W. Davis
Dept. of Chemistry
Univ of Cal.
Berkeley

THE

ORE DEPOSITS

OF THE

UNITED STATES AND CANADA.

BY

JAMES FURMAN KEMP, A.B., E.M.,

PROFESSOR OF GEOLOGY IN THE SCHOOL OF MINES, COLUMBIA UNIVERSITY.

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PREFACE.

THE following pages presuppose for their apprehension some acquaintance with geology and mineralogy. The materials for them have been collected and arranged in connection with lectures on economic geology, first at Cornell University and later at the School of Mines, Columbia College. To the descriptions of others the author has endeavored to add, as far as possible, observations made by himself in travel during the last ten years. The purpose of the book is twofold, and this fact has been conscientiously kept in view. It is, on the one hand, intended to supply a condensed account of the metalliferous resources of the country, which will be readable and serviceable as a text-book and work of reference. For this reason every effort has been put forth to make the bibliography complete, so that, in cases where fuller accounts of a region are desired, the original sources may be made available in any good library. But, on the other hand, it has also been the hope and ambition of the author to treat the subject in such a way as to stimulate investigation and study of these interesting phenomena. If, by giving an extended view over the field, and by making clear what our best workers have done in late years toward explaining the puzzling yet vastly important questions of origin and formation, some encouragement may be afforded those in a position to observe and ponder, the second aim will be fulfilled. In carrying out this purpose, the best work of recent investigators on the origin and changes of rocks, especially as brought out by microscopic study, has been kept constantly in mind, and likewise in the artificial production of the ore and gangue minerals. So much unsound and foolish theorizing has been uttered and believed about ores, that too much care cannot be exercised in basing explanations on reasonable and right foundations.

Acknowledgments are due to many friends for encouragement, suggestion, and criticism. To Prof. Henry S. Williams, now of Yale, but late of Cornell, whose interest made the book possible, these are especially to be made. On particular regions much advice has been obtained from Dr. W. P. Jenney, for which the author is grateful. In the same way Prof. H. A. Wheeler, of St. Louis, Prof. R. A. F. Penrose, of Chicago, and several other friends have contributed. Dr. R. W. Raymond suggested the method of enumerating the paragraphs. It has the advantages of being elastic and of showing at once in what part of the book any paragraph is situated.

The geologists of the United States Geological Survey, who have been engaged in the study of our great mining regions, especially in the West, have laid the whole scientific world under a debt of gratitude, and in this country have probably been the most potent influences toward right geological conceptions regarding ores. Of authors abroad, Von Groddeck has been a means of inspiration to all readers of German who have interested themselves in this branch of geology. The writer cannot well forbear acknowledging their influence.

Should errors be noted by any reader, the writer will be very appreciative of the kindness if his attention is called to them.

J. F. KEMP.

COLUMBIAN COLLEGE, IN THE CITY OF NEW YORK, 1892.

PREFACE TO THE SECOND EDITION.

In the second edition many pages have been rewritten and expanded. The endeavor has been also made to introduce into the body of the work the new materials that have become available in the last year. This is especially true of iron ores, of the geology of the Sierras, and of nickel and cobalt. In all some fifty pages of new matter have been added, and fifteen cuts. Acknowledgments are herewith made to Professors W. H. Pettee, of Ann Arbor; H. S. Munroe, of New York; and C. H. Smyth, Jr., of Hamilton College; and to Mr. now Prof. H. L. Smyth, of Cambridge, and Prof. W. C. Knight, of Laramie, for suggestions, as requested in the preface to the first edition.

1895. J. F. K.

PREFACE TO THE THIRD EDITION.

In the third edition the title has been expanded so as to include Canada, since the nature of the contents now justifies this change. About one hundred pages of new matter have been added, and considerable portions of the former text have been rewritten. The figures have been doubled in number, and many maps have been introduced. The writer's thanks are due for advice and assistance to Messrs. W. H. Weed, H. W. Turner and John D. Irving, of the United States Geological Survey, to Mr. H. F. Bain, of the Iowa Geological Survey, to Mr. S. S. Fowler, of Nelson, B. C., and to many of his students, now in the active practice of the profession of mining engineering. J. F. K.

December, 1899.

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ABBREVIATIONS.

Amer. Assoc. Adv. Sci., or *A. A. A. S.*—Proceedings of the American Association for the Advancement of Science.

Amer. Geol.—*American Geologist.* Minneapolis, Minn.

Amer. Jour. Sci.—*American Journal of Science,* also known as *Silliman's Journal.* Fifty half-yearly volumes make a series. The *Journal* is now (1893) in the third series. In the references the series is given first, then the volume, then the page.

Ann. des Mines—*Annales des Mines.* Paris, France.

Bost. Soc. Nat. Hist.—See Proceedings of same.

Bull. Geol. Soc. Amer.—Bulletin of the Geological Society of America.

Bull. Mus. Comp. Zoöl.—Bulletin of the Museum of Comparative Zoölogy, Harvard University. Cambridge, Mass.

B. und H. Zeitung.—*Berg- und Huettenmännische Zeitung.* Leipzig, Germany.

Neues Jahrb.—Neues Jahrbuch für Mineralogie, Geologie und Palæontologie, often called Leonhard's Jahrbuch. Stuttgart, Germany.

Oest. Zeit. f. Berg. u. Huett.—*Oesterreichische Zeitschrift für Berg- und Huettenwesen.* Vienna, Austria.

Philos. Mag.—*Philosophical Magazine.* Edinburgh, Scotland.

Proc. Amer. Acad.—Proceedings of the American Academy of Arts and Sciences. Boston, Mass.

Proc. and Trans. N. S. Inst. Nat. Sci.—Proceedings and Transactions of the Nova Scotia Institute of Natural Science. Halifax, Nova Scotia.

Proc. Bost. Soc. Nat. Hist.—Proceedings of the Boston Society of Natural History. Boston, Mass.

Proc. Colo. Sci. Soc.—Proceedings of the Colorado Scientific Society. Denver, Colo.

Raymond's Reports.—Mineral Resources West of the Rocky Mountains, Washington, 1867–1876. The first two volumes were edited by J. Ross Browne, the others by R. W. Raymond.

Trans. Amer. Inst. Min. Eng.—Transactions of the American Institute of Mining Engineers.

Trans. Min. Assoc. and Inst., Cornwall.—Transactions of the Mining Association and Institute of Cornwall. Tuckingmill, Camborn, England.

Trans. N. Y. Acad. of Sci.—Transactions of the New York Academy of Sciences, formerly the Lyceum of Natural History.

Zeit. d. d. g. Ges.—Zeitschrift der deutschen geologischen Gesellschaft. Berlin, Germany.

Zeitsch. f. B., H. und S. im. P. St.—Zeitschrift für Berg-, Huetten-, und Salinenwesen im Preussischen Staat. Berlin, Germany.

Zeitschr. f. Krys.—Zeitschrift für Krystallographie. Munich, Germany.

Zeitsch f. prakt. Geol.—Zeitschrift für praktische Geologie. Berlin, Germany.

The remaining abbreviations are deemed self-explanatory. The numbering of the paragraphs is on the following principle: The first digit refers invariably to the part of the book, the second digits to the chapter, and the last two to the paragraph of the chapter.

PART I.

INTRODUCTORY.

CHAPTER I.

GENERAL GEOLOGICAL FACTS AND PRINCIPLES.

1.01.01.[1] In the advance of geological science the stand points from which the strata forming the earth's crust are regarded necessarily change, and new points of view are established. In the last few years two have become especially prominent, and there are now two sharply contrasted positions from which to obtain a conception of the structure and development of the globe. The first is the physical, the second the biological. For example, we consider the surface of the earth as formed by rocks, differing in one part and another, and these different rocks or groups of rocks are known by different names. The names have no special reference to the animal remains found in them, but merely indicate that series of related strata form the surface in particular regions. On the other hand, the rocks are also regarded as having been formed in historical sequence, and as containing the remains of organisms characteristic of the period of their formation. They illustrate the development of animal and vegetable life, and in this way afford materials for historical-biological study. In the original classification, the biological and historical considerations are all-important. But when once the rocks are placed in their true position in the scale, and are named, these considerations, for many purposes, no longer concern us. The formations are regarded simply as members in the physical constitution of the outer crust. The International Geological Congress held in Berlin in 1885 expressed these different points of view in two parallel and equivalent series of geological terms, which

[1] The numbers at the beginning of the paragraphs are so arranged that the first figure denotes the part of the book, the next two figures the chapter, and the last two the paragraph. Thus 1.06.21 means Part I., Chapter VI., Paragraph 21 under Chapter VI.

are tabulated on p. 4. They are now very generally adopted. For clearness in illustration, the equivalent terms employed by Dana are appended.

Biological Terms.	*Physical Terms.*	*Dana's Terms.*	*Illustrations.*
Era.	Group.	Time.	Paleozoic.
Period.	System.	Age.	Devonian.
Epoch.	Series.	Period.	Hamilton.
Age.	Stage.	Epoch.	Marcellus.

The United States Geological Survey divides as follows: Era and System, Period and Group, Epoch and Formation. In considering the ore deposits of the country, we employ only the physical terms. We understand, of course, the chronological position of the systems in historical sequence, but it is of small moment in this connection what may be the forms of life inclosed in them. The purely physical character of the rocks—whether crystalline or fragmental; whether limestone, sandstone, granite or schists; whether folded, faulted, or undisturbed—are the features on which we lay especial stress. In all the periods the same sedimentary rocks are repeated, and in the hand specimen it is almost always impossible to distinguish those of different ages from one another. The classification, briefly summarized, is as follows:

1.01.02. Archean Group.—I. Laurentian System. II. Huronian System. Additional subdivisions have been introduced by Canadian and Minnesota geologists (Animikie, Montalban, etc.), and it is a growing custom to call all those which are sediments or later than sediments, especially in the region of the Great Lakes, by the name of Algonkian. (See discussion under Example 9.)

Paleozoic Group.—III. Keweenawan System. (This may belong with the Archean.) IV. Cambrian System: (*a*) Georgian Stage; (*b*) Acadian Stage; (*c*) Potsdam Stage. V. Lower Silurian System. (*A*) Canadian Series: (*a*) Calciferous Stage; (*b*) Chazy Stage. (This will probably experience revision.) (*B*) Trenton Series: (*a*) Trenton Stage; (*b*) Utica Stage; (*c*) Cincinnati or Hudson River Stage. VI. Upper Silurian System. (*A*) Niagara Series: (*a*) Medina Stage; (*b*) Clinton Stage; (*c*) Niagara Stage. (*B*) Salina Series. (*C*) Lower Helderberg Series. VII. Devonian System. (*A*) Oriskany Series. (*B*) Corniferous Series; (*a*) Cauda-Galli Stage;

(*b*) Schoharie Stage; (*c*) Corniferous Stage. (*C*) Hamilton Series: (*a*) Marcellus Stage; (*b*) Hamilton Stage; (*c*) Genesee Stage. (*D*) Chemung Series: (*a*) Portage Stage; (*b*) Chemung Stage. VIII. Carboniferous System. (*A*) Sub-carboniferous or Mississippian Series. (*B*) Carboniferous Series. (*C*) Permian Series.

MESOZOIC GROUP.—IX. Triassic System. X. Jurassic System. IX. and X. are not sharply divided in the United States, and we often speak of Jura-Trias. A stratum of gravel and sand, along the Atlantic coast, that contains Jurassic fossils has been called the Potomac formation by McGee. XI. Cretaceous System. Subdivisions differ in different parts of the country. Atlantic Border: (*a*) Raritan Stage; (*b*) New Jersey Greensand Stage. Gulf States: (*a*) Tuscaloosa Stage; (*b*) Eutaw Stage; (*c*) Rotten Limestone Stage; (*d*) Ripley Stage. Rocky Mountains: (*a*) Comanche Stage; (*b*) Dakota Stage; (*c*) Benton Stage; (*d*) Niobrara Stage; (*e*) Pierre Stage; (*f*) Fox Hills Stage; (*g*) Laramie Stage. Stages (*c*) and (*d*) are sometimes collectively called the Colorado Stage; while (*e*) and (*f*) are grouped as the Montana Stage. Pacific Coast: (*a*) Shasta Stage; (*b*) Chico Stage.

CENOZOIC GROUP.—XII. Tertiary System. Gulf States. (*A*) Eocene Series: Midway, Lignitic, Lower Claiborne, Claiborne. Jackson and Vicksburg Stages. (*B*) Oligocene, wanting. (*C*) Miocene Series, Chattahoochee, Chipola and Chesapeake Stages. (*D*) Pliocene Series: Floridian Stage. Interior Region. (*A*) Eocene Series: Puerco, Torrejon, Wasatch, Wind River, Bridger and Uinta Stages. (*B*) Oligocene Series: White River Stage. (*C*) Miocene Series: John Day, Deep River, and Loup Fork Stages. (*D*) Pliocene Series: Good-night (Palo Duro) and Blanco Stages. Pacific Coast. The Eocene is called the Tejon. Miocene and Pliocene are used for the others.

XIII. Quaternary System. (*A*) Glacial Series. (*B*) Champlain Series. (*C*) Terrace Series. (*D*) Recent Series. Pleistocene is sometimes employed as a name for the early Quaternary, especially south of the Glacial Drift. In accord with the practice of the U. S. Geological Survey, the Tertiary is now generally divided into the Eocene and the Neocene (including Oligocene, Miocene and Pliocene) series.

Other terms are also often used, especially when we do not wish to speak too definitely. "Formation" is a word loosely employed for any of the above divisions. "Terrane" is used much in the same way, but is rather more restricted to the lesser divisions. A stratum is one of the larger sheet-like masses of sedimentary rock of the same kind; a bed is a thinner subdivision of a stratum. "Horizon" serves to indicate a particular position in the geological column; thus, speaking of the Marcellus Stage, we say that shales of this horizon occur in central New York.

1.01.03. The rock species themselves are classified into three great groups—the Igneous, the Sedimentary, and the Metamorphic.

The Igneous (synonymous terms, in whole or in part: massive, eruptive, volcanic, plutonic) include all those which have solidified from a state of fusion. They are marked by three types of structure—the granitoid, the porphyritic, and the glassy, depending on the circumstances under which they have cooled. Under the first type of structure come the granites, syenites, diorites, gabbros, diabases, and peridotites; under the second, quartz-porphyries, rhyolites, porphyries, trachytes, porphyrites, andesites, and basalt; under the third, pitchstone, obsidian, and other glasses.

The Sedimentary rocks are those which have been deposited in water. They consist chiefly of the fragments of pre-existing rocks and the remains of organisms. They include gravel, conglomerate, breccia, sandstone—both argillaceous and calcareous—shales, clay, limestone, and coal. In volcanic districts, and especially where the eruptions have been submarine, extensive deposits of volcanic lapilli and fine ejectments have been formed, called tuffs. With the sedimentary rocks we place a few that have originated by the evaporation of solutions, such as rock salt, gypsum, etc.

The Metamorphic rocks are usually altered and crystallized members of the sedimentary series, but igneous rocks are known to be subject to like change, especially when in the form of tuffs. They are all more or less crystalline, more or less distinctly bedded or laminated, of ancient geological age, or in disturbed districts. They include gneiss, crystalline schists, quartzite, slate, marble, and serpentine.

After a brief topographical survey, we shall employ the above terms to summarize the geological structure of the United States. The several purely artificial territorial divisions are made simply for convenience. Nothing but intelligent travel will perfectly acquaint one with the topographical and geological structure of the country, and in this connection Macfarlane's "Geological Railway Guide" and a geological map are indispensable.

1.01.04. On the east we note the great chain of the Appalachians, with a more or less strongly marked plain between it and the sea. This is especially developed in the south, and is now generally called the Coastal Plain. It is of late geological age, and contains the pine barrens and seacoast swamps. The Appalachians themselves consist of many ridges, running on the north into the White Mountains, the Green Mountains, and the Adirondacks. Farther south the Highlands of New York and New Jersey, the South Mountain of Pennsylvania, the Alleghenies, the Blue Ridge, and the other southern ranges make up the great eastern continental mountain system. In western New York and Ohio we find a rolling, hilly country; in Kentucky and Tennessee, elevated tableland, with deeply worn river valleys. Indiana, Illinois, Iowa, and Missouri contain prairie and rolling country, more broken in southern Missouri by the Ozark uplift. In Michigan, Wisconsin, and Minnesota, the surface is rolling and hilly with numerous lakes. In Arkansas, Louisiana, and Mississippi there are bottom lands along the Mississippi and Gulf with low hills back in the interior. Across Arkansas and Indian Territory runs the east and west Ouachita uplift. West of these States comes the region of the great plains, and then the chain of the Rocky Mountains, consisting of high, dome-shaped peaks and ridges, with extended elevated valleys (the parks) between the ranges. Some distance east of the main chain are the Black Hills, made up of later concentric formations around a central, older nucleus. To the east lies also the extinct volcanic district of the Yellowstone National Park. In western Colorado, Utah, and New Mexico, between the Rocky Mountains and the Wasatch, is the Colorado plateau, an elevated tableland. This is terminated by the north and south Wasatch range, and is traversed east and west by the Uintah range. To the west lies the region called the Great Basin, characterized by alkaline deserts, and subordinate north and south ranges of mountains. Next comes the chain of the Sierra Nevada, and lying between it and the Coast range is the great north and south valley of California. This rises in the comparatively low Coast range, which slopes down to the Pacific Ocean. To the north, these mountains extend into eastern Oregon and Washington, with forests and fertile river valleys. These topographical features are important in connection with what follows, for the reason that the ore deposits especially favor mountainous regions. Mountains themselves are due to geological disturbances—upheaval, folding, faulting, etc.—and are often accompanied by great igneous outbreaks. They therefore form the topographical surroundings most favorable to the development of cavities, waterways, and those subterranean, mineral-bearing circulations which would fill the cavities or replace the rock with useful minerals.

1.01.05. *Geological Outline. I. New England, New York, New Jersey, and Eastern Pennsylvania District.*—In New England and northern New York the Archean is especially developed, forming the White Mountains, the Adirondacks, and the Highlands of New York and New Jersey. These all consist of granite and other igneous rock, of gneiss, and of crystalline schists. There are also great areas of metamorphic rocks whose true age may be later. The Green Mountains are formed of such, and were elevated at the close of the Lower Silurian. In New England there are small, scattered exposures of the undoubted Paleozoic (Devonian, Carboniferous). In eastern New York, and to some extent in New Jersey and eastern Pennsylvania, the entire Paleozoic, except the Carboniferous, is strongly developed. Up and down the coast there are narrow north and south estuary deposits of red Jura-Trias sandstone, which are pierced by diabase eruptions. The Cretaceous clays are strong, and the Tertiary strata occur at Martha's Vineyard, in Massachusetts, while over all, as far south as Trenton, is found the glacial drift. Between the Archean ridges of the Highlands, and the first foldings of the Paleozoic on the west is found the so-called Great Valley, which also runs to the south and is a very important topographic and geologic feature. It follows the outcrop of the Siluro-Cambrian limestones, to whose erosion it is due.

II. *Eastern-Middle and Southeastern Coast District.*—The low plains of the coast are formed by Quaternary, Tertiary, and Cretaceous, consisting of gravel, sand, shell beds, and clay. Inland there are exposures of Jura-Trias, as in the north. The Archean crystalline rocks are also seen at numerous points not far from the ocean. Florida is largely made up of limestones, with a mantle of calcareous sand.

III. *Allegheny Region and the Central Plateau.*—The Appalachian mountain system, from New York to Alabama, consists principally of folded Paleozoic (largely Carboniferous), with Archean ridges on its eastern flank. There is an enormous development of folds, with northeast and southwest axes. On the west they are succeeded by the plateau region of Kentucky and Tennessee, chiefly Paleozoic. Along central latitudes the Archean does not appear again east of the Mississippi.

