the surface, which became sealed by mineral veins of barite, calcite, and fluorite from ascending vapors and solutions.

On the accompanying map the names are shown of the different sections of the line of disturbance here discussed, which indicate something of its nature from point to point. Through the literature of the state geological surveys of Pennsylvania, West Virginia, Kentucky, Illinois, and of the United States Geological Survey there are numerous references that bear on the subject. But the object of this paper is to point out the connection between known segments and leave the matter of detailed descriptions for a more complete report, which should be prepared by some one who has the time at his command to assemble the known data and to make additional observations in the field. It will be found that the nature of the disturbance varies from a low anticline, with dips of from 25 to 100 feet per mile in Pennsylvania, West Virginia, and eastern Kentucky, to a fault zone showing displacements as much as 1,000 feet westward through Kentucky and across southern Illinois.

INDEX TO VOLUME 26

THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS, 1915

President:

Arthur P. Coleman, Toronto, Canada

Vice-Presidents:

L. V. Pirsson, New Haven, Conn.
H. P. Cushing, Cleveland, Ohio
Edward O. Ulrich, Washington, D. C.

Secretary:

Edmund Otis Hovey, American Museum of Natural History, New York, N. Y.

Treasurer:

Wm. Bullock Clark, Johns Hopkins University, Baltimore, Md.

Editor:

J. Stanley-Brown, 26 Exchange Place, New York, N. Y.

Librarian:

F. R. Van Horn, Cleveland, Ohio

Councilors:

(Term expires 1915)

Whitman Cross, Washington, D. C.
Willet G. Miller, Toronto, Canada

(Term expires 1916)

R. A. F. Penrose, Jr., Philadelphia, Pa.
W. W. Atwood, Cambridge, Mass.

(Term expires 1917)

Charles K. Leith, Madison, Wis.
Thomas L. Watson, Charlottesville, Va.