IV. *Region of the Great Lakes.*—In Michigan, Wisconsin, and Minnesota the Archean rocks are extensively developed, both Laurentian and Huronian. Around Lake Superior are found the igneous and sedimentary rocks of the Keweenawan, followed by the lower Paleozoic. Lake Michigan and Lake Huron are surrounded by Silurian, Devonian, and Carboniferous; Lake Erie by Devonian; Lake Ontario, by Silurian. Running south through Ohio, we find an important fold known as the Cincinnati uplift, with a north and south axis. It was elevated at the close of the Lower Silurian. In the lower peninsula of Michigan and in eastern Ohio and western Pennsylvania the Carboniferous is extensively developed.

V. *Mississippi Valley.*—The headwaters of the Mississippi are in the Archean. It then passes over Cambrian and Silurian strata in Minnesota. Wisconsin, northern Iowa, and Illinois, which in these States lie on the flanks of the Archean "Wisconsin Island" of central Wisconsin. These are succeeded by subordinate Devonian, and in Southern Iowa, Illinois, and Missouri by Carboniferous. In southern Missouri the Lower Silurian forms the west bank. Thence to the Gulf the river flows on estuary deposits of Quaternary age, with Tertiary and Cretaceous farther inland.

VI. *The Gulf Region.*—The Gulf States along the water front are formed by the Quaternary. This is soon succeeded inland by very extensive Tertiary beds, which are the principal formation represented.

VII. *The Great Plains.*—West of the Paleozoic rocks of the States bordering on the Mississippi is found a broad strip of Cretaceous running from the Gulf of Mexico to and across British America, and bounded on the west by the foothills of the Rocky Mountains. A few Tertiary lake deposits are found in it. Quite extensive Triassic rocks are developed on the south. The surface is a gradually rising plateau to the Rocky Mountains.

VIII. *Region of the Rocky Mountains, the Black Hills, and the Yellowstone National Park.* The Rocky Mountains rise from the prairies in long north and south ranges, consisting of Archean or Algonkian axes with the Paleozoic in relatively small amount in Colorado, but present in a large cross-section in Montana. There is abundant Mesozoic on the east and west flanks. In the parks are found lake deposits of Tertiary age. There are also great bodies of igneous rocks, which attended the various upheavals. The principal upheavals began at the close of the Cretaceous. The outlying Black Hills consist of an elliptical Archean core, with concentric Paleozoic and Mesozoic strata laid up around it. The National Park consists chiefly of igneous (volcanic) rocks in enormous development.

IX. *Colorado Plateau.*—The Rocky Mountains shade out on the west into a great elevated plateau, extending to central Utah, where it is cut off by the north and south chain of the Wasatch. The Uintah Mountains are an east and west chain in its northern portion. The rocks on the north are chiefly Tertiary, with Mesozoic and Paleozoic in the mountains. To the south are found Cretaceous and Triassic strata, with igneous rocks of great extent. The principal upheaval of the Wasatch began at the close of the Carboniferous, and seems still to be in progress.

X. *Region of the Great Basin.*—Between the Wasatch and the Sierra Nevada ranges is found the Great Basin region, once lake bottoms, now very largely alkaline plains of Quaternary age. The surface is diversified by subordinate north and south ranges, formed by great outflows of eruptive rocks, and by tilted Paleozoic. The ranges are extensively broken and the stratified rocks often lie in confused and irregular positions. There is no drainage to the ocean.

XI. *Region of the Pacific Slope.*—The depression of the Great Basin is succeeded by the heights of the Sierra Nevada. On the west the Sierras slope down into the Central Valley of California. The flanks are largely metamorphosed Jurassic and Cretaceous rocks with great developments of igneous outflows. The surface rises again in the Coast ranges, which slope away farther west to the ocean. In addition to the Jurassic and Cretaceous, the Tertiary and Quaternary are also developed, and in the Coast ranges are many outflows of igneous rock. The principal upheaval of the Sierra Nevada began at the close of the Jurassic, that of the Coast range at the close of the Miocene Tertiary.

XII. *Region of the Northwest.*—Washington and Oregon, along the coast, are formed by Cretaceous and Tertiary strata similar to California. But inland, immense outpourings of igneous rocks cover the greater portion of both States and extend into Idaho. On the north the Carboniferous is extensive, running eastward into Montana. Quaternary and Tertiary lake deposits are also not lacking.

1.01.06. *On the Forms Assumed by Rock Masses.*—All sedimentary rocks have been orginally deposited in beds, approximately horizontal. They are not of necessity absolutely horizontal, because they may have been formed on a sloping bottom, or in a delta, in both of which cases an apparent dip ensues. We find them now, however, in almost all cases changed from a horizontal position by movements caused primarily by the compressive strain in the earth's crust. Beds thus assume folds known as monoclines, anticlines, and synclines.

A monocline is a terrace-like dropping of a bed without changing the direction of the dip. There is usually a zone, more or less shattered, along the folded portion, and such a zone may become a storage receptacle. Monoclines of a gentle character in Ohio, which have been detected by Orton in studies of natural gas, have been called "arrested anticlines." An anticline is a convex fold with opposing dips on its sides, while a syncline is a concave fold with the dips on its sides coming together. We speak of the axis of a fold, and this marks the general direction of the crest or trough. The axis is seldom straight for any great distance. Folds are often broken and faulted across the strike of their axes, and this causes what is called a "pitch" of the axes and makes the original dips run diagonally down on the final one. Folds are the primary cause of the phenomena of dip and strike. Horizontal beds have neither. A dome-like elevation of the beds, with dips radiating in every direction from its summit, is called a quaquaversal, but it is a rare thing. An anticline or syncline with equal dips on opposite sides of its axis is called a normal fold. If the dip is steeper on one side than on the other, it is an overthrown fold; if the sides are crushed together, it is a collapsed, or sigmoid fold.

Igneous rocks are in the form of sheets (the term "bed" should be restricted to sedimentary rocks), knobs or bosses, necks, laccolites, and dikes. A sheet is the form naturally assumed by surface flows, and by an igneous mass which has been intruded between beds. It has relatively great length and breadth as compared with its thickness, and coincides with its walls in dip and strike. A knob, or boss, is an irregular mass, of approximately equal length and breadth, which may be related in any way to the position of its walls. Such masses are often left projecting by erosion. A neck is the filled conduit of a volcano, which sometimes remains after the overlying material has been denuded. A laccolite is a lenticular sheet which has spread between beds laterally from its conduit, and thus has never reached the surface, unless revealed by subsequent erosion. A dike is a relatively long and narrow body of igneous rock which has been intruded in a fissure. It is analogous to a vein, but the term "vein" ought not to be applied to an undoubtedly igneous rock. Some granitic mixtures, however, of quartz, feldspar, and mica, leave us yet in uncertainty as to whether they are dikes or veins. (See Example 51.) From the above it will be seen at once that bosses, knobs, and necks may be practically indistinguishable.

CHAPTER II.

THE FORMATION OF CAVITIES IN ROCKS AND THEIR SECONDARY MODIFICATION—SUBTERRANEAN WATERS.

1.02.01. *Tension Joints.*—In the contraction caused by cooling, drying, or hardening, both igneous and sedimentary rocks break into more or less regular masses along division planes, called joints, or diaclases. Numerous cracks and small cavities result. Basaltic columns, or the prismatic masses, formed by the separation, in cooling and consolidating, of the heavier basic rocks, along planes normal to the cooling surface, are good illustrations of the first. Larger manifestations of them often become filled with zeolites, calcite, and other secondary

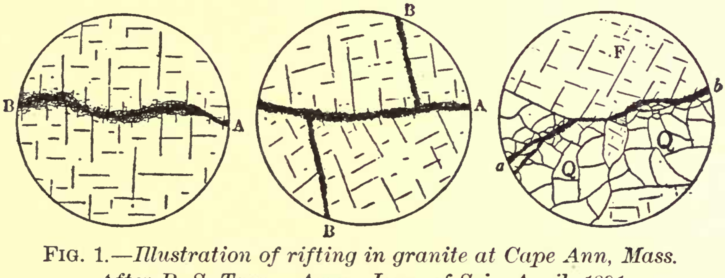

FIG. 1.—*Illustration of rifting in granite at Cape Ann, Mass. After R. S. Tarr. Amer. Jour. of Sci., April, 1891.*

minerals. Granitic rocks and porphyries break up less regularly from the same cause, but still exhibit prismoids and polygonal blocks and benches.[1] Large cracks have been referred to this cause, which have afterward formed important receptacles for ores. (See Example 11*a*.)

The nature of the strain which produces the fissuring makes

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[1] J. P Iddings' paper on "The Columnar Structure in the Igneous Rocks on Orange Mountain, N. J.," *Amer. Jour. Sci.*, III., xxxi. 320, is an excellent discussion.

the term "tension joint" an excellent name for them.[1] There are, however, other varieties of tension joints. Sedimentary rocks, that contain a large quantity of water when first formed, may lose it in whole or in part, and may shrink and crack for this reason, precisely as does the mud on the bottom of a dried puddle. Ledges in many parts of the world are exposed during the day to a hot sun, and during the night cool down to a comparatively low temperature, The alternate expansion and contraction may produce tensional stresses leading to the production of joints. The concentric surfaces of parting which are so often displayed in granite quarries, and which resemble the coats of an onion, have been referred to this cause. When stratified rocks become folded into anticlines and synclines, tensional strains are developed in the upper layers of the anticline, and the lower layers of the syncline, respectively above and below the surface of no strain. Rupture almost always results, and cracks or joints are produced, which run parallel with the axis of the fold. Cross-folding may then develop another series at an angle with the first.

1.02.02. *Cleavage, Fissility and Compression Joints.*—In speaking of the effects of pressure upon rocks, it is in many respects convenient to follow again the nomenclature of Van Hise, as established in the paper last cited,[2] and to distinguish at the outset between cleavage and fissility. Cleavage is the "capacity present in some rocks to break in some directions more easily than in others;" whereas fissility is "a structure in rocks by virtue of which they are already separated into parallel laminæ in a state of nature." Fissility is therefore practically a development of joints on a very extensive and closely set scale, and chiefly in one direction. Cleavage, on the other hand, does not necessarily imply cavities and has not a very important bearing on the present discussion. A case has been met in the granites of Cape Ann, however, that deserves mention. The granites are known to possess a tendency to split along certain planes that greatly facilitates the operations of the workmen. R. S. Tarr discovered by microscopic study,

[1] C. R. Van Hise, "Principles of North American Pre-Cambrian Geology," *XVI Annual Report Director U. S. Geological Survey,* Part I., p. 668.

[2] *Op. cit.*, p. 633.

that coincident with this "rifting" there was a minute brecciation that had no connection with the cleavage of the component minerals or their bounding surfaces. The brecciation has manifestly resulted from compression, and it is obvious that its presence made the granite much more permeable to water. A rock of this character, if in a region of ore deposition, would quite readily become impregnated.

Both the joints produced by cooling and those formed by drying and consolidation may be afterward modified or increased by rock movements, and still different ones may be brought about independently of either. Indeed, it is a growing belief among observers, that even the joints in sedimentary strata, which have been usually referred to contractional strains during consolidation, are the products of pressure or of other dynamical causes, external to the rock mass itself. It may be a very difficult matter to differentiate the effect of one from that of the other, but pressure and torsion would naturally occasion displacement, if only on a microscopic scale. W. O. Crosby has suggested the undulatory tremor of an earthquake as of possible importance. The experiments of Daubrée indicated that pressure would produce joints, and that in a homogeneous medium two sets would result at right angles with each other, and each at 45° with the direction of the pressure. This theoretical regularity is not met in nature, alike from the heterogeneous character of rocks and from the complexity of the strains to which they are subject. G. F. Becker has sought in the several recent papers cited below to analyze in a mathematical way the theoretical application and effects of such strains. Torsional stresses referred to above have been suggested as having important bearings on natural phenomena, and especially since the experimental work of Daubrée along these lines, but Becker is led to question their extended application to rocks.

As regards the finer textural characteristics of certain joint surfaces, J. B. Woodworth has contributed some very interesting observations, which, it is to be hoped, will be extended to a wide series of rocks. In certain slaty rocks near Boston, the joint surfaces for a limited area exhibited small undulations, which diverge from a central axis, like the branches of a feather, but which then bend in curved surfaces of much larger development, so as to form somewhat extended corrugations. The author remarks the resemblance which the distribution of certain great fractures in the earth's crust bears to these hand specimens, a suggestion that might be tested in fractured areas containing veins.

It is manifest that the passage from joints, properly speaking, and as outlined above, to slaty cleavage, schistosity and dynamic effects, that are the results of many small fractures and shearing surfaces, is a gradual one, and that the two are intimately connected. The references below, therefore, embrace both, although schistosity is but briefly referred to here, as its connection is not particularly close with the origin of ore bodies, however much it may afterward affect them.[1]

1.02.03. *Cavities Formed by More Extensive Movements in the Earth's Crust.*—The strains produced by compression in the outer portion of the earth are by far the most important causes of fractures. The compression develops a tangential stress which is resisted by the archlike disposition of the crust. (By the term "crust" is simply meant the outer portion of the

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[1] G. F. Becker on the production of fissures. See paper on "The Structure of a Portion of the Sierra Nevada of California," *Bulletin Geological Society of America*, II. 49, 1891; also "Finite Homogenous Strain, Flow and Rupture of Rocks," *Idem.*, IV. 13, 1893; "The Finite Elastic Stress-strain Function," *Amer. Jour. Sci.*, Nov., 1893, p. 337. The above are rather mathematical for the general reader and the following are less so. "The Torsional Theory of Joints," *Trans. Amer. Inst. Min. Eng.*, XXIV. 130, 1894; "Schistosity and Slaty Cleavage," *Journal of Geology*, IV. 429, 1896; "Reconnoissance of the Gold Fields of the Southern Appalachians," *XVI Ann. Rep. Dir. U. S. Geol. Survey*, Part III., 265–272; W. C. Crosby, "Absence of the Joint Structure at Great Depths," *Geol. Magazine*, Sept., 1881, p. 416; "Classification and Origin of Joint Structures," *Proc. Boston Soc. Nat. Hist.*, XXII. 72, 1882; "On the Joint Structure of Rocks," *Technology Quarterly*, 1890; "The Origin of Parallel and Intersecting Joints, *Idem.*, VI. 230, 1893; also in *Amer. Geologist*, Dec., 1893, 368; G. K. Gilbert, "On the Origin of Jointed Structure," *Amer. Jour. Sci.*, July, 1882, 50; J. Le Conte, "Origin of Jointed Structure in Undisturbed Clay and Marl Deposits," *Amer. Jour. Sci.*, III., xxiii. 233; W. J. McGee, "On Jointed Structure," *Amer. Jour. Sci.*, III. xxv. 152, 476.

An excellent bibliography on slaty cleavage up to 1885 will be found in a paper by Alfred Harker, in *Rep. British Assoc. for the Advancement of Science*, 1885, 813, and upon this and other kindred subjects, Daubrée's Etudes Synthetiques de Geologie Experimentale, 1879, Part I.; Sub Part II., Chaps. I.–IV.

globe without reference to the character of the interior.) Where there is insufficient support, gravity causes a sagging of the material into synclinals, which leave salient anticlinals between them. Where the tangential strain is also greater than the ability of the rocks to resist, they are upset and crumpled into folds from the thrust. Both kinds of folds are fruitful causes of fissures, cracks, and general shattering, and every slip from yielding sends its oscillations abroad, which cause breaks along all lines of weakness. The simplest result, either from sagging or from thrust, is a fissure, on one of whose sides the wall has dropped, or on the other of which it has risen, or both, as will be more fully described under "Faults." If the rocks are firm and quite thickly bedded, as is the case with limestones and quartzites, the separation is cleanly cut; but if they are softer and more yielding, they are sheared downward on the stationary or lifting side, and upward on the one which relatively sinks. Such fissures may pass into folds along their strike, as at Leadville, Colo.

1.02.04. A phenomenon which is especially well recognized in metamorphic regions, and which is analogous to those last cited, is furnished by the so-called "shear zones." A faulting movement, or a crush, may be made apparent in rocks of this character by changes in mineralogical composition and structure, as well as by clearly fractured rocks. Massive diabases, for instance, pass into hornblende schists or amphibolites for limited stretches. Garnets and other characteristically metamorphic minerals appear, and pyroxenes alter to amphiboles. Strains are manifested in the optical behavior of the minerals in thin sections of specimens taken from such localities. These crushed strips, or shear zones, may be formed with very slight displacement, but they afford favorable surroundings for the formation of ore bodies. This conception of the original condition of a line of ore deposition is a growing favorite with recent writers, and combined with the idea of replacement is often applicable. Fahlbands, which are very puzzling problems, may have originated as shear zones.

1.02.05. A more extended effect is produced by the monocline, which has a double line of shattered rock marking both the crest and foot of its terrace. Anticlines and synclines occasion the greatest disturbances. Comparatively brittle materials like rocks cannot endure bending without suffering extended fractures. When strained beyond their limit of resistance, along the crest of an anticline, and in the trough of a syncline, cracks and fractures are formed which radiate from the axis of each fold. As these open upward and outward in anticlines, they become the easiest points of attack for erosion, so that it is a very common thing to find a stream flowing in a gorge, which marks the crest of an anticline, while synclinal basins are frequently left to form the summits of ridges, as is so markedly the case in the semi-bituminous coal basins of Pennsylvania. It is quite probable, however, that the anticline may have been leveled off at this fissured crest because it was upheaved under water and became exposed at its vulnerable summit to wave action.

Ore deposits may collect in these fissured strips, of which the lead and zinc mines of the upper Mississippi Valley (Example 24) are illustrations. Such fissures are peculiar in that they exhibit no displacement. The accompanying figure is from a photograph of a gaping crack in the Aubrey (Upper Carboniferous) limestone, twenty-five miles north of Cañon Diablo station, Ariz., on the Atlantic and Pacific Railroad. It was caused by a low anticlinal roll and contained water about one hundred feet below the top. Its reproductions of the conditions of a vein, with horse, pinches and swells, devious course, and all, is striking. The photograph was made by Mr. G. K. Gilbert, of the United States Geological Survey, and to his courtesy its use is due.

While it is true that in many regions the folds and fractures have resulted in this simple way, and exhibit the unmistakable course through which they have passed, yet geological structure is by no means always so clear. Extended disturbances, great faults and displacements, combined with folds and the intrusion of igneous rocks, have often so broken up a district that it is a matter of much difficulty to trace out the course through which it has passed. Subsequent erosion, or the superposition of heavy beds of gravel or forest growths, etc., may so obstruct observation even of the facts as to add to the obscurity. The expense of making and the consequent scarcity of accurate contour maps to assist in such work are other obstacles. The profound dynamic effects wrought by mountain-making processes, although in individual cases producing only the simpler phenomena already cited, yet in general are much more extensive, and must be considered in the study of many large districts. When folds are the result of compression or thrust, the dynamic effects are more marked than in those formed by sagging. Faults are larger and more abundant. When sedimentary beds have been laid down along an older axis of granite or some equally resistant rock and the thrust crowds the beds against this axis, the conditions are eminently favorable to great fracturing and disturbance. The flanks of the Rocky Mountains furnish such examples.

1.02.06. There are also great lines of weakness in the outer portion of the earth, which seem to have been the scene of faulting movements from a very early period. Thus, on the western front of the Wasatch Mountains, in Utah, is a great line of weakness, that was first faulted, as nearly as we can discover, in Archean times, and has suffered disturbances even down to the present. A few instances of actual movements within recent years have been recorded. In 1889 a sudden small fold and fissure developed under a paper mill near Appleton, Wis., and heaved the building four and a half inches. (See F. Cramer, "Recent Rock Flexure," *Amer. Jour. Sci.*, III., xxxix. 220.) This occurred in what was regarded a settled region, and one not liable to disturbance.

1.02.07. Wherever igneous rocks form relatively large portions of the globe they necessarily share extensively in terrestrial disturbances. Not being often in sufficiently thin sheets, they rarely furnish the phenomena of dip and strike. Folds are largely wanting. They are replaced by faults and shattering. The fissures thus formed are at times of great size and indicate important movements. The Comstock Lode fissure is four miles long and in the central part exhibits a vertical displacement of three thousand feet. (See 2.11.21.) Such fissures seldom occur alone, but minor ones are found on each side and parallel with the main one.

1.02.08. The intrusion of igneous dikes may start earthquake vibrations which fracture the firm rock masses. Fissures caused in this way radiate from the center of disturbance or else appear in concentric rings. The violent shakings which so often attend great volcanic eruptions, and the sinking of the surface from the removal of underlying molten material, all tend to form cracks and cavities. They are possible causes which may well be borne in mind in the study of an igneous district.

1.02.09. *Faults.*—When fractures have been formed by any of the means referred to above, and the opposite walls slip past each other, so as not to correspond exactly at all horizons, they are called "faults," a term which indicates this lack of correspondence.

The separation is chiefly due to the relative slipping down or sinking of one side. The distance through which this has taken place is called the amount of displacement, or throw.

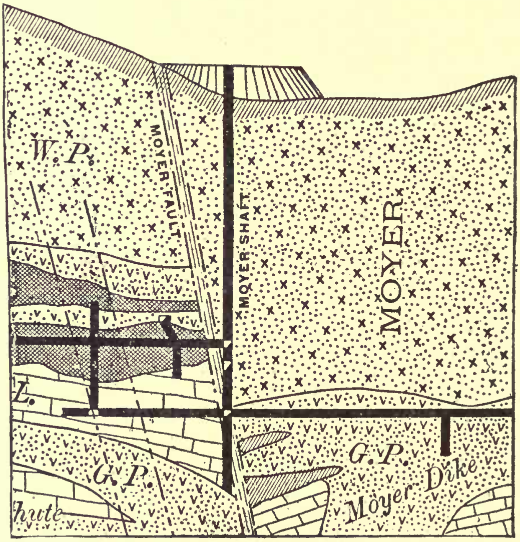

FIG. 3.—*Normal fault, Leadville, Colo. After A. A. Blow. Trans. Amer. Inst. Min. Eng., XVIII.,* 180. *Plate IV.*

Faults are most commonly inclined to the horizon, so that there is both a vertical and a horizontal displacement. The inclination of a fault plane to the horizontal is called the dip, just as in the case of stratified rocks. Its inclination to the vertical is the hade. Faults most commonly run parallel with the strike of inclined rocks, and are then called "strike-faults." When they cut across the strike and are in the direction of the dip they are called "dip-faults." Experience has shown that

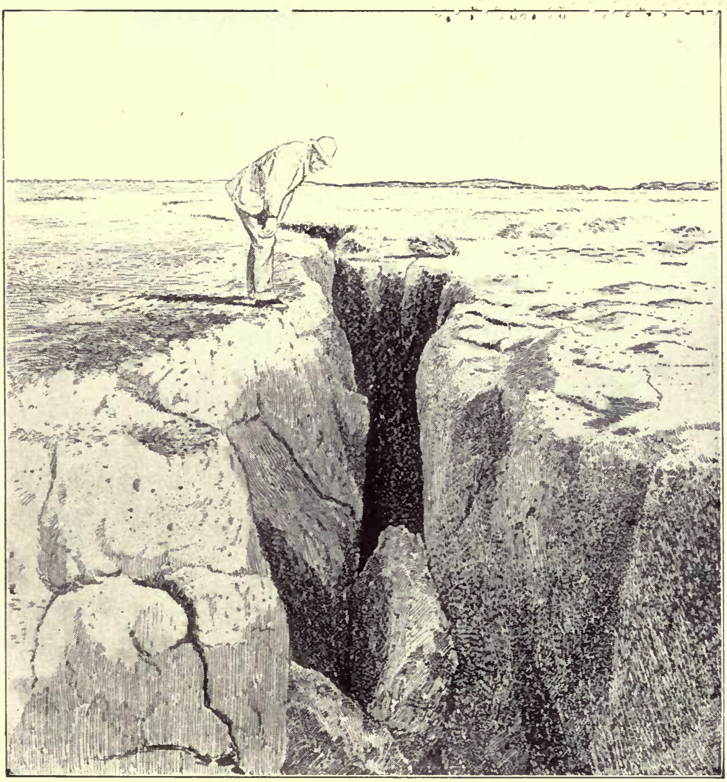

FIG. 2.—*Open fissure in the Aubrey limestone (Upper Carboniferous) 25 miles north of Cañon Diablo Station, Ariz., on the A. & P. R. R. Reproduced from a photograph by G. K. Gilbert,* 1892 (*Science, August* 2, 1895, 118.)

where beds or veins encounter faults and operations are brought to a standstill, the continuation is usually found as follows, according to Schmidt's law. If the fault dips or hades away from the workings, the continuation is down the hade; if it dips toward the workings, it should be followed upward. Such a fault is called a normal, or gravity fault, and is illustrated in the figure on p. 20, after A. A Blow. This is a natural result of the drawing apart of the two sides. The least supported mass would slip down on the one which has the larger base. Less commonly the opposite movement results. Thus, when the fault is due to compression, the beds pass each other in the reverse direction, and what is called a reverse fault results. The accompanying cut illustrates a very extended one in the

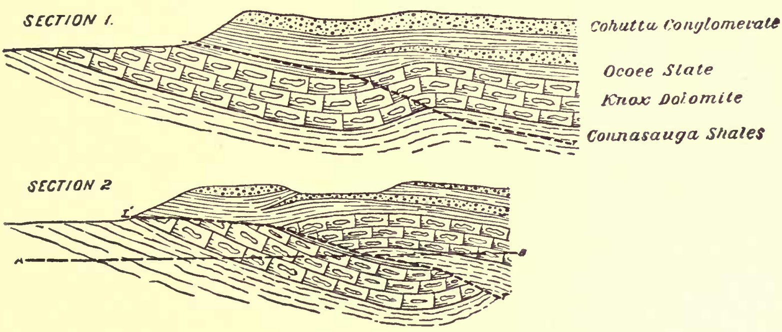

FIG. 4. *Reversed Fault at Holly Creek, near Dalton, Ga. After C. W. Hayes, Bull. G. S. A., Vol. II., Pl. 3, p. 152*

southern Appalachians. While we would naturally think of a reversed fault as resulting from a compressive strain, in that in this case the lower wedge-shaped portion would be forced under the upper one, yet normal faults can likewise, in instances, be explained by compression. If we consider the fault to be caused by the vertical thrust or component, that would always be present in the compression of a completely supported arch, this would tend to heave upward the portion next the fissure that had the larger base. Along an inclined fracture such portion is manifestly the under one. Again, if the compressive strain is applied in a direction parallel with the fissure, and not at right angles to it, the hanging wall might be forced to bulge downward and the footwall upward, thus yielding a normal fault by compression. It is important to note whether the fault plane, both in normal and in reversed faults, cuts inclined beds in the direction of the dip or across it, because the relative amount of vertical and lateral displacement is much affected by these considerations. (See Margerie and Heim, *Dislokation der Erdrinde*, Zurich, 1888.)

1.02.10. The movement of the walls on each other produces grooves and polished surfaces called slickensides, or slips. They are usually covered with a layer of serpentine, talc, or some such secondary product. The strain caused by the movement may in rare instances leave the slips in such a state of tension that when, from any cause, such as excavation, the pressure is relieved, they will scale off with a small explosion.[1] Observations on the directions of slips may, in cases of doubt, throw some additional light on the direction of the movement which occasioned the fault. Some particular and recognizable bed or vein may be crushed and dragged down by the faulting movement, and afford the so-called "trail of the fault," which will indicate the direction of movement and direct the miner. But the best guide in stratified rocks is a knowledge of the succession of the beds as revealed by drill cores or excavations. Attempts have been made to deduce mathematical formulas for the calculation of the amount of downthrow or upthrow, and when sufficient data are available, as is often the case in coal seams, this may be done. The methods depend on the projection of the planes in a drawing, on the principles of analytical geometry, and on the calculation of the displacements by means of spherical trigonometry.[2] Prof. Hans Hoefer has called attention to the fact that in faulting there is frequently a greater displacement in one portion of the fissure than in a neighboring part, and even a difference of hade. This causes a twisting, or circular movement of one wall on the other, and

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[1] See A. Strahan, "On Explosive Slickensides," *Geological Magazine*, IV. 401, 522.

[2] See G. Koehler, *Die Störungen der Gänge, Flötze und Lager*, Leipzig, 1886; William Englemann. A translation by W. B. Phillips, entitled, "Irregularities of Lodes, Veins and Beds," appeared in the *Engineering and Mining Journal*, June 25, 1887, p. 454, and July 2, 1887, p. 4. A very excellent paper, having a quite complete bibliography, is F. T. Freeland's "Fault Rules," *Trans. Amer. Inst. Min. Eng.*, XXI. 491, 1892.

needs to be allowed for in some calculations.[1] In the *Engineering and Mining Journal* for April and May, 1892, a quite extended discussion of faults by several prominent American mining engineers and geologists is given, apropros of the question raised by Mr. J. A. Church as to whether fissure veins are more regular on the dip or on the strike. In a relatively uniform massive rock the regularity should be greater on the dip, but in inclined and diversified stratified rocks too many variables enter to warrant any sweeping assertions. In soft rocks like shales the fissure may become so split into small stringers as to be valueless. Again, in very firm rock, where there is little drawing apart, the fissure may be very tight.

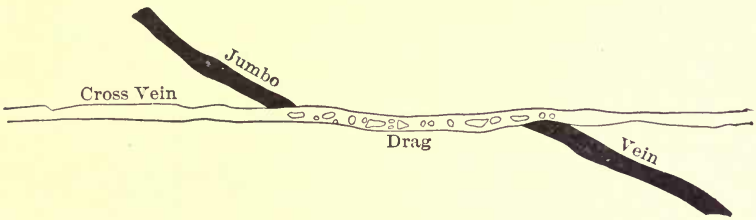

FIG. 5. *Illustration of an older vein, the Jumbo, faulted by a later one, (cross-vein) at Newman Hill, near Rico, Colo. After T. A. Rickard, Trans. Amer. Inst. Min. Eng., XXVI.*, 951.

In the veins of Newman Hill, near Rico, Colo. (see 2.09.11), the fissure is so narrow above a certain statum as practically to fail. Quartzite is a favorable rock for such effect. Despite all rules, faults are often causes of great uncertainty, annoyance, and expensive exploration.

1.02.11. If a number of faults succeed one another in a short distance, they are called "step faults." An older and completed vein may also be faulted by one formed and filled later. In such a case the continuous one is the younger. Figure 5 above will illustrate each case. At the intersection of the two, the later vein is often richer than in other parts.

1.02.12. If a faulted series of rocks is afterward tilted and eroded, so as to expose a horizontal section across the strike of the faulting plane, an apparent horizontal fault may result; or

[1] *Oesterreiches Zeitschrift für Berg-und Hüttenwesen*, Vol. XXIX. An abstract in English is given by R. W. Raymond, *Trans. Amer. Inst. Min Eng.*, X. 456, 1882.

if the erosion succeeds normal faulting and lays bare two unconformable beds each side of the fissure, a lack of correspondence in plan as well as in section may be seen. Faulting fractures are seldom straight; on the contrary, they bend and corrugate. When the walls slip past each other, they often stop with projection opposite projection, and depression opposite depression. These irregularities cause pinches and swells in the resulting cavity, and constitute one of the commonest phenomena of veins. Fissures also gradually pinch out at their extremities, or break up into various ramifications that finally entirely cease. They may pass into folds, as stated above. It is not surprising, therefore, that in stratified rocks, the largest faults, as a matter of observation, are usually parallel with the general strike. They cross the strike or run in the sense of the dip much less frequently.

1.02.13. *Zones of Possible Fracture in the Earth's Crust.* —In a discussion of the deformation of rocks C. R. Van Hise[1] has recently established the conception of three zones in the earth's crust, which are intimately connected in a large way with the subjects just discussed. They are (1) an upper zone of fracture; (2) a middle zone of combined fracture and plasticity; (3) a lower zone of plasticity. (1) Rocks under less weight than their ultimate strength, when rapidly deformed, are in the zone of fracture. This is manifestly incontrovertible and the conception adds to the points touched on in preceding paragraphs the important further one of the load under which the rocks stand at the time of experiencing the strain. As already pointed out, the character of the wall rock will influence the resulting fissure, firm rocks giving clean-cut fissures, while soft rocks, such as shales, will more readily break along multitudes of small cracks. The amount of load is also important, for with its increase even the firmest rock could not fracture, as is shown in describing the next two zones. It is also manifest that the depths of the zones are variable in different regions, on account of local differences of rocks, and that they are not to be too sharply viewed in a quantitative way.

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[1] Principles of North American Pre-Cambrian Geology, *XVI. Annual Rep Dir U. S Geol. Survey,* Part I., 589, 1896. See also *Journal of Geology,* IV. 195. 312, 449, 593.

In round numbers the maximum depths at which cavities can exist varies from 500 meters (1,625 ft.) for soft shales to 10,000 meters (32,500 ft.) for firm granites. These maximum depths introduce zone (3), or the zone of flowage, wherein the load is so excessive that the yielding to deformation comes in the way of a viscous flow, or plastic yielding, evidences of which are visible in many gneisses. That such a zone exists will appear to any one who reflects upon the necessary behavior and yielding of rocks, which are confined on all sides and yet are compressed beyond their limits of resistance. The second or intermediate zone embraces the border region between (1) and (3), or the region of combined fracture and flowage.

These considerations have an important bearing on the formation of veins, because they indicate that veins must be limited to the outer portions of the globe and must have always formed in such surroundings. The considerations as regards their practical bearing are largely theoretical, it must be admitted, because even moderate estimates of the depth of zone (1) soon reach below the limit of possible mining,[1] but in their broad scientific bearings they are a valuable aid to the formation of correct views on the necessary place of origin of veins. The "ewige Teufe" of the earlier miners is therefore quite limited.

1.02.14. *Secondary Modifications of Cavities.*—Fractures and cavities of all sorts speedily become lines of subterranean drainage. The dissolving power of water, and to a much smaller degree its eroding power, serve to modify the walls very greatly. An enlargement may result, and what was perhaps a small joint or fissure may become a waterway of considerable size. This is especially true in limestones, in which great caverns (like the Mammoth Cave and Luray's Cave) are excavated. Caves are, however, almost always due to surface water, and do not extend below the permanent water level unless they have been depressed after their formation.[2]

1.02.15. The subterranean movements of water are of prime importance in connection with so many aspects of the subject of ore deposits that it is necessary to have a fairly definite con-

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[1] See in this connection A. C. Lane, "How Deep Can we Mine?" *The Mineral Industry*, IV. 767. 10,000 ft. is placed as a general limit, with possibilities as far as 15,000, but probably not much beyond.

[2] See J. S. Curtis, *Monograph VII., U. S. Geol. Survey*, Chap. VIII.

ception of their nature and causes. Water falling on the surface as rain in part runs off at once, in part evaporates, at least before it has gone far, and in part sinks into the ground. With the last named we are especially concerned. World-wide experience long ago demonstrated that under all portions of the land, unless possibly in excessively arid and exceptional districts, there is a body of almost stationary water, that maintains a very constant level and that will fill a well if one is sunk sufficiently deep. Where the rainfall is heavy this "permanent water level" or "ground water" stands only a short distance below the surface, it may be only a few feet; but in regions of slight rainfall, it is correspondingly depressed. It varies also, more or less, with the nature of the local rocks, with the nearness or remoteness of low-lying valleys and with the geological structure.[1] The "ground water" that stands at this level is to be distinguished from the actively circulating water above it—the "vadose" circulation of Posepny,[2] whose recent treatise has served to focus attention upon this phase of the subject—and is not itself without motion, because where it is situated above some more or less remote and lower lying outlet it passes toward it by a slow, gradual flow, or sinks downward, moves laterally and rises again by a siphonic action. Cracks and clefts are the chief lines of movement in both these circulations, and instances are known of communications across wide intervals. Capillary circulations are also not lacking but are of less quantitative moment. As solvents of rocks the ground-water circulations are not comparable with the vadose, for, as already remarked, caves, the chief results of such solution and removal, are essentially products of the latter.

1.02.16. The ground-water stands between the motive power of the overlying hydrostatic column and the further motive power of the underlying heated zones of the earth, to which some of the surface water attains, more or less by capillary movements. Daubrée has shown that capillary attraction is

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[1] See, in this connection, T. C. Chamberlin, "The Requisite and Qualifying Conditions of Artesian Wells," *Fifth Annual Rep. Dir. U. S. Geol. Survey*, 131, 1885.

[2] *Transactions Amer. Inst. Min. Eng.*, XXIII. 213, 1893. Reissued as "Genesis of Ore Deposits," in which see p. 17.

effective even against steam pressure.[1] Cooling but still heated intrusions of igneous rocks, which may not necessarily reach the surface, are doubtless the most serious of all these internal stimulators, and furnish us with the most reasonable cause for those active circulations, that have led to ore-deposition in regions of extended mineral veins. They are at once localized, of relatively abrupt development, and they bring great stores of heat within the conceivable zones of the groundwater's existence. It is also quite probable that waters and other fluid or vaporous substances are emitted and driven outward, which are not derived from infiltrations from the surface, but which have been involved in the substance of igneous magmas since their derivation from the original nebula. All these circulations from deep-seated sources are more likely to be fillers than enlargers of cavities in the upper portions of the zone of fracture.

It is conceivable that the heat necessarily developed in the crushing and fracture of rocks on a large scale may also be an important local stimulus and in this way contribute in no small degree to the final results.

1.02.17. The solvent action of water is vastly augmented by the carbonic acid which it gathers from the atmosphere, and this is the chief cause of the excavations wrought by it in limestones. Pure cold water has comparatively small dissolving and almost no eroding power. It has also been advocated that various acids which result from the decay of vegetable matter aid in such results.[2] This may be true, but in general carbonic acid is the chief agent. Iron in minerals falls an easy prey, as does calcium, and both are dissolved out in large amount. (See Example 1.) When charged with alkaline carbonates, water has the power to attack other less soluble minerals, such as quartz and silicates, and by such action the walls of a cavity in the crystalline rocks may be much affected.

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[1] The most important works bearing on this entire question of underground waters are those of Daubrée, viz.:

"Etudes Synthétiques de Géologie Expérimentale," 1879.

"Les Eaux Souterraines aux Époques anciennes," 1887.

"Les Eaux Souterraines a l'Epoque actuelle," 1887, 2 vols.

Suggestive reading will also be found in C. R. Van Hise, "Metamorphism of Rocks and Rock-flowage, *Bull. Geol. Soc. Amer.*, IX. 269.

[2] A. A. Julien, *Amer. Asso. Adv. Sci.*, 1879, p. 311.

1.02.18. As has been set forth in a previous paragraph, waters percolating to great depths in the earth, or circulating in regions of igneous disturbances, become highly heated, and this too at great pressure. Under such circumstances the solvent action is very strongly increased, and all the elements present in the rock-making minerals are taken into solution. Alkaline carbonates are formed in quantity; silica is easily dissolved; alkaline sulphides result in less amount; and even the heaviest and least tractable metals enter into solution, either in the heated waters themselves, or in the alkaline liquors formed by them. The action on the walls of cavities and courses of drainage is thus profound, and accounts for the frequent decomposed character of the walls and the general lack of sharpness in their definition. The vast amount of siliceous material deposited by hot springs and geysers is additional evidence of its importance. When the uprising solutions reach the regions of diminished temperature and pressure they contribute their burden of dissolved minerals to veins and surface accumulations.

1.02.19. The composition of mineral springs is of the greatest interest in this connection,and is a subject that has received much attention in recent years.[1] The vast majority of those recorded contain chiefly silica and salts of alkalies and alkaline earths, of which a few represent the gangue minerals. Here and there, however, examples with metallic contents have been detected, and in several instances springs have been met in deep mines and the waters have been analyzed. Often the ore deposition, as indicated by these, seems to have ceased, but again either in the waters themselves or in crusts formed by them, metallic minerals have been detected. In the table below the first seven relate to American cases, the last three to

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[1] R. N. Brackett, "Mineral Waters of Arkansas," *Geological Survey of Arkansas*, 1891, I.

Gooch and Whitfield, "Analyses of Waters of the Yellowstone National Park," *Bulletin* 47, *U. S. Geol. Survey.*

A. C. Peale, "Lists and Analyses of the Mineral Springs of the United States, *Bulletin* 32, *Idem.*

F. Posepny, "Genesis of Ore Deposits," pp. 26–48.

J. Roth, "Allgemeine und Chemische Geologie," I. Chap. x., 407.

P. Schweitzer, "The Mineral Springs of Missouri," *Mo. Geol. Survey*, III. 1892.

European. All the amounts are expressed in parts per million, *i. e.*, grams per 1,000 liters.

1.02.20. In analyses I. and II. metallic salts were not themselves detected, but ammonium carbonate was, and on its presence, as well as the results of experiment, Becker bases his explanation of the introduction of the cinnabar. Cinnabar is found to be soluble in ammoniacal liquors under pressure and heat, but to precipitate again as the pressure and temperature fall. The water from Steamboat Springs did yield traces of quicksilver, but the crusts which had been precipitated at the surface of the ground in past time afforded in this order: sulphides of arsenic and antimony, ferric hydrate, lead sulphide, copper sulphide, mercuric sulphide, gold and silver, and traces of zinc, manganese, nickel and cobalt.[1] The waters from the Geyser mine were of exceptional interest. When compared with each other it is noticeable that the vadose waters (IV.) have much less metallic matter than the deep-water (V.), and that in the latter the metals appear in much the same relative abundance as in the ore (VI. and VII.). In the "Genesis of Ore Deposits," from which analyses VIII., IX. and X. have been taken, Posepny has collected many more, and cites some instances abroad in which the metals have also been noted. Antimony, arsenic, bismuth, iron, manganese, copper, tin, cobalt, nickel, lead, zinc and uranium are to be numbered among them. So far as the metals are concerned all the analyses indicate extremely dilute solutions, and the waters must have required a very long period of time to yield the ore bodies. The dissolved content of alkaline salts must have flowed away on the surface and have disappeared.

I. Water from the Hermann shaft at Sulphur Bank, California, from a quicksilver mine. *Monograph XIII.*, *U. S. Geol. Survey*, p. 259. W. H. Melville, Analyst.

II. Parrott shaft, same locality. *Idem.*

III. Steamboat Springs, Nev. *Idem.* p. 349.

IV. Calculated composition of the vadose water at the 500-ft. level of the Geyser silver mine. Silver Cliff, Colo., in rhyolite tuff. The analysis is made up from analyses of the water and of the sediment that settled from it, chiefly by precipita-

[1] *Monograph XIII.*, *U. S. Geol. Survey*, 343.

	I.	II.	III.	IV.	V.
SiO_2	37.15	41.85		25.90	24.42
Al_2O_3			0.25		1.06
Al_2O_3, P_2O_5				0.80	
$FeCO_3$		0.98	0.29	1.50	7.25
$MnCO_3$				1.70	1.19
$CaCO_3$	35.20	50.55	15.77	93.50	366.03
$CaSO_4$	23.40				
$Ca_3P_2O_8$			1.37		Trace.
CaF_2					Trace.
$SrCO_3$					3.29
$MgCO_3$	18.90	5.55	0.99	42.85	621.84
K_2SO_4				4.20	19.18
KCl	47.05	74.70	197.35	16.60	361.34
KBr, KI					Trace.
Na_2CO_3	1,946.75	322.60	43.14	38.70	1,489.67
Na_2SO_4		689.05	111.47	60.50	223.53
$NaCl$	1,102.70	1,039.75	1,411.75		
$NaNO_3$					2.19
$Na_2B_4O_7$	1,878.40	2,404.35	313.68		Trace.
$Na_2Si_4O_9$			390.90		
$NaHCO_3$			290.23		
$NaHS$			3.58		
NA_2AsS_3			8.66		
Na_2SbS_3			1.00		
Li_2SO_4			56.50		
$LiCl$					17.30
$(NH_4)_2CO_3$	6.64	2.82			
H_2S	4.55	0.74			
CO_2	262.41	1,751.31		37.20	1,418.61
Organic matter	5.00	7.6			
HgS, nNa_2S			Trace.		
$PbCO_3$				Trace.	1.74
$CuCO_3$				Trace.	0.04
$ZnCO_3$				0.40	0.66

	VI.	VII.		VIII.	IX.	X.
Gold	Trace.	Trace.	Alk. Carbonates	352.00	1,150.00	2,297.00
Silver	1.05	1.27	Earthy Carbonates	55.00	510.00	729.00
Lead	23.80	17.60	Alk. Sulphates	12.00	82 00	37.00
Zinc	14.00	11.10	Earthy Sulphates			6.00
Copper	1.50	2.30	Chlorides	6.00	62.00	58.00
Iron	2.30	2.00	Silica	51.00		72.00
Manganese	1.20	0.80	Others			6.00
Lime	1.70					
Sulphur	12.60	9.50				
Silica	33.60	46.90				
Total	91.75	91.47				

tion in the carboy. *XVII. Ann. Rep. Dir. U. S. Geol. Surv.*, Part II., p. 463. W. F. Hillebrand, Analyst.

V. Calculated composition of deep waters, 2,000-ft. level, same place and conditions. *Idem.*

VI., VII. Analyses of two carload lots of ore from same mine, made at Arkansas Valley smelter, Leadville. *Idem*, p. 457. The gangue was chiefly barite, calcite and chalcedony.

VIII. Water from the Einigkeit's shaft, Joachimsthal, Bohemia, presumably at a depth of 533 meters (1,774 ft.), as stated on p. 27 of citation. Analysis on p. 38, "Genesis of Ore Deposits."

Analyst, J. Seifert. The table of equivalent temperatures on p. 37 of original is incorrect.

IX. Gottesgeschick mine, Schwarzenberg, Saxony. *Idem.* Analyst, R. Richter.

X. "Sprudel" spring in a colliery at Brux, Bohemia. *Idem.* Analyst, J. Gintl.

1.02.20. Magnesia is one of the alkaline earths readily taken into solution by carbonated waters, and when such waters again meet limestone the effect is often very great, and constitutes one of the most important methods of the formation of cavities. Solutions of magnesium carbonate, on meeting calcium carbonate, effect a partial exchange of the former for the latter. This leaves the rock a double carbonate of calcium and magnesium, which is the composition of the mineral and rock dolomite. The process is therefore called dolomitization. (See Example 25.) It may bring about a general shrinkage of eleven or twelve per cent. In any extended thickness of strata this would cause vast shattering and porosity. As an illustration of its results, the following analysis of normal, unchanged Trenton limestone of Ohio, and of well drillings from the porous, gas-bearing, dolomitized portions of the same, are given. They are taken from a paper by Edward Orton. (*Amer. Manuf. and Iron World*, Pittsburg, Dec. 2, 1887.)

	$CaCO_3$.	$MgCO_3$.	Fe_2O_3, Al_2O_3.	SiO_2.
Unchanged Trenton limestone..	79.30	0.92	7.00	12.00
" " " ..	82.36	1.67	0.58	12.34
Dolomitized " " ..	53.50	43.50	1.25	1.70
" " " ..	51.78	36.80		

1.02.21. Recent studies in ore deposits by Posepny, Curtis and Emmons indicate also that solutions of metallic ores may affect an interchange of their contents with the carbonate of calcium or magnesium in limestones and dolomities, leaving an ore body in place of the rocks. This change is effected molecule by molecule, and is spoken of as a metasomatic interchange or replacement. (See Example 30.) By "metasomatic" is meant an interchange of substance without, as in pseudomorphs, an imitation of form. Alteration of the metallic ores may follow and occasion cavities from shrinkage. (See Example 36, and Curtis, on Eureka, Nev., *Monograph VIII. U. S. Geol. Survey*, Chap. VIII.)

CHAPTER III.

THE MINERALS IMPORTANT AS ORES; THE GANGUE MINERALS, AND THE SOURCES WHENCE BOTH ARE DERIVED.

1.03.01. The minerals which form the sources of the metals are almost without exception included in the following compounds: the sulphides and tellurides, the arsenides and antimonides, the oxides and oxidized compounds such as hydrous oxides, carbonates, sulphates, phosphates, and silicates, and one or two compounds of chlorine. A few metals occur in the native state. All the other mineral compounds such as a chromate or two, a bromide or iodide, etc., are rarities. It may be said that nine-tenths of the productive ores are sulphides, oxides, hydroxides, carbonates, and native metals. The ores of each metal are subsequently outlined before its particular deposits are described.

1.03.02. The most common gangue mineral is quartz, while in less amount are found calcite, siderite, barite, fluorite, and in places feldspar, pyroxene, hornblende, rhodonite, etc. The silicates are chiefly present where the gangue is a rock and the ore is disseminated through it. All the common rocks serve in this capacity in one place or another.

1.03.03. *Source of the Metals.*—The metallic contents of the minerals which constitute ores must logically be referred to a source, either in the igneous rocks, or in the ocean. If the nebular hypothesis expresses the truth—and it is the best formulation that we have—all rocks, igneous, sedimentary, and metamorphic, must be traced back to the original nebula. This, in cooling, afforded a fused magma, which chilled and assumed a structure analogous to the igneous rocks with which we are familiar. Igneous rocks must thus necessarily be considered to have furnished by their erosion and degradation the materials of the sedimentary rocks; while igneous and sedimentary alike have afforded the substances whose alterations have produced the metamorphic rocks. It may also be true that eruptive rocks, especially when basic, have been formed, by the oxidation and combination with silica, of inner metallic portions of the earth, for this is one of our most reasonable explanations of volcanic phenomena, suggested alike by the composition of basalts, by the high average specific gravity of the globe, and by analogy with meteorites.

1.03.04. As opposed to this conception, there are those who would derive the metallic elements of ores from the ocean, in which they have been dissolved from its earliest condensation. Thus it is said that substantially all the metals are in solution in sea water. From the sea they are separated by organic creatures, it may be, through sulphurous precipitation, attendant on the decay of dead bodies. The accumulations of the remains of organisms bring the metals into the sedimentary strata. Once thus entombed, circulation may concentrate them in cavities. When present in igneous rocks, the latter are regarded as derived from fused sediments. If the metallic contents of sedimentary rocks do not come from the ocean in this way, the igneous rocks as outlined above are the only possible source. No special mention is here made of the metamorphic rocks, because in their original state they are referable to one or the other of the two remaining classes. But it is not justifiable in the absence of special proof to consider them altered sediments, any more than altered igneous rocks, and it is doubtless true that the too generally and easily admitted sedimentary origin for our gneisses and schists has materially hindered the advance of our knowledge of them in the last forty years.

1.03.05. Microscopic study of the igneous rocks has shown that, with few exceptions, the rock-making minerals separate from a fused magma on cooling and crystallizing, in a quite definite order.[1] Thus the first to form are certain oxides, magnetite, specular hematite, ilmenite, rarely chromite and picotite, a few silicates, unimportant in this connection (zircon, titanite), and the sulphides pyrite and pyrrhotite. Next after these metallic oxides, etc., the heavy, dark-colored, basic sili-

[1] H. Rosenbusch, "Ueber das Wesen der koernigen und porphyrischen Structur bei Massengesteine," *Neues Jahrbuch*, 1882, ii., 1.

cates, olivine, biotite, augite, and hornblende are formed. All these minerals are characterized by high percentages of iron, magnesium, calcium, and aluminum. They are very generally provided with inclusions of the first set. Following the bisilicates in the order of crystallization, come the feldspars, and after these the residual silica, which remains uncombined, separates as quartz.

1.03.06. If we regard the igneous rocks as the source, the metallic elements are thus to be ascribed to the first and second series of crystallizations, while the elements of the gangue minerals are derived from the last three. It is a doubtful point whether the less common metals, such as copper, silver and nickel, enter into the composition of the dark silicates as bases, replacing the iron, alumina, lime, etc., or whether they are present in them purely as inclusions of the first series. F. Sandberger[1] argues in support of the first view, but his critics, notably A. W. Stelzner, cast doubt upon his conclusions on the ground that his chemical methods were indecisive. The case is briefly this: Sandberger, as an advocate of views which will be subsequently outlined, separated the dark silicates of a great many rocks. By operating on quantities of thirty grams he proved the presence in them of lead, copper, tin, antimony, arsenic, nickel, cobalt, bismuth, and silver, and considered these metals to act as bases. The weak point of the demonstration consists in dissolving out from the powdered silicate any possible inclusions. There seems to be no available solvent which will take the inclusions and be without effect on the silicates. This is the point attacked by the critics, and apparently with reason. It is, however, important to have shown the presence of these metals, even though their exact relations be thus doubtful. Quite recently in a series of "Notes on Chilean Ore Deposits." Dr. Möricke[2] mentions native gold in pearlstone (obsidian) from Guanaco, in skeleton crystals in the

[1] The principal paper of Professor Sandberger is his "Untersuchungen fiber Erzgänge," 1882, abstracted in the *Engineering and Mining Journal*, March 15, 22, and 29, 1884; but a long series of others might be cited in which the investigations, notably at Pribram, Bohemia, are interpreted as indicated above A. W. Stelzner, *B. and H. Zeit.*, xxxix., No. 3, *Zeitsch. d. d. g. Gesell.*, xxxi. 644. "Die Lateral-secretions-Theorie, etc.' Reprint Freiberg, 1889.

[2] Tschermaks *Min. and Petrog. Mitth.*, XII., p. 195.

glass, as inclusions in perfectly fresh plagioclase and sanidine crystals, and in spherulites. G. P. Merrill has recorded gold as an original mineral in biotite-granite from Sonora, Mexico.[1] A. Simundi reported years ago the existence of gold in the granites of Owyhee Co., Idaho, far from any vein, to an amount equal to 25 cents per ton.[2] The existence of silver in quartz-porphyry has been demonstrated in this country by J. S. Curtis, at Eureka, Nev.;[2] both the precious metals have been shown by G. F. Becker to be in the diabase near the Comstock Lode;[3] and, by the same investigator, antimony, arsenic, lead and copper, were proved to be contained in the granite near Steamboat Springs, Nev.[4] S. F. Emmons has also shown that the porphyries at Leadville contain appreciable, though small, amounts of silver.[5] Of forty-two specimens tested, thirty-two afforded it; of seventeen tested for lead, fourteen yielded results. Emmons has also recorded determinations of silver by L. G. Eakins in the eruptive rocks of Custer Co., Colo., in connection with investigations upon the interesting ore-bodies of the district. Nine rocks were assayed, embracing trachytes, an andesite-breccia, a different andesite, rhyolite, red granite, black granite, the separated bisilicates of the last-named, and diorite. Five out of the nine contained appreciable amounts, viz., one trachyte, the rhyolite, the diorite, and both granites. The amounts vary from 0.005 to 0.402 of an ounce per ton. The separated bisilicates yielded 0.045 per cent. lead and 0.04 of an ounce of silver.[6] Undoubtedly the multiplication of tests will show similar metallic contents in other regions. Thus the augite of the eastern Triassic diabase will probably yield copper, for this metal is abundant in connection with the outflows.

1.03.07. Among the igneous rocks certain metals seem to be characteristically associated with some varieties, others again with a different series, while to many no generalizations apply. The basic rocks are the richest in iron, but the metal is not lacking in the most acidic. Copper in association with

[1] G. P. Merrill, Gold in Granite, *Amer. Jour. Sci.*, April 1896, 309, Simundi's results are given by G. F. Becker.—*Tenth Census*, XIII. 52.

[2] *Monograph VII., U.S. Geol. Survey*, p. 80.

[3] *Monograph III., U. S. Geol. Survey.*

[4] *Monograph XIII., U. S. Geol. Survey*, p. 350.

[5] *Monograph XII., U. S. Geol. Survey*, p. 569.

[6] *XVII. Annual Rep. Director U. S. Geol. Survey*, Part II., 471.

nickel and some cobalt is found in widely separated parts of the world in basic gabbros, but other cases are equally pronounced in which it seems connected with igneous rocks of medium acidity, or with sediments having no visible connection with igneous rocks at all. The greatest copper district now productive, Butte, Mont., has only granites and rhyolites (quartz-porphyries) exposed for miles around. Lead and zinc are more commonly associated with limestones than with any other one rock, but the precipitating action of this rock, rather than any original content of the metals in it, is probably responsible for the association. In other respects no generalizations are possible. Gold and silver are cosmopolitan in their relations. The former has been found in the native state in igneous granite and perlite, and with pyrrhotite in basic gabbros, aside from its occurrence in veins. Silver in one locality and another is a companion of almost all types of rock; chromium and platinum are certainly at home in the basic peridotites and their serpentinous alteration products, and tin is seldom seen except in connection with granite. The other lesser metals that are of serious, practical importance admit of no general statements that are not largely speculative.[1] The rarer elements do, however present some striking associations. The "rare earths" seldom if ever occur in notable amount except in pegmatites and granitic rocks. Vanadium finds its peculiar home in titaniferous magnetite, but it is of remarkably wide distribution in basic rocks in general, as shown by over sixty analyses by Hillebrand and Stokes.[2] The amounts are small, in only one case reaching a tenth of one per cent., and the vanadium favors the dark silicates, especially biotite. It has also been detected in surprising quantities in the ashes of coals in Argentina and Peru.[3]

[1] These questions have been discussed at length by L. De Launay, "Contribution a l'Etude des Gîtes Métalliféres," *Annales des Mines*, XII, 1897, 119–228.

J. H. L. Vogt, "Ueber die relative Verbreitung der Elemente, besonders der Schwermetalle und ueber die Concentration des ursprünglich fein vertheilten Metallgehaltes zu Erzlagerstätten. *Zeitsch. fur praktische Geologie*, August, 1898, to January, 1899.

[2] W. F. Hillebrand, "Distribution and Quantitative Occurrence of Vanadium and Molybdenum in Rocks of the United States," *Amer. Jour. Sci.* September, 1898, 209.

[3] W. P. Blake, *Engineering and Mining Journal*, Aug. 11, 1894, p. 128. Vanadium has been detected by R. S. McCaffery, E. M., in coals used at Casapalca, Peru.

Molybdenum is much rarer and appears to be limited to the acidic rocks. The mineral molybdenite is seldom met except in pegmatites. Tungsten has practically the same associations as tin.

1.03.08. That the metals are so generally combined with sulphur in ore deposits seems to be due to the extended distribution of this element, and to its vigorous precipitating action on nearly all the metals at the temperatures and pressures which prevail near the earth's surface. Sulphur is widespread in pyrrhotite and pyrite, original minerals in many igneous rocks, and ones much subject to alteration; while sulphuretted hydrogen is common in waters from sedimentary rocks, and is a very general result of organic decomposition. Natural gas and petroleum from limestone receptacles almost always contain it.[1] Many sulphides, too, are soluble under the pressures and temperatures prevailing at great depths, but are deposited spontaneously at the pressures and temperatures prevailing at or near the surface.

1.03.09. Where veins occur in igneous rocks the bases for gangue minerals have been obtained from the rock-making silicates. Calcium is afforded by nearly all the important ones; silicon is everywhere present; barium has been proved in many feldspars, in small amount; and magnesia is present in many pyroxenes and amphiboles. Of the sedimentary rocks, limestone of course affords unlimited calcium, and recently Sandberger reports that he has identified microscopic crystals of barite in the insoluble residues of one.[2] This is of interest, as barite is such a common gangue in limestone.

1.03.10. It may be remarked that the natural formation of both ore and gangue minerals has doubtless proceeded in nature with great slowness, and from very dilute solutions. Both classes exhibit a tendency to concentrate in cavities, even from a widely dispersed condition through great masses of comparatively barren rock. The formation may have proceeded when the walls were far below their present position with regard to

[1] See, in this connection, J. F. Kemp, "The Precipitation of Metallic Sulphides by Natural Gas," *Engineering and Mining Journal*, Dec. 13, 1890.

[2] *Sitzungsberichte d. Math. phys. Classe d. k. bayer, Akad. d. Wiss.*, 1891, xxi. 291. See also, W. F. Hillebrand, "The Widespread Occurrence of Barium and Strontium, in Silicate Rocks."—*Jour. Amer. Chem. Soc.*, February, 1894, p. 81.

the surface, so that to those inclined a wide latitude for speculation on origin is afforded. It is possible that in the earlier history of the globe circulations were more active than they are now—a line of argument on which a conservative writer would hesitate to enlarge.

1.03.11. In the above discussion of the sources of the ores and gangue, the vein-filling has been considered as primarily derived from the barren wall rock or from deep-seated sources, and as precipitated in its present position in the first concentration. Yet in instances it is by no means improbable that vein-fillings as found to-day are the product of several concentrations, and that a deposit sufficiently rich to work may be the result of two, or more migrations since the first departure from an originally sparsely disseminated condition in the mother rock. L. De Launay has elaborated this view in the paper cited above.[1] In a later paragraph of this book, 1.05.06, the secondary alterations of those portions of veins that lie in the region of the vadose circulation is taken up, but M. De Launay carries the idea much further in suggesting that in many veins the present filling may be due to the concentration of ore from much more of the vein than now appears above the rich places. It is certainly true, that, if a vein were formed several geological periods back, it would have shared in all the elevations and depressions to which its region had been subjected and consequently to considerable changes in the relations of the ground water and the vadose circulations. An explanation would also be afforded of the richness of some veins that has been marked within limited distances of the surface and that has decreased in depth. W. H. Weed has noted cases of this character in Montana that are not as yet (1899) described in print.

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[1] The full title of M. De Launay's paper is: I. Sur l' importance des gites d' inclusion et de segregation dans une classification des gites métallifères. II. Sur le role des phénomènes d'alteration superficielle et de remise en mouvement dans la constitution de ces gisements. This may be freely translated. I. On the importance of magmatic inclusions and segregations in a classification of ore deposits. II. On the part played by phenomena of superficial alteration and of the renewal of migration in the constitution of these deposits.

CHAPTER IV.

ON THE FILLING OF MINERAL VEINS.

1.04.01. Bearing in mind what precedes, the preliminaries for the discussion of mineral veins are set in order. We have traced the formation of cavities by the shrinkage of rock masses in cooling or drying, by the movements and disturbances of the earth's crust (which are far the commonest and most important causes), and by dolomitization. The enlargement of such cavities by subterranean circulations followed, and the general effect of waters, cold and heated. The sources of the elements of the useful minerals were pointed out so far as known. All these general and indisputable truths assist in the drawing of right conclusions. It should be emphasized, as will appear later, that mineral veins or cavity fillings do not embrace all metalliferous deposits. On the contrary, the deposits which either form beds by themselves, or which are disseminated through beds of barren rock and are of the same age with them, do not enter into the discussion. They are characterized by being younger than their foot walls, and older than the hanging. Their geological structure is far simpler, and, as will appear in the discussion of particular examples, the working out of their origin does not so often carry the investigator into the realms of speculation and hypothesis. And yet it is not to be inferred from the prominence here given to the discussion of veins that bedded deposits yield to them, in any degree, in importance. Iron ores, for instance, are often in beds.

1.04.02. *Methods of Filling*—Methods of filling were summed up a very long time ago by Von Herder and Von Cotta,[1] as follows: 1. Contemporaneous formation. 2. Lateral

[1] *Erzlagerstätten*, 2d ed., 1859, Vol., I., p. 172. A later tabulation is given by G. F. Becker in *Monograph XIII. U. S. Geological Survey*, pp. 444, 445.

secretion. 3. Descension. 4. Ascension by (*a*) infiltration, or (*b*) sublimation with steam, or (*c*) by sublimation as gas, or (*d*) by igneous injection. To these should be added the more recent theory of (5) replacement, which, however, is rather a method of precipitation than of derivation. No one longer believes in contemporaneous formation, and descension has an extremely limited, if, indeed, any application. Ascension by sublimation as gas or with steam, or by igneous injection, has very few good applications. The discussion is practically reduced to lateral secretion and to ascension by infiltration.

1.04.03. *Lateral Secretion.*—By lateral secretion is understood the derivation of the contents of a vein from the wall rock. The wall rock may vary in character along the strike and in depth. Three interpretations may be made, two of which approach a common middle ground with ascension by infiltration. It may first be supposed that the vein has been filled by the waters near the surface which are known to be soaking through all bodies of rock, even where no marked waterway exists, and which seep from the walls of any opening that may be afforded. Being at or within comparatively short distances of the surface, the waters are not especially heated. As they emerge to the oxidizing and evaporating influence of the air in the cavity, their burden of minerals is deposited as layers on the walls. The second interpretation supposes the walls to be placed during the time of the filling at considerable depths below the surface, so that the percolating waters are brought within the regions of elevated temperature and pressure. Essentially the same action takes place as in the first case. The third interpretation increases the extent of the rock leached. Thus, if a mass of granite incloses a vein and extends to vast depths, we may suppose the waters to come from considerable distances, and to derive their dissolved minerals from a great amount of rock of the same kind as the walls. Portions of this may even be in the regions of high temperature, while the place of precipitation is nearer the surface. These last two interpretations have much in common with the theory of ascension by infiltration, and on this common middle ground lateral-secretionists and infiltration-ascensionists may be in harmony.

1.04.04. *Ascension by Infiltration.*—The theory of infiltration by ascension in solution from below considers that ore-bearing solutions come from the heated zones of the earth, and that they rise through cavities, and at diminished temperatures and pressures deposit their burdens. No restriction is placed on the source from which the mineral matter has been derived. Indeed, beyond the fact that it is "below," and yet within the limits reached by waters, all of which have descended from the surface, and that the metals have been gathered up from a disseminated condition in rocks—igneous, sedimentary and metamorphic—no more definite statement is possible. This theory is of necessity largely speculative, because the materials for its verification are beyond actual investigation.

1.04.05. In favor of lateral secretion the following arguments may be advanced. I. According to Sandberger, actual experience with the conduits, either natural or artificial, of mineral springs, shows that a deposit seldom, if ever, gathers in a moving current. It is only when solutions come to rest on the surface and are exposed to oxidation and evaporation that precipitation ensues. Deposits in veins have therefore formed in standing waters, whose slight overflow or evaporation would be best compensated by the equally slight and gradual inflow from the walls. If in hot springs there were a strong and continuous flow from below, and discharge from above, the mineral matter would reach the surface.[1] Hence the deposit would be more likely to gather by the slow infiltrations from the wall rock, which would stand in cavities like the water of a well. We have, however, some striking instances of deposits in artificial conduits.

Prof. H. S. Munroe has called the writer's attention to a case met by him in 1891. The fourteen-inch column pipe of a pump at the Indian Ridge Colliery, Shenandoah, Pa., which was raising ferruginous waters, became reduced in diameter to five inches within two years by the deposit of limonite. The same amount of water was forced through the five-inch hole as through the fourteen-inch. By figuring out the stroke and cylinder contents, it was found that in the clear pipe the water moved 162 feet per minute, and in the contracted pipe 1,268 feet. And yet the deposit gathered. The conditions necessitated the continuous action of the pump, and it was not idle

[1] Sandberger, *Untersuchungen über Erzgänge,* Heft I.

over two hours in each two months of that period. The boiler feed-pipes of steamers plying on the Great Lakes also become coated with salts of lime. Years ago a disastrous boiler explosion occurred from the virtual stoppage of the feed by this precipitation.

1.04.06. II. If a vein were opened up, in mining, which ran through two different kinds of rock, and if in the one rock one kind of ore and gangue minerals were found, and in the other a different set, the wall rock would clearly have some influence. Thus in a mine at Schapbach, in the Black Forest, investigated by Sandberger, a vein ran through granite and gneiss. The mica of the granite contained arsenic, copper, cobalt, bismuth and silver, but no lead. The principal ore in this portion was tetrahedrite. The mica of the gneiss contained lead, copper, cobalt, and bismuth, and the vein held galena, chalcopyrite, and a rare mineral, schapbachite, containing bismuth and silver, but probably a mixture of several sulphides. No two ores were common to both parts of the vein. Another well-established foreign illustration is at Klausen, in the Austrian Tyrol. Lead, silver, and zinc occurred in the veins where they cut diorite and slates, but copper where mica schist and felsite formed the walls. In America there are a number of similar cases. At the famous Silver Islet mine[1] on Lake Superior the vein runs through unaltered flags and shales, and then crosses and faults a large diorite dike. Where the diorite forms the walls, the vein carries native silver and sulphides of lead, nickel, zinc, etc., but where the flags form the walls the vein contains only barren calcite. Along the edges of the estuary Triassic sandstones of the Atlantic border, where they adjoin Archean gneiss, a number of veins are found which yield lead minerals, while in the sandstones near the well-known diabase sheets and dikes are others carrying copper ores. It was early remarked by J. D. Whitney that the

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[1] W. M. Courtis. "On Silver Islet," *Engineering and Mining Journal*, Dec. 21, 1878. *Trans. Amer. Inst. Min. Eng.*, V. 474.

E. D. Ingall, *Geol. Survey of Canada*, 1887-88, p. 27, H.

F. A. Lowe, "The Silver Islet Mine," etc., *Engineering and Mining Journal*, Dec. 16, 1882, p. 321.

T. MacFarlane, "Silver Islet," *Trans. Amer., Inst. Min. Eng.*, VIII. 226. *Canadian Naturalist*, IV. 38.

McDermott, *Engineering and Mining Journal*, January, 1877.

lead was usually associated with the gneiss, the copper with the diabase.

1.04.07. From instances like these it is inferred that the ores were derived each from its own walls, and by just such a leaching action by cold surface waters as is outlined above. As opposed to this, it has usually been claimed that each particular wall exerted a peculiar selective and precipitating action on the metals found adjacent to it and none on the others, so that if a solution arose carrying both sets, each came down in its particular surroundings while the others escaped. Dr. W. P. Jenney has called the writer's attention to such a case. The Head Center mine, in the Tombstone district, Arizona, is on a vein which pierces slates, and in one place forty feet of limestone. In the slates it carried high-grade silver ores, with no lead, but in the limestone, lead-silver ores. A rock like limestone might well exercise a precipitating action, which, however, we cannot attribute to rocks composed of the more inert silicates. Again, it has been said that the solutions coming from below have varied in different portions of the vein or at different periods. An earlier opening would thus be filled with one ore, a later opening with another. This is hypothetical, but has been advanced for Klausen by Posepny.[1] A further general objection to the first interpretation of lateral secretion is the weak dissolving power of cold surface waters, and this is a very serious one.

1.04.08. As opposed to the second interpretation, it may be advanced that precipitation in a cavity at a great depth would be retarded by the heat and the pressure, to just that extent to which solution in the neighboring walls would be aided. The temperature and pressure being practically the same, the tendency to remain in solution would be great until the minerals had reached the upper regions and filled the cavity by ascension. Under such circumstances ores would only be deposited below, by some such action as replacement. To the third interpretation no theoretical objections can be made.

1.04.09. *Infiltration by Ascension.*—On the side of infiltration by ascension, if two veins or sets of veins were found in the same wall rock, but with different kinds of ores and minerals, the conclusion would be irrefutable that the respective so-

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[1] *Archiv. f. Praktische Geologie,* p. 482.

lutions which formed them had come from two different sources below. Thus at Butte, Mont., there is a great development of a dark, basic granite. It contains two series of veins, of which one produces copper sulphides in a siliceous gangue, while around this series, to the south, west and north the veins yield sulphides of silver, lead, zinc, and iron, also in a siliceous gangue, but abundantly associated with manganese minerals, especially rhodonite. No manganese occurs in the copper belt, nor is any copper found in the silver belt. Such results could originate only in different, deep-seated sources. Again, at Steamboat Springs, Nev., and Sulphur Bank, Cal., the hot springs are still in action and are bringing their burdens of gangue and ore to the surface. The former has afforded a long series of metals, the latter chiefly cinnabar. G. F. Becker[1] has shown that the cinnabar probably comes up in solution with alkaline sulphides.

1.04.10. *Replacement.*—The conception of replacement is one that has been applied of late years by some of the most reliable observers. About 1873 it appears to have been first extensively developed by Franz Posepny, an Austrian geologist, in relation to certain lead-silver deposits at Raibl, in the Province of Kaernthen. At nearly the same time it was suggested by Pumpelly, then State Geologist of Missouri, to Adolph Schmidt, who was engaged in studying the iron deposits of Pilot Knob and Iron Mountain (see Examples 11 and 11*a*), and by Schmidt it was considered applicable to them.[2] Some ten years later J. S. Curtis, at the suggestion of S. F. Emmons, based his explanation of the formation of the Eureka, Nev., lead-silver deposits on the same idea, and according to Emmons (1886) it holds good for Leadville. R. D. Irving, who credited Pumpelly with bringing it to his attention, published in 1886 an explanation of the hematite ores of the Penokee-Gogebic range (Example 9*c*), in which the idea is applied, and Van Hise has since elaborated it. In the process of replacement no great cavity is supposed to exist previously. There is little, in fact, but a circulation or percolation of ore-

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[1] G. F. Becker, "Natural Solutions of Cinnabar, Gold, and Associated Sulphides," *Amer. Jour. Sci.*, III., xxxiii. 199; *Eighth Ann. Rep. Director U. S. Geol Survey. Monograph XIII., U. S. Geol. Survey*, p. 343.

[2] "Iron Ores and Coal Fields," *Missouri Geol. Survey*, 1873.

bearing solutions which exchange their metallic contents, molecule by molecule, for the substance of the rock mass. We would not ordinarily expect the ore body to be as sharply defined against the walls as when it fills a fissure, but rather to fade into barren material. Thus rock may be impregnated but not entirely replaced, and, while apparently unchanged, yet carry valuable amounts of ore. Some of the ores of Aspen, Colo. (Example 30*d*), are at times only to be distinguished by assay from the barren limestones. Yet decomposition may bring out the limits of each.

1.04.11. The chemistry of the replacement process is none too well understood, but it presents fewer difficulties when applied to a soluble rock, like limestone or dolomite, than when rocks composed of silicates and quartz have given way to ores. Acid solutions would readily yield to calcium carbonate; but if the metals are present as sulphides, some reducing agent, such as organic matter, is necessary in order to change the metallic sulphate to sulphide.[1] Or else, if the metallic sulphides come up in solution with alkaline sulphides, some third agent is needed to remove the calcium carbonate, *pari passu* just before the metallic sulphide is precipitated. It must be confessed that for enormous bodies of ore, like those of Leadville, the small amount of organic matter present seems hardly equal to the task assigned it, and the delicate balance of the latter case—causing deposition to tread so closely on the heels of rock removal, in order to avoid assuming an extended cavity—makes it appear that the entire chemistry of the process is perhaps hardly understood.

1.04.12. When silicate rocks are replaced, leaving a siliceous gangue, the process may have been somewhat as suggested by R. C. Hills for the mines of the Summit district, Rio Grande County, Colorado.[2] Alkaline solutions remove silica and have slight action on silicates, but solutions acid with sulphuric acid attack silicates, such as feldspar and biotite, change the alumina to a soluble sulphate, and cause the separation of free silica. In the alteration products abun-

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[1] Compare S. F. Emmons, "On the Replacement of Leadville Limestones and Dolomites by Sulphides," *Monograph XII., U. S. Geol. Survey*, p. 563.

[2] See *Proc. Colo. Sci. Soc.*, Vol. I., p. 20.

dant opportunity would be afforded for the precipitation of sulphides, which would in part at least replace the rock. Along a crack or line of drainage definite walls would thus easily fade out. Such phenomena are afforded by innumerable ore deposits[1] and often come under the notice of every one familiar with mining. Yet we cannot but hope that in the future our knowledge of the chemical reactions involved will be increased.

It may again be stated that the formation of ore deposits has proceeded with great slowness, and that the solutions bringing the metals have been, beyond question, very dilute. The extremely small amounts of the metals which have been detected in relatively large amounts of igneous rocks, even by the most refined analytical methods, have necessarily made the progress of solution a protracted one. Curtis records some careful observations on the growth of aragonite at Eureka, Nev., where he found that in three weeks, so long as wet by a drop of water, the crystals increased in one case as a maximum five-eighths of an inch, and in another three-eighths. But this was where the whole inclosing mass of rock consisted of the compound deposited.

[1] See R. W. Raymond, discussion of S. F. Emmons' "Notes on the Geology of Butte, Mont.," *Trans. Amer. Inst. Min. Eng.*, XVI., p. 59, 1887.

CHAPTER V.

ON CERTAIN STRUCTURAL FEATURES OF MINERAL VEINS.

1.05.01. *Banded Structure.*—Mineral veins sometimes exhibit a banded strucure, by which is understood the arrangement of the ore and gangue in parallel layers that correspond on opposite walls. They are most conspicuous where the walls are well defined. The solutions which have brought the minerals have varied from time to time, and the precipitated coatings correspond to these variations. They alternate from gangue to ore, it may be, several times repeated. The ore may be in small scattered masses preserving a distinct lineal arrangement in the midst of the barren quartz, calcite, barite, fluorite, siderite, etc., or itself be so abundant as to afford continuous parallel streaks. The commonest ores so observed are pyrite, chalcopyrite, galena, blende, and the various sulphides of silver. The veins of the Reese River district, in Nevada, furnish good illustrations of alternating ruby silver ores and quartz. Those of Gilpin County, Colorado (Example 17*a*), afford alternations of pyrite, chalcopyrite, and gangue. (See figures in Endlich's report, *Hayden's Survey*, 1873, p. 280.) The Bassick mine, in Colorado, has pebbles remarkably coated. Figure 6 shows a vein at Newman Hill, near Rico, Colo.

Banded veins, however, except of a rude character, are not common in this country. They have received much more attention in Germany, where, especially near Freiberg, they show remarkable perfection. The famous Drei Prinzen Spat Vein, Fig. by Von Weissenbach and copied in many books, has ten corresponding alternations of six different minerals on each wall. Banded structure, whether of veins or vuggs or stalactites, etc., has been called "crustification" by Posepny, who considers it an infallible symptom of deposition from solution.

1.05.02. A line of cavities, or vuggs, is often seen at the central portion of a vein, into which crystals of the last-formed minerals protrude, forming a comb (see Fig. 6). These may project into each other and interlock—especially in quartz—forming a comb in comb. The same may occur between side layers. These cavities are a most prolific source of finely crystallized minerals. If, after the fissure—perhaps at the time small—has become once filled, subsequent movements take place, it may strip the vein from one wall and cause a new series of minerals to be deposited, with the previously formed vein on one side and the wall rock on the other. This occasions unsymmetrical fillings. But it may also happen that, with other-

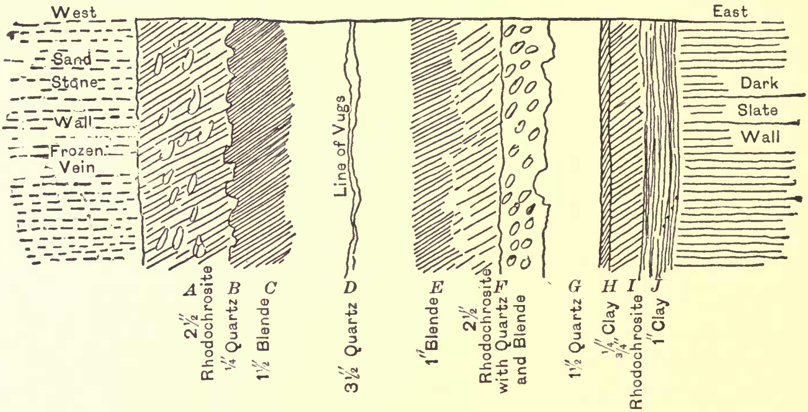

FIG. 6.—*Banded Vein at Newman Hill, near Rico, Colo. After J. B. Farish, Proc., Colo. Sci. Soc., April 4, 1892; Engineering and Mining Journal, August 20, 1892.*

wise symmetrical fillings, one layer may be lacking on one side or the other. Where portions of the wall rock have been torn off by the vein matter in these secondary movements, they may be buried in the later deposited vein filling, and form great masses of barren rock called "horses." The vein then forks around them. If the ore and the gangue have partly replaced the wall in deposition, unchanged masses of wall may also become inclosed and afford horses of a different origin. An originally forked fissure gives an analogous result.

It is a curious fact that veins are often most productive just at the split. If the masses are small, or if the vein fills a shattered strip and not a clean fissure, or if it occupies an old volcanic conduit, deposition and replacement may surround unchanged cores of wall rock with concentric layers of ores and minerals. Thus the Bassick, at Rosita, Colo., referred to above, consists of rounded cores of andesite, inclosed in five concentric layers of metallic sulphides. The Bull Domingo, in the same region, exhibits shells of galena and quartz mantling nodules of gneiss. Such cores strongly resemble rounded, water-worn boulders, a similarity which has suggested some rather improbable hypotheses of deposition.

1.05.03. *Clay Selvage.*—An extremely common feature is a band of clay, most often between the vein matter and the wall. This is called a selvage, gouge, flucan, clay seam, or parting. It may come in also between layers of different minerals, and may even rest as a mantle on the crystals which line cavities. It is at times the less soluble portion left by the decay and removal in solution of wall rock (residual clay), at times the comminuted material resulting from the friction of moving walls (attrition clay), and again it may be taken up by currents and redeposited from bodies of the first two sorts. Such layers of clay, being well-nigh impervious to water, may have exercised an important influence in directing the subterranean circulations.[1]

1.05.04. *Pinches, Swells, and Lateral Enrichments.*—The swells and pinches of veins have been referred to above and explained. Aside from these thicker portions of the ore, it is often seen that the richer, or even the workable bodies follow certain more or less regular directions, forming so-called "chutes." They probably correspond to the courses taken and followed by the richer solutions. J. E. Clayton observed that they follow the directions of the slips, or striæ, of the walls rather more often than not, and in the West this disposition or tendency is called Clayton's law. Chute is sometimes spelled "shoot" or "shute." Chimney and ore-course are synonyms of chute. Bonanza is used, especially on the Comstock Lode, to indicate a localized, rich body of ore.

Lateral enrichments are caused by the spreading of the ore-bearing currents sidewise from the vein, and often along particular beds of rock, which they may replace more or less with

[1] See citation from Becker on the Comstock Lode, 2.11.19.

ore. Beds of limestone—it may be quite thin, when in a series composed of shales or sandstones—are favorite precipitants, and from such lateral enlargement the best returns may be obtained. The valuable ore bodies of Newman Hill, near Rico, Colo., whose interesting descriptions by J. B. Farish and T. A. Rickard have already been several times cited, are found as lateral enrichments along a bed of limestone less than three feet thick and embedded in shales. Above the limestone the veins practically cease, as the fissures become tight in a series of sandstones and shales. Lateral enrichments may closely resemble bedded deposits if the supply fissures are relatively small, but it is generally safe to infer the presence of supply conduits, although they may be obscure. The Potsdam ores of the Black Hills are good illustrations.

1.05.05. *Changes in Character of Vein Filling.*—In discussing the influence of wall rock the changes that occur in veins were briefly mentioned. But even where the walls remain uniform there is always variation in contents, and of course in value, from point to point. Ore, gangue, horses, and walls alternate both longitudinally and in depth, and such changes must be allowed for and averaged by keeping exploration well in advance of excavation. Even a series of parallel veins may all prove fickle. In illustration of the above the Marshall tunnel of Georgetown, Colo., may be cited. It cut twelve veins below their actual workings, and every one was barren at the tunnel though productive above.[1]

1.05.06. *Secondary Alteration of the Minerals in Veins.*—It has already been stated that the chief ore minerals in vein fillings are sulphides. Where these lie above the line of permanent subterranean water they are exposed to the oxidizing and hydrating action of atmospheric waters, which, falling on the surface, percolate downward. The ores are thus subjected to alternating soakings and dryings which encourage alteration. The sulphides change to sulphates, carbonates, oxides, or hydrous forms of the same, and the metallic contents are in part removed in the acid waters which are also formed. Pyrite, which is the most widespread of the sulphides, becomes limonite, staining everything with its characteristic color. Galena becomes cerussite or anglesite. Blende affords cala-

[1] J. J. Stevenson, Wheeler's Survey, *Geology*, Vol. III., p. 351.

mine and smithsonite. Copper ores, of which the usual one is chalcopyrite, change to malachite, azurite, chrysocolla, cuprite, and melaconite, and to the sulphide, chalcocite. The silver sulphides afford cerargyrite. The rarer metals alter to corresponding compounds of less frequency. These upper portions are also more cellular and porous, being at times even earthy. The rusty color from the presence of limonite often marks the outcrop and is of great aid to the prospector. It has been called the iron hat, or gossan. This feature has important economic bearings. The character of ores may entirely change at a definite point in depth, and the later products, if not lower in grade, as is often the case, may demand different, perhaps more difficult, modes of treatment. Oxidized ores are the easiest to smelt, and the desirability of careful exploration before indulging in too confident expectations may be emphasized. As examples, the Ducktown copper deposits (See Example 16), the Leadville silver mines (Example 30), the southwest Virginia zinc deposits (Example 26), the copper and silver veins at Butte, Mont. (Example 17), and others in Llano County, Texas (Example 17*b*), may be cited. At Ducktown a considerable thickness of chalcocite, melaconite, and carbonates accumulated just at the waterline and abruptly changed to low-grade, unworkable pyrite and chalcopyrite below it. At Bonsacks, near Roanoke, Va., very rich, easily treated,earthy limonite and smithsonite (30 to 40 per cent. zinc) passed into a refractory, low grade (15 to 20 per cent. zinc), intimate mixture of blende and pyrite. Excavations in dry districts may not reach the water line for great depths. Thus at Eureka, Nev., in the rainless region of the Great Basin, the oxidized ores continue to 900 feet or more.

It is worthy of remark in this connection that possibly some deposits of oxidized ores may have been formed originally as such. Wendt has argued this for the copper mines of the Bisbee district, Arizona; but in this case recent exploration has established the former presence of sulphides. (See Example 20*b*.) If oxidized ores are now found below the water line, it may indicate a depression of the rocks from a previous, higher position. R. C. Hills has brought out a very interesting instance of the concentration of gold and silver in the lower part of the oxidized zone, or at least at a considerable depth below the outcrop. The upper portion of the vein, in this case with a quartz gangue, was impoverished. The gold is thought to have been carried down in solution with ferrous and ferric sulphates, which were decomposed by feldspar, while the precious metal was thrown down. The ore bodies lie in the Summit district,[1] Rio Grande County, Colorado.

1.05.07. The waters of mines which have opened up and exposed sulphides to oxidation are often charged with sulphuric acid and even metallic salts. This is especially true of mines in copper sulphides, and the pumps are much corroded. In instances considerable metallic copper has been removed by passing the mine drainage over scrap iron, as at Ducktown, Tenn., and as has been introduced at Butte, Mont. Mine timbers have been preserved very long periods by the deposition of copper on them, because of their reducing action on the solutions. Pumps and timbers placed by the Romans in the Rio Tinto mines, in Spain, are still in good preservation. Even gold has been detected in Australian mine waters.[2]

1.05.08. *Electrical Activity.*—Among the writers of fifty or sixty years ago, electrical or galvanic action was a favorite theoretical precipitant of ores in veins, and careful experiments were made in England and Germany to detect it. By connecting the opposite ends of a vein with a wire, in which was a galvanometer, the attempt was made again and again to establish the existence of galvanic action. At times the results gave some grounds for belief, but at others they were contradictory or uncertain, so that no very definite or reliable conclusions were established Other experiments were made in Germany about 1844, by Reich, while lately quite elaborate investigations have been carried out by Dr. Carl Barus on the Comstock Lode, and at Eureka, Nev. Great difficulties are met in preserving the necessary insulation throughout the wet and devious underground workings,

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[1] R. C. Hills, *Proc. Colo. Sci. Soc.*, Vol. I., p. 32; S. F. Emmons, quoting Hills, *Engineering and Mining Journal*, June 9, 1883.

For a very complete discussion of the alteration of ore deposits above the ground water and of the formation of gossan minerals, see R. A. F. Penrose, Jr., "The Superficial Alteration of Ore Deposits," *Journal of Geology*, II. 288, 1894.

[2] See *School of Mines Quarterly*, Vol. XI., 364, for review of literature bearing on this subject.

and amid such surroundings in detecting the currents, which would be necessarily small. With Barus the thesis was not alone to establish a galvanic action, such as might be a precipitating agency, but also to observe what effect, if any, was exerted by the intervention of an ore body on the normal terrestrial currents. Had this latter been proved of sufficient amount, the existence of such bodies might be indicated by plotting electrical observations. While in some respects of interest, the results of Dr. Barus are not very decisive, and this line of investigation is hardly to be considered a promising one. The importance attached to it in former years may be illustrated by these words of De la Beche, one of the ablest of English writers, in 1839. Speaking of veins in general, after discussing those of Cornwall in particular, he says: "Mineral veins result from the filling of fissures in rocks by chemical deposits, from substances in solution in the fissures, such deposits being greatly due to electro-chemical agency." The influence of terrestrial magnetism upon the distribution of mineralized districts has been urged by T. F. Van Wagenen, who endeavors to show for the Cordilleran region of North America that the productive areas lie along mean magnetic curves and that they are separated by barren belts. The productive belts are thought to converge at the magnetic pole of the earth north of Hudson Bay.[1]

[1] Theo. F. Van Wagenen, "System in the Location of Mining Districts," *School of Mines Quarterly,* January, 1898, p. 109.

CHAPTER VI.

THE CLASSIFICATION OF ORE DEPOSITS—A REVIEW AND A SCHEME BASED ON ORIGIN.

1.06.01. In the classification of ore deposits the same systematic arrangement is not to be expected as in the grouping of plants, animals, or minerals. Ore deposits have not the underlying affinities and relationships of living organisms nor of definite chemical compounds. The series of objects is too diverse, and, in the nature of the case, the standards of appeal must be different. The subject is, however, one of great practical importance as well as of great scientific interest. A vocabulary of intelligible terms is indispensable for description and comparison, and, under our mining laws, often for valid titles, while as a vehicle for the spread of knowledge and reasonable conceptions regarding these phenomena, its importance cannot be overestimated.

1.06.02. All schemes of classification rest on these principles: form, origin—or the genetic principle (including method, relative time of origin as contrasted with the walls, etc.)—state of aggregation, and mineral contents. Of these, the principle of form is usually esteemed the weightiest, and is given the greatest prominence, partly because it has been thought to be the one most closely affecting exploitation, and partly because it involves less that is or has been, up to very recent times, more or less hypothetical. Yet form is largely fortuitous, and it has, of course, no law, while, with sufficient knowledge, the genetic principle is the one giving a far more thoroughly scientific basis. Every one, in opening up or searching for an ore body, must be influenced by some hypothesis, either of shape or of origin. It is the conviction of the writer that, with all our deficiencies of knowledge, the genetic principle is also the best guide, even in practical development.

1.06.03. Very early in the development of mining literature the distinction was made between those ore bodies which are parallel to the stratification and those which break unconformably across it. This took place long before the epoch-making time of Werner, and even before the conception of the relative ages of strata had been at all generally grasped. Thus among the Germans we find the terms "Lager" and "Flötze"[1] on the one side, being set off in contrast to "Gang" (vein) on the other. Werner, writing in 1791, quotes Von Oppel's distinctions between Flötze (strata beds) and Gänge (veins), which were published in 1749; but without doubt, as mining terms, they go much further back. Beyond this simple indication of the views of the older writers, no attempt will be made here to quote authorities earlier than 1850. This is justifiable, because the important works, like De la Beche's *Geology of Cornwall and Devon*, and Henwood's *Metalliferous Deposits of Cornwall and Devon*, are rather discussions of veins than systematic attempts at classification.

1.06.04. In Appendix I. will be found the principal schemes of classification which have thus far been suggested. They are grouped according to certain relationships and similarities that run through them. The scheme here given finds its natural

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[1] Lager and Flötze are difficult to render into English while retaining their native shades of meaning The later writers in Germany (Serlo, Gätzchmann, Von Groddeck, Köhler) define them as being interbedded bodies, each later than the foot wall in formation, and older than the hanging; and that Lager are much more limited in horizontal extent than Flötze R. Wabner shows, however, in the *Berg.- u. Hüt. Zeitung*, Jan. 2, 1891, p. 1, that writers in the earlier part of the century did not entirely restrict the term Lager as regards age relative to the foot and hanging, but applied it to ore bodies, which follow the general bedding, although they may have been introduced much later than the formation of the walls. Thus the frequent occurrence of lead ores in limestone along certain beds (southeast Missouri for example) would be called Lager. We would apply the terms impregnation, or dissemination, or bed-vein, to such. Flötze we would call stratum, and Lager, as defined by the later authors "bed" or "seam." Werner, for instance, in his classification of the rock formations of the globe, made: I. Urgebirge (Primitive, Primary, etc., having no fossils). II. Secondary, subdivided into A. Uebergangsgebirge (transitional, more or less metamorphosed sediments, but fossiliferous). B. Flötzgebirge (unaltered strata). From this the meaning of Flötz may be grasped. By contrast, a magnetite lens is a good illustration of Lager.

place as No. 17, and at the time that it was first prepared it was unique in being a purely genetic one, except that one by F. D. Power, which appeared in Melbourne the same year, ran along the same lines. The literature of the next few years proved, however, that the subject was active in many minds, and other schemes were independently published in different parts of the world, which were conceived from the same point of view. In the one below, the four important methods of origin, viz., the igneous, the methods of precipitation from solution or by deposition from suspension or by deposition as residual concentrations, are made fundamental and then the ore-bodies belonging under each are referred so far as possible to well-recognized and familiar geological phenomena. The close analogy of this grouping in some of its particulars to the commonly accepted classification of rocks, will be at once apparent, and our general knowledge of rocks may be used to throw light upon the ore deposits, but the latter with the exception of a few involving iron, are never in sufficient amount to be considered particular forms of rock, in and of themselves. The scheme is also the natural result of the general exposition of the subject in the preceding pages, which have consistently led up to it. Certain obscure ore bodies, which are not well understood, receive special mention after the general discussion.

1.06.05. J. F. Kemp, 1892. Revised from the *School of Mines Quarterly*, November, 1892.

I. Of Igneous Origin. Excessively basic developments of fused and cooling magmas. Peridotite, forming iron ore at Cumberland, Rhode Island.[1] Titaniferous magnetite, Jacupiranga, Brazil;[2] in Minnesota gabbros;[3] in Adirondack gabbros;[4] in Swedish and Norwegian gabbros.[5] Nickeliferous pyrrhotite.[6] Chromite.[7] Corundum.[7]

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[1] M. E. Wadsworth, *Bull. Mus. Comp. Zoöl.*, 1880, VII.

[2] O. A. Derby, *Amer. Jour. Sci.*, April, 1891.

[3] N. H. Winchell, *Tenth Ann. Rep Minn. Geol. Survey*, pp. 80–83, *Bull. VI.* of same survey, p. 135.

[4] J. F. Kemp, *Bull. Geol. Soc. Amer.*, V. 222, 1894. *XIX. Annual Rep. Dir. U. S. Geol. Survey.* (In press, March, 1899.)

[5] J. H. L. Vogt, *Geol. Foren. i. Stockholm Förhand*, XIII., 476, May, 1891. English abstract and review by J. J. H. Teall, *Geol. Mag.*, February, 1892. See also *Zeitschr. für Praktische Geologie*, I., 4.

[6] See references under paragraph 1.06.08 below.

[7] See references under paragraph 1.06.13.

II. Deposited from solution.

1. Surface precipitations, often forming beds and caused by—

(*a*) Oxidation. Bog ores. Ferruginous oölites, as in some Clinton ores.[1]

(*b*) Sulphurous exhalations from decaying organic matter, etc. (Pyrite.)

(*c*) Reduction, chiefly by carbonaceous, organic matter. (Pyrite from ferrous sulphate.)

(*d*) Evaporation, cooling, loss of pressure, etc. Hot spring deposits, as at Steamboat Springs, Nev.[2]

(*e*) Secretions of living organisms. (Iron ores by algæ.[3]

NOTE.—These same causes of precipitation operate in subterranean cavities, although not again specially referred to.

2. Disseminations (impregnations) in particular beds or sheets, because of—

(*a*) Selective porosity. (Silver Cliff, Colo., silver ore in porous rhyolite.[4] Amygdaloidal fillings as in copper-bearing amygdaloid. Keweenaw Point, Mich.; Santa Rita, N. M.[5] Impregnations of porous Sandstone as at Silver Reef, Utah.[6]

(*b*) Selective precipitation by calcareous matter. Potsdam or siliceous gold ores, Black Hills, S. D.[7]

3. Filling joints caused by cooling or drying (Mississippi Valley gash veins in part).

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[1] C. H. Smyth, Jr., *Amer. Jour. Sci.*, June, 1892, p. 487.

[2] G. F. Becker, *Monograph XIII., U. S. Geol. Survey*, pp. 331, 468; Laur, *Ann. des Mines*, 1863, p. 421; J. Leconte, *Amer. Jour. Sci.*, June, 1883, p. 424, July, p. 1; W. H. Weed, *idem*, August, 1891, p. 166.

[3] Sjogrun, *Berg.- und Hütt. Zeit.*, 1865, p. 116.

[4] Clark, *Engineering and Mining Journal*, Nov. 2, 1878, p. 314.

[5] A. F. Wendt, *Trans. Amer. Inst. Min. Eng.*, XV., 27.

[6] C. M. Rolker, *idem*, IX., 21.

[7] J. D. Irving, *Annals N. Y. Acad. Sci.*, XII. Part II, 1899. Other citations will be found under 2,01.03.

4. Occupying chambers (caves) in limestone. (Cave Mine, Utah.[1])

5. Occupying collapsed (brecciated) beds, caused by solution and removal of support, or from dolomitization of limestone. (Southwest Missouri zinc deposits.[2] Occupying cracks at Monoclinal bends, Anticlinal summits, Synclinal troughs, often with replacement of walls. (Gash veins in part; galena deposits at Mine la Motte, Missouri; zinc blende deposits in the Saucon Valley, Pennsylvania.[3]) Elkhorn Mine, Mont.

6. Occupying shear-zones, or dynamically crushed strips along faults, whose displacement may be slight, closely related to No. 8. (Butte, Mont.)[4]

7. True veins filling an extended fissure, often with lateral enlargements. See also under 5.

8. Occupying volcanic necks, in agglomerates. (Bassick Mine, near Rosita, Colo.)[5]

9. Replacements in troughs of some impervious rock or rocks. (Lake Superior hematites.)[6]

10. Contact deposits. Igneous rocks always form one wall. Fumaroles. (Greisen.)

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[1] J. S. Newberry, *School of Mines Quarterly*, March, 1880. See also J. P. Kimball, on Santa Eulalia, Chihuahua, *Amer. Jour. Sci.*, II., xlix. 161.

[2] F L. Clerc, *Lead and Zinc Ores in Southwest Missouri Mines*, Carthage, Mo., 1887; A. Schmidt, *Missouri Geol. Survey*, 1874, p. 384. See later papers cited under Example 25.

[3] F. L. Clerc, *Mineral Resources*, 1882, p. 361; H. S. Drinker, *Trans. Amer. Inst. Min. Eng.*, I., 367.

[4] S. F. Emmons, *Trans. Amer. Inst. Min. Eng.*, XVI., 49; W. P. Blake, *Idem*, XVI., 65. Butte Special Folio, *U. S. Geol. Survey*.

[5] C. W. Cross, *Proc. Colo. Sci. Soc.*, 1890, p. 269. S. F. Emmons, *XVII. Rep. U. S. Geol. Surv.*, Part II., p. 430.

[6] C. R. Van Hise, *Amer. Jour. Sci.*, February, 1892, p. 116. *Monograph XXVIII U. S. Geol. Surv.*

11. Segregations formed in the alteration of igneous rock. (Chromite in serpentine.)

III. Deposited from Suspension. Residual Deposits.

1. Metalliferous Sands and Gravels, whether now on the surface (placers, magnetite beach sands), or subsequently buried. (Deep gravels, magnetite lenses?)
2. Residual Concentrations, left by the weathering of the matrix. (Iron Mountain, Mo., hematite in part.[1])

1.06.06. It is believed that under the above heads are included all the forms of ore bodies which constitute well-recognized and fairly well-understood geological phenomena. To these categories year by year we are enabled, by the results of extended and careful investigation, to refer many that have been obscure. A number of familiar terms for ore bodies in mining literature fail to appear, but are mentioned in the classifications quoted from others. (See Appendix I.) Many of these refer only to form, and geologically considered are only convenient admissions of ignorance as to origin. Some other ore bodies whose methods of origin are involved in the processes of regional metamorphism are placed by themselves further on. The explanations of them are as yet hypothetical. A few comments on the scheme may now be added, although in the main it explains itself.

1.06.07. I. The writings of Lagorio, Iddings, Rosenbusch and others, regarding the development of rocks from fused magmas, have emphasized the fact that the laws of solution do not fail to apply, because the magmas are raised to very elevated temperatures; and that they hold good for fused rock precisely as for heated water or any other solvent. Other laws of physical chemistry and of thermodynamics have also been recognized by many as fundamental to the true understanding of the reactions, but the subject is a difficult one, and our knowledge is as yet incomplete. The reactions are complex and occur at such elevated temperatures as to render observation difficult. The magmas known in Nature are of endless va-

[1] R. Pumpelly, *Bull. Geol. Soc. Amer.*, II., p. 220.

riety, and involve a number of bases. Just which portion is solvent and which is dissolved matter may not always be clear, nor do we certainly know the actual state in which the elements exist at these high temperatures, nor the influence of electrical currents or still more obscure forces. Nevertheless, we do know that as the magma cools from a perfectly fluid condition the first minerals to separate are those which first, under the diminishing temperature (and perhaps pressure) reach a state of saturation and *must* therefore crystallize. If this is expressed in the terms of thermodynamics, we may say that those compounds will first form which liberate the most heat in crystallizing, and so on down to complete solidification. Usually the order is that described in paragraph 1.03.05, but mass action, brought about by the superabundance of one element or another, may affect the order, and the variability of composition shown by igneous rocks is also a serious factor.

Students of rocks have very generally reached the conclusion that a great parent magma which stands molten for long periods in the earth will break up into different component or fractional magmas before any mineral crystallizes. The fractional magmas by successive eruptions afford various different types of rocks of greatly contrasted composition. The process is called differentiation, and it is of interest in this connection as showing in a general way the tendency of fused rock masses to break up and vary.

All the above theoretical considerations throw light on the formation of the igneous ore bodies.

1.06.08. The first ore bodies to which an igneous origin was attributed in the past were those portions of a basic intrusion, such as a peridotite or a gabbro, which were so enriched with magnetite as to become an ore. The magnetite is almost always titaniferous and may indeed be ilmenite. The classic occurrence of this type is Taberg,[1] in Sweden, where a great boss of basic igneous rock 1.5 kilometers (1.2 miles) long, 0.5 kilometer (0.4 mile) broad and 130 meters (400 ft.) high is

[1] A. Sjogren, Ueber das Eisenerzvorkommen von Taberg in Smaland, *Geol. Foren. in Stockholm, Forhandl*, III., 42–62, 1876, and VI., 1882; *Neues Jahrbuch*, 1876, 434.

A E. Törnebohm, Om Taberg i Smaaland och ett par dermed analoga jernmalmförekomster. *Idem*, V. 610–619, 1881. *Neues Jahrbuch*, 1882, II., 66.

found intruded in granite-gneiss, with its long axis parallel to the foliation. In the central part of the boss is found the ore, a mixture of titaniferous magnetite and olivine, but the boss shades from ore, outwardly, by the increase of feldspar to the variety of gabbro, called hyperite in Sweden. In the basic core and acidic rim the boss differs from most intrusions, because the latter shade from acidic cores to basic rims. The Cumberland ore, Rhode Island, forms a boss of titaniferous magnetite mingled with olivine and pyroxene. It is much like that of Taberg. The ore of Brazil is strongly titaniferous, but occurs in basic rocks with nepheline, and much the same is true of Alnö, Sweden,[1] where nepheline syenite is the geological associate. In the Adirondacks, and in Minnesota, Quebec, Wyoming and Norway, huge masses of quite pure titaniferous magnetite occur in anorthosite gabbros. As a peculiar phase of the Cortlandt series of gabbros on the Hudson River, near Peekskill, there are richly aluminous, but feebly titaniferous ores which consist of spinel, corundum and titaniferous magnetite. At Routivara, Sweden,[2] practically the same aggregate has been found.

1.06.09. In addition to the igneous magnetites, chromite has been met by Vogt in an outcrop of unaltered peridotite within the Arctic circle, in Norway,[3] and J. H. Pratt[4] attributes the same method of origin to the chromite of North Carolina, although hitherto chromite in serpentine has usually been considered a segregation produced during the weathering of rocks which possess chrome-bearing silicates. Corundum is now recognized in a few places as a result of crystallization from fusion. The special conditions of its formation will be noted below.

1.06.10. Aside from the metallic oxides just cited, certain great deposits of metallic sulphides, and especially of chalcopyrite and nickel-bearing pyrrhotite, are likewise regarded as the products of crystallization from fusion. Many Norwegian lo-

[1] A. G. Högbom, Ueber das Nephelinsyenitgebiet auf der Insel Alnö. *Geol. Fören. Förhandl*, XVII., 100, 214, 1895, *Neues Jahrbuch*, 1896, I., 252.

[2] W. Peterson. Geol. Fören. Förhandl, XV., 45–54, 1893. H. Sjogren, *Ibid.*, 55, 140–143.

[3] J. H. L. Vogt, *Zeitsch. für prakt. Geologie*, January, 1894, p. 389.

[4] J. H. Pratt, *Engineering and Mining Journal*, Dec. 10, 1898, p. 696 *Trans. Amer. Inst. Min. Eng.* (issued May, 1899).

calities and in America the Gap Mine, Pa.; the Sudbury mines, Ont., are of this type. The gold-bearing pyrrhotites of Rossland, British Columbia, resemble it, but have also been esteemed replacements. All these sulphides are found in the outer portions of the intrusions.

1.06.11. In discussing the chemical and physical processes which have led to the production of the igneous types of ore bodies, it is important to emphasize their position with regard to the mass of the intrusion, *i.e.*, whether in the center or at some other point well within the intrusion, or whether in the outer portions near the contacts. Somewhat different processes may be invoked in explanation according to these several relations.

1.06.12. The titaniferous magnetites are either centrally placed or else are so far within the mass as to show no relations to its borders. They are also merely exceptional and local enrichments of the magma with one of its more abundant component bases, and with a particular mineral, which is among the earliest to separate in the process of crystallization, and which has the highest specific gravity of any of those entering into the rock. Morozewicz[1] has sought by artificial experiments to determine the laws which govern its separation, but he finds them complex. The experiments indicated that mass action played a prominent part, and that with an abundance of the iron oxides the crystallization of the magnetite preceded that of the ferromagnesian silicates; with less it began after them. The iron oxides enter as bases into so many rock-forming minerals that enough to satisfy the ferromagnesian group is obviously necessary before large amounts of magnetite can be expected. If, therefore, we assume a magma excessively rich in iron together with much magnesia, but low in lime, alumina and alkalies, an aggregate of magnetite, olivine and some pyroxene will necessarily result on crystallization, as at Taberg and Cumberland. To explain, however, the central position of this basic portion in an otherwise more acidic, average magma is not so simple. If again we assume a magma fairly rich in iron, soda, lime, alumina, and silica, but lacking magnesia, it is conceivable that magnetite and labradorite will result as in the anorthosites. The concentration of the magnetite seems to

[1] Jósef Morozewicz. Experimentelle Untersuchungen über die Bildung der Minerale im Magma. *Tschermaks Mittheilungen*. XVIII., 84, 1898.

the writer best explained by its settling in the still molten mass until it has formed considerable aggregates. When once these rich aggregates have formed, they may in the process of eruption or intrusion take almost any place in the resulting rock.[1] Physico-chemical reactions may, however, be operative of which at present we are not aware. Vogt[2] has suggested that when magnetite crystals have formed in the still molten magma they may become aggregated by their magnetic attractions, but the mineral loses its magnetism even at a temperature below redness, and it is doubtful if this property could affect the result.

1.06.13. Chromite appears at times in masses well within the peridotite or serpentine which contains it, and it also is noticeably abundant near the contact[3] in other occurrences. Corundum furnishes a close parallel. It has been met in very great quantity in Ontario,[4] north of Lake Ontario, in nepheline-syenite, favoring certain varieties of the rock, but distributed all through it. In North Carolina[5] it favors the outer portions of the peridotite (dunite) in which it is found. Sapphires of gem quality have been found in Montana in a basic dike consisting chiefly of biotite, diopside and magnetite. Some secondary products from unrecognizable originals are also present.[6]

The chemical conditions under which corundum separates from igneous magmas have been very clearly shown by Morozewicz.[7] Without regard to the percentage of silica in the rock,

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[1] J. F. Kemp, "The Titaniferous Magnetites of the Adirondacks," etc., *XIX. Ann. Rep. Dir. U. S. Geol. Survey* (in press).

[2] Dannelse af Jernmalmforekomster, Kristiania, 1892, Resumé in German, p. 145. Vogt also mentions the concentration by settling which is set forth above.

[3] J. H. Pratt, "The Occurrence, Origin and Chemical Composition of Chromite" (abstract), *Engineering and Mining Journal*, Dec. 10. 1898, p. 696. *Trans. Amer. Inst. Min. Eng.*, February, 1899, New York meeting. Refers especially to North Carolina.

[4] W. G. Miller, Report of the Ontario Bureau of Mines, VII., 207, 1898.

[5] J. H. Pratt, "On the Origin of the Corundum Associated with the Peridotites in North Carolina," *Amer. Jour. Sci.*, July, 1898, p. 49.

[6] L. V. Pirsson, "Corundum-bearing Rock from Yogo Gulch, Montana," *Amer. Jour. Sci.*, December, 1897, p. 421.

[7] Jozef Morozewicz, Experimentelle Untersuchungen über die Bildung der Minerale im Magma, *Tshermaks Mittheilungen*, XVIII., 30, 1898.

provided that it lies within the limits met in natural magmas, free alumina will separate as corundum, when the moleculaı ratio of the alumina to the other bases is greater than unity, *i. e.*, $\frac{Al_2O_3}{R_2O+RO+R_2O_3}$ greater than 1. In this case spinel may be anticipated as an associate. When, therefore, corundum is found in a natural igneous rock this condition must have been met at the time it crystallized. As to the causes which have produced the concentration at the borders, the discussion is the same as that given under the next topic.

1.06.14. The deposits of nickeliferous and auriferous pyrrhotite and of chalcopyrite, which are found in the rims of basic intrusions, present, so far as mining is concerned, much larger developments than the chromite and corundum just referred to, and the important applications of nickel in armorplate have led to careful study of the ores. They are recognized by most observers as crystallizations from fusion,and the problem arises as to the causes which have brought them into their present position.

That individual intrusions vary from a more acidic (or siliceous) composition at the center to a more basic one at the borders is well established by observation and by progressive analyses in a number of instances.[1]

An explanation of these relations has been sought in what is known as Soret's principle.[2] It was proved by experiments in 1879 by Soret, a French chemist, that if differences of temperature are induced in a solution of common salt or other substance in water, the dissolved material will become relatively concentrated in those portions in which the temperature is lowest. It has also been shown that this would follow from the laws of osmosis, and that the relative degrees of concentration

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[1] See Lawson and Shutt, on a diabase dike in the Rainy Lake Region, *Proc. Amer. Assoc. Adv. Sci.*, 1889, 246; Alfred Harker on an English gabbro, *Quarterly Journal of the Geological Society*, 1894, 326; W. S. Bayley on Minnesota gabbros, *Journal of Geology*, III., 824, 1895.

[2] The bearing of this explanation of magmatic differentiations in igneous rocks upon these nickeliferous deposits has been especially set forth by J. H. L. Vogt of Kristiania, Norway, in the *Zeitschrift für Praktische Geologie*, I., 125, 1893, under the title "Sulphidische Ausscheidungen von Nickel-sulphid-erzen," etc.. Other related papers appear in the same, I. 4 and 257; II. 41, 134 and 173.

would be to one another inversely as the absolute temperatures (*i.e.*, temperature Centigrade plus 273). The lower the temperature, therefore, the more dissolved material would collect in such chilled portion. If now we consider a fused rock magma as a complex solution of several silicates, oxides, sulphides and one or two rarer compounds, some in others, and if we regard as the least soluble those that crystallize first in the process of cooling, we are led by Soret's principle to infer that these would tend to become concentrated in the portions first cooled, and that in such portions they would be especially abundant after consolidation. The portions of an igneous intrusion that are first cooled are obviously those next the wall rock. The minerals which crystallize first are, as set forth earlier under 1.03.05, magnetite, ilmenite, apatite, pyrite, pyrrhotite, and several minor ones.

In the case of nickeliferous pyrrhotite the ore bodies are especially rich along or near the contacts of gabbroic and dioritic intrusions with their walls, and the paper of J. H. L. Vogt, cited in the footnote, has served to bring out some extremely interesting facts. The geological relations are more fully set forth later on under nickel and in connection with several American occurrences, but it may be here added that away from the outer wall the ore bodies fade (at least at the Gap Mine, Pa.) into barren gabbro, by a fairly gradual transition. In these respects they conform quite closely to conditions which would result from a development according to Soret's principle. We also find in such ore bodies much the same association of minerals, wherever they are mined. Pyrrhotite is in greatest amount and contains the nickel and cobalt replacing a portion of its iron; as the rarer mineral pentlandite,[1] or as secondary coatings of millerite in cracks. Chalcopyrite is invariably present, often in important quantity. Vogt has sought to trace out some constancy in the relative amounts of these several metals, but the attempt is not specially successful. He also cites in connection with a dis-

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[1] S. L. Penfield, 'Pentlandite from Sudbury, Ont.," etc., *Amer. Jour. Sci.*, June, 1893, 493 Pentlandite is a sulphide of iron and nickel, isometric, non-magnetic, and with a somewhat varying percentage of nickel, which reaches at Sudbury 34.23. The general formula from Penfield's analysis is (NiFe)S.

cussion of their early formation and combination with sulphur in the fused magma, the laws which we know apply in the metallurgical processes involving slags and mattes.[1]

1.06.15. Admitting that the bases iron, nickel and copper, along with others, have been concentrated, while still in the state of ions,[2] at the borders by Soret's principle, or by some other process, perhaps not clearly understood, objection has still been made to the igneous origin of sulphides, because it is believed that the conditions in a fused magma are oxidizing—as witness the presence of the several metals in almost all igneous rocks as oxides—and because oxidizing conditions would be inimical to the production of sulphides. When sulphides form in a furnace, it is urged that the fuel creates a reducing action, and that, otherwise, sulphides would be impossible. The analogy of a furnace is not to be too sharply urged in objection, for the reason that no blast of oxygen is blown through a magma, so as to create of itself an intense oxidation. The abundance, moreover, of ferrous oxide in basic rocks indicates that the oxidizing conditions are not marked. Nevertheless, to meet the objections to the formation of sulphides in magmas, while assuming the greater basicity of the outer portions of the mass, the writer[3] has suggested that the escape of sulphurous gases through the still molten rock along the contacts would produce sulphides of metals already there, even though the general conditions in the magma were oxidizing. In the original paper the reactions involved are justified on the basis

[1] As is well known the common metals may be ranged in the following order ("Fournet's Series") according to their decreasing affinity for sulphur, Cu, Ni, Co, Fe, Sn, Zn, Pb, Ag, Sb, As, see Vogt, *Zeitsch. für prakt. Geologie,* I. 263. In their bearings on geological phenomena these metallurgical laws were discussed many years ago by Leonhard in *Hüttenerzeugnisse und andere auf Künstlichem Wege gebildete Mineralien als Stüzpunkte geologisher Hypothesen,* Stuttgart, 1858. The succession is determined by the laws of thermo-chemistry, and necessarily the sulphides will form in order according to the amounts of heat developed by the reaction, from the greatest to the least.

[2] The term ion is employed in modern chemistry to describe those partial molecules that are held in an incomplete state by electrical force. The word is derived from the Greek for "going" or "moving," and was suggested by the partial molecules that are in transit in an electroplating bath.

[3] J. F. Kemp, *The Mineral Industry* for 1895, Vol. IV., 761-766.

of physical chemistry, and the process conceived is analogous to bessemerizing a bath of oxides with sulphur vapor, as contrasted with the usual artificial process of oxidizing a bath of molten sulphides with a blast of air.

G. F. Becker[1] has presented a strong argument against the ability of Soret's principle to accomplish serious results in effecting a differentiation of an originally homogeneous fluid magma into others of different compositions, and cites in support of his argument the slowness and feebleness of molecular flow and diffusion as indicated by artificial experiments with soluble salts. The viscosity of fused rock gives additional force to the objection. He therefore attributes[2] the changes to convection currents, which would be inevitably set up in the mass by its differences of temperature and which, as they passed along the cold surfaces inclosing the molten fluid, would coat them with the earlier and less mobile crystallizations.[3] This process of "fractional crystallization" is beyond question a most important suggestion, and it may obviate some of the difficulties that have hitherto been serious.

1.06.16. As opposed to the igneous view others have regarded ores of this type as contact deposits, brought about by solutions circulating along the outer portions of the intrusions, and replacing or impregnating the gabbro, more or less, with ore. The conception is a time-honored one; it involves nothing unreasonable, and has the support of some of our ablest investigators, as Emmons[4] and Posepny,[5] but the objections to the igneous conception, it is fair to state, were not based on observations of the phenomena, but on general theoretical considerations.

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[1] G. F. Becker, "Some Queries on Rock Differentiation," *Amer. Jour. Sci.*, January, 1897, 21.

[2] G. F. Becker, "Fractional Crystallization in Rocks," *Idem*, October, 1897, 257.

[3] A very suggestive paper in this connection and one that has important applications to the Sudbury, Ont., ores, is the following: "Segregation in Ores and Mattes," by David H. Browne, *School of Mines Quarterly*, July, 1895, 297–311.

[4] S. F. Emmons, "Geological Distribution of the Useful Metals in the United States," *Trans. Amer. Inst. Min. Eng.*, Chicago, 1893. Reprint pp. 18–19.

[5] F. Posepny, "The Genesis of Ore Deposits," *Idem*. Reprint p. 194.

1.06.17. Under II. 1, the precipitating agencies are mentioned, which are the chief causes in the chemical reactions of deposition, and these run through all the subterranean cavities as well. Their general application is esteemed self-evident. The large part played by organic matter, both when living and when dead and decaying, is notable. Its office, even in precipitating the gangue minerals in surface reactions, we are just beginning to appreciate. Siliceous sinters have been shown by W. H. Weed to be formed in the hot springs of the Yellowstone Park through the agency of algæ, and A. Rothpletz has recently proved that the calcareous oölites around the Great Salt Lake are referable to minute organisms. Many accumulations of iron ores have, with reason, been attributed to the same agency; but for this metal ordinary and common chemical reactions are oftenest applicable. When organic matter decays, sulphurous gases are one of the commonest products, and likewise one of the most vigorous of precipitants. Thus, under Example 24, Paragraph 2.06.03, when speaking of the Wisconsin zinc and lead mines, it will be seen that such an agency from decaying seaweeds has been cited by both Whitney and Chamberlin. When the products of this decomposition become imprisoned in the rocks as oils and gases, their action is unmistakably important and is especially available in limestones. Organic matter is a powerful reducing agent as well, and in this way is capable of bringing down metallic compounds. The silver-bearing sandstones of southern Utah are cases in point, as they afford plant impressions now coated with argentite. The purely physical agencies cited under (*d*) have also an important rôle.

1.06.18. Under 2(*a*) the uprising solutions may be diverted by porous strata, so as to pass through them, and be subjected to precipitating agents of one kind or another. Porous beds furnish the simplest kind of cavities, and starting with these the scheme is developed in a crescendo to the most complicated. The purely chemical action of limestone beds, however, seems at times to come into play and to cause precipitation along them. Of all rocks they are the most active chemical reagent. It may be questioned with reason as to whether caves or caverns (4), properly so called, have formed a resting-place for ores as often as some observers have supposed. So many which have been cited as such may with greater reason be referred to shrunken replacements that each case should be clearly proven.

1.06.19. Under (5) brecciated beds, whose fragments are coated and whose interstices are filled with ore, are, with great reason, referred to the collapse from the removal of a supporting layer. In addition to the illustration cited, the red hematite deposits of Dade and Crawford counties, Missouri, have been thought to have had a similar origin. Such phenomena are only to be expected in regions that have long been land. Cracks at the bends of folds may have occasioned, in cases, impregnations and disseminations, even when their character is obscured. The cracks need be but small and numerous to have produced far-reaching results. If a fault fissure, as a possible conduit of supply, crosses the axis of the fold, the necessary conditions are afforded for extended horizontal enrichment. Recent explorations with the diamond drill at Mine la Motte seem to corroborate such an hypothesis. Should the anticline or roll afterward sink toward the horizontal, a very puzzling deposit might originate. Shear zones have been already discussed at length (1.02.03), as have true veins and volcanic necks (see also 2.09.20). As regards contact deposits, the igneous rock, which usually forms one wall, may serve two different purposes. It may act merely as an impervious barrier which directs solutions along its course, or serves to hold them, either because it is itself bent into a basin-like fold, or because it forms a trough with a dense bed dipping in an opposite direction. Such relations occur in the Marquette and Gogebic ranges of the Lake Superior iron region. It is not apparent that in these cases the heat of the igneous rock has in any degree stimulated circulations. In the more characteristic "contact deposits" the igneous rock has apparently been a strong promoter of ore-bearing solutions, and has often been the source of the metals themselves. This form of deposit becomes, then, an attendant phenomenon, or even a variety, of contact metamorphism.

The classic illustration of it is furnished by the deposits of tin ore which have been especially developed along the contacts of granite intrusions. Granite, as is well-known, is the most potent of all rocks in bringing about contact metamorphism. It seems to be especially rich in mineralizers, and as its great, intruded, batholitic masses slowly crystallize, they emit boracic, hydrofluoric and other vapors in exceptional volume. Wall rocks are greatly corroded and charged with tourmaline, fluorite, axinite, topaz, fluoric micas and cassiterite. Pegmatite dikes or veins are sent off as apophyses, and are charged with the same association of minerals. If the walls are themselves granitic in composition, the feldspar becomes greatly corroded, and may be replaced by quartz and fluoric micas with more or less cassiterite. Pegmatites consisting essentially of the same minerals are also produced, and both varieties are called greisen, and are recognized as the characteristic gangue of tin ores the world over. The clue to the formation of the cassiterite in these surroundings was furnished by the early experiments of Daubrée,[1] who volatilized the bichloride of tin and brought it into contact with steam in a tube, obtaining by double decomposition crystals of oxide of tin, identical in form with the natural ones. In Nature, however, the fluoride of tin is the more probable source. The processes by which minerals and ores are emitted from igneous rocks, in the form of heated vapors, are often called pneumatolitic; and if water also plays a part, pneumato-hydatogenic.

Under 11 chromite is the chief illustration. The mineral is practically limited to serpentinous rocks, and is distributed through them in irregular masses. It has been considered to be a product of alteration.

1.06.20. III. The débris that results from the weathering of rock masses under the action of frost, wind, rain, heat and cold, is washed along by the drainage system of a district, and the well-known sorting action transpires, which is so important in connection with the formation of the sedimentary rocks. Minerals of great specific gravity tend to concentrate by themselves, while lighter materials are washed farther from the starting point, and settle only in still water. Stream bottoms supply the most favorable situations, and in their bars are found accumulations of the heavier minerals which are in the surrounding rocks. The commonest of these are magnetite, garnet, ilmenite, wolframite, zircon, topaz, spinel, etc., and with these, in some regions, native gold, platinum, iridosmine, etc.;

[1] *Annales des Mines,* XVI., 129.

in other places cassiterite, or stream tin, as described under tin. Even an extremely rare mineral, such as monazite, may make a sandbar of considerable size.[1] The action of the surf or smaller shore waves is also a favorable agent. The throw of the breaker tends to cast the heavier material on the beach, where its greater specific gravity may hold it stationary. The heavier minerals may be sorted out of a great amount of beach sand. Magnetite sands, which have accumulated in this way, are of quite wide distribution, and at present are of some though not great importance. (Example 15.) With the magnetite are found grains of garnet, hornblende, augite, etc., and often ilmenite. Gold is concentrated in the same way along the Pacific by the wash of surf against gravel cliffs. In abandoned beaches of Lake Bonneville, near Fish Springs, Tooele County, Utah, placers of rolled bowlders of argentiferous galena have been worked.

A superficial deposit of somewhat different origin is the bed of hematite fragments that mantles the flanks of Iron Mountain, Missouri, and runs underneath the Cambro-Silurian sandstones and limestones. This seems to have been produced by the subaerial decay of the porphyry which formerly inclosed the ore. The heavier specular ore has thus been concentrated by its greater specific gravity and resistant powers.[2]

1.06.21. There remain a few of great importance, but whose geological history is less clearly understood. They are nearly all involved in processes of regional metamorphism, and therefore in some of the most difficult problems of the science. Lenticular beds or veins of magnetite and pyrite that are interbedded with schists, slates, or gneisses are the principal group. Such magnetite bodies have been regarded as intruded dikes, as original bodies of bog ore in sediments, which have later become metamorphosed; and as concentrated delta, river, or beach magnetite sands. It is possible that in instances they may be replaced bodies of limestone, afterward metamorphosed. The lenticular shape and the frequent overlapping arrangement of the feathering edges in the foot wall are striking phenomena.

The overlap was referred by H. S. Munroe, in the *School*

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[1] See O. A. Derby, *Amer. Jour. Sci.*, III., xxxvii., p. 103.

[2] See R. Pumpelly, "The Secular Disintegration of Rocks," *Proc. Geol Soc. Amer.*, Vol. II., December, 1890.

of Mines Quarterly, Vol. III., p. 34, to stream action during mechanical deposition, and a figure of some hematite lenses in the Marquette region was given in illustration. The arrangement in instances also suggests the shearing and buckling processes of dynamic metamorphism and disturbance. The individual lenses, now in linear series, were thus all one original bed. The crumpling of the schistose rocks has pinched them by small buckling folds and shoved the ends slightly past each other in the process so familiar in the production of reversed faults from monoclines. Sheared granitic veins on a small scale are a not uncommon thing in areas of schistose rocks, such as Manhattan Island, in the city limits of New York, and suggest strongly this explanation. Should the compression not go so far as to bring rupture of the bed, but only a thickening by the formation of a sigmoid fold, it would occasion an enlarged cross section, as has been suggested by B. T. Putnam[1] for the great magnetite ore body at Mine 21, Mineville, in the Lake Champlain region.

1.06.22. Quartz veins, often auriferous and of a lenticular character, furnish another puzzling ore body. They are commonly called segregated veins, and lie interfoliated in slates or schistose rocks. If in a pre-existing cavity, the cavity must have been formed, either by the opening of beds under compression, or by displacement along the bedding, so that depressions came opposite each other. Replaced lenses of limestone which had been squeezed into this shape from an original, connected bed should also be instanced as a possibility. But notwithstanding the time-honored nature of the conception of these "segregated" veins, there is little doubt that they are practically all mere varieties of fissure veins, which have been pinched into the separated lenses by pressure.

1.06.23. The veins that contain cassiterite in many parts of the world, and that yet have the mineralogical composition of granite, are another product of metamorphic action, both contact and regional. The gangue minerals, feldspar, quartz, and mica, are quite characteristic of acid, igneous rocks, but the coarseness of the crystallization in the comparatively narrow veins bars out a normal igneous form of origin. All our artificial methods of reproducing these minerals lead us to

[1] *Tenth Census*, Vol. XV., 110.

infer that the veins were filled at a high temperature and pressure, therefore at considerable depths, and through the aid of steam. Cassiterite has also been detected in a few rare cases, under such circumstances that it seemed to be an original mineral in igneous granite. It is probable, therefore, that it may in instances be an original and early crystallization from an igneous magma, much as is magnetite. More observed cases would be welcome as evidence.

1.06.24. Fahlbands should be mentioned here. The term refers to belts of schists, which are impregnated with sulphides, but not in sufficient amount in the locality where the name was first applied (Köngsberg, Norway) to be available for ores. The decomposition of the sulphides gave the schists a rusty or rotten appearance that suggested the name. Whether the ores are an introduction into the schist, subsequent to metamorphism, or a deposit in and with the original sediment, is a doubtful point. The practical importance of these fahlbands lies in the enriching influence that they exert on the small fissure veins that cross them.

1.06.25. The phraseology of the above schemes will be employed in the subsequent descriptions. In addition, much emphasis will be placed on the character of the rocks containing the deposits, whether unaltered sedimentary, igneous, or metamorphic, and whether in the first and last cases igneous rocks are near, for these considerations enter most largely into questions of origin. The ore deposits are illustrated by examples, somewhat as has been done by one of the best of modern writers abroad, Von Groddeck. The word "example" is preferred to "type," which was employed by Von Groddeck, because it implies less of an individual character. We may cite deposits under different metals thus which all might belong to one type. Under each metal will be given, first, a list of general treatises and papers. These will be marked "Hist." when especially valuable as history, and "Rec." when recommended for ordinary examination. If not marked by either, they are more adapted for special investigations.

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PART II.

THE ORE DEPOSITS.

CHAPTER I.

THE IRON SERIES (IN PART)—INTRODUCTORY REMARKS ON IRON ORES—LIMONITE—SIDERITE.

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Table of the Iron Ores, Limonite, Siderite, Hematite, Magnetite, Pyrite.

	Fe.	H_2O.	CO_2.	S.
Limonite (brown hematite, bog ore), $2Fe_2O_3$ $3H_2O$	59.89	14.4	......	......
Siderite (Spathic ore, clay-ironstone, black-band) $FeCO_3$	48.27	......	37.92	......
Hematite (red and specular), Fe_2O_3	70.0	......	......	......
Magnetite, FeO, Fe_2O_3, or Fe_3O_4	72.4	......	......	......
Pyrite, FeS_2	46.7	......	......	53.3

2.01.01. No one of the iron ores ever occurs pure in large amounts. Only a few closely approach this condition. The largest quantity of rich ore as yet mined in the United States was doubtless obtained from the Lovers' Pit opening, operated by Witherbee, Sherman & Co., on Barton Hill, near Mineville, N. Y. The pit yielded 40,000 tons of magnetite that averaged 68.6% Fe, with many carloads at 72%. The micaceous specular of the Republic mine, Mich., is said to have been shipped an entire season at 69%. The Minnesota mines, near Tower, Minn., have cleared many cargoes at 68 to 68.4%. The richest are the magnetites and specular hematites, and many mines of the Lake Champlain district have produced the former, and Lake Superior mines the latter, at 63 to 65%, or even more. The separated ores in the Lake Champlain district run about 65%. The unseparated ores have much less, and indeed all percentages from 50 to 65. Thus the lump ore (shipped as mined) from Chateaugay, N. Y., has about 50%. The Cornwall (Pa.) magnetite holds even less. The Clinton red hematites from New York afford about 44% in the furnace, as the result of long experience. The limonites, as usually mined, produce from 40 to 50%. The crude spathic ores are the lowest of all, and in the variety black-band may even be about 30%. They are easily calcined, however, and on losing their carbonic acid, moisture and bituminous matter the percentage of iron rises a third or more. A. H. Chester found in 1875, as the result of an endeavor to determine the average yield of certain standard ores in the furnace, Lake Superior specular, 62.5%; Lake Superior limonite, 49.5%, which is much too low to be salable to-day; Rossie (N. Y.) red hematite, 54.5%; Wayne County (N. Y.) Clinton ore, 40%.

2.01.02. The common impurities in iron ores are the common elements or oxides that enter most largely into rocks, and those which make up the walls of the deposit are usually the ones that appear most abundantly in the ore. Silica (SiO_2), alumina (Al_2O_3), lime (CaO), magnesia (MgO), titanium oxide (TiO_2), carbonic acid (CO_2), and water (H_2O) appear in large amounts and determine to a great extent the character, fluxing properties, etc., of the ore. With these, and of more far-reaching influence, are smaller amounts of sulphur and phosphorus.

The last two and titanium chiefly determine the character of the iron which is yielded in the furnace, and are the first foreign ingredients sought by analysis. The sulphur is present in pyrite. the phosphorus in apatite. As is well known, 0.1% of phosphorus is set as the extreme limit for Bessemer pig irons, and as ores for these command the best market, they are eagerly sought. To obtain the allowable limit of phosphorus in the ore, its percentage in iron is divided by 1000. Thus a 65.3% ore should not have over 0.065% phosphorus to be ranked as Bessemer. If at the same time, with sufficiently low phosphorus, the gangue in highly siliceous, a composition desirable for Bessemer practice, ores have been of value, although of comparatively low grade, and remotely situated. For Lake Superior ores the buyers insist to-day on a still lower Bessemer limit, and do not call any ore over 0.05% phosphorus a strictly Bessemer ore. The ore is required to be low enough to carry the phosphorus in both fuel and flux, and still yield a pig iron of not over 0.1% P. On the other hand a moderate amount of phosphorus is not only no drawback for ordinary foundry irons, and such as are subjected to tool treatment, but is a prime necessity. Excessive amounts are desired only for weak but very fluid irons or for the basic steel process. Considerations like these, which are rather metallurgical than geological, largely determine the availability of a deposit, and to some extent the present locations of the mining districts.

2.01.03. Iron itself is one of the most abundant and widely disseminated elements entering into the composition of the earth. Several writers have attempted to deduce the general composition of the outer portions of the globe,[1] but the most reliable computation is that of F. W. Clarke in *Bulletin 78 of the U. S. Geol. Surv.*, pp. 34-43. The crust to a depth of ten miles below sea-level is the subject of the estimate, and the air and ocean are included. The composition of the solid crust is reached by averaging analyses of igneous and crystalline rocks, 880 in all; 321 from the United States, 75 from Europe, and 486 from all quarters. Igneous rocks, being the ultimate source of the others, furnish a good average. The final result

[1] Compare Alex. Winchell, *Geological Studies*, pp. 19–20, and Prestwich's *Geology*, I. p. 10—both of which were quoted in the first edition of this work.

is the following, in which amounts less than 0.01% are omitted. The total is 100.

O..........49.98	Na..........2.28	P..........0.09
Si..........25.30	K..........2.23	Mn..........0.07
Al.......... 7.26	H..........0.94	S..........0.04
Fe.......... 5.08	Ti..........0.30	Ba..........0.03
Ca.......... 3.51	C..........0.21	N..........0.02
Mg.......... 2.50	Cl. Br..........0.15	Cr..........0.01

From this it is seen that iron is much the most abundant of the useful metals, and that its common impurities, titanium, phosphorus and sulphur are all present in appreciable amounts.

2.01.04. A general comparison of tabulated analyses of igneous rocks (Roth's *Gesteinsanalysen* and *Allgemeine Geologie*) shows that granites contain 0.0-7% iron oxides, porphyries 0.0-14%, rhyolites, 0.0-8%, diorites and diabases 4-16%, andesites 3-15%, basalts 12-20%. Limestones invariably have at least small amounts, and at times very considerable percentages. Sandstones are often low, but not seldom are stained through and through. The metamorphic rocks offer close analogies to the igneous. In general distribution and in quantity, iron leads the list of the distinctively metallic elements. Its peculiar property of possessing two oxides, of different chemical quantivalence, assists greatly in the formation of ores and the general circulation of the metal. This is set forth under the following examples:

LIMONITE.

2.01.05. Example 1. *Bog Ore.*—Beds of limonite, superficially formed in marshes, swamps, and pools of standing water. The general circulation of water through the rocks enables it very frequently to take up iron in solution. Ferruginous minerals are among the first and easiest that fall a prey to alteration. Carbonic acid in the water aids in dissolving the iron, which thus, in waters containing an excess of CO_2, passes into solution as the protocarbonate $FeCO_3$. Organic acids may also play a part. The alteration of pyrite affords sulphuric acid and ferrous sulphate, and the latter enters readily into solution. On meeting calcium carbonate, both ferric and ferrous sulphate are decomposed, yielding in the first case calcium sulphate, ferric hydrate, and carbonic acid; in the second, if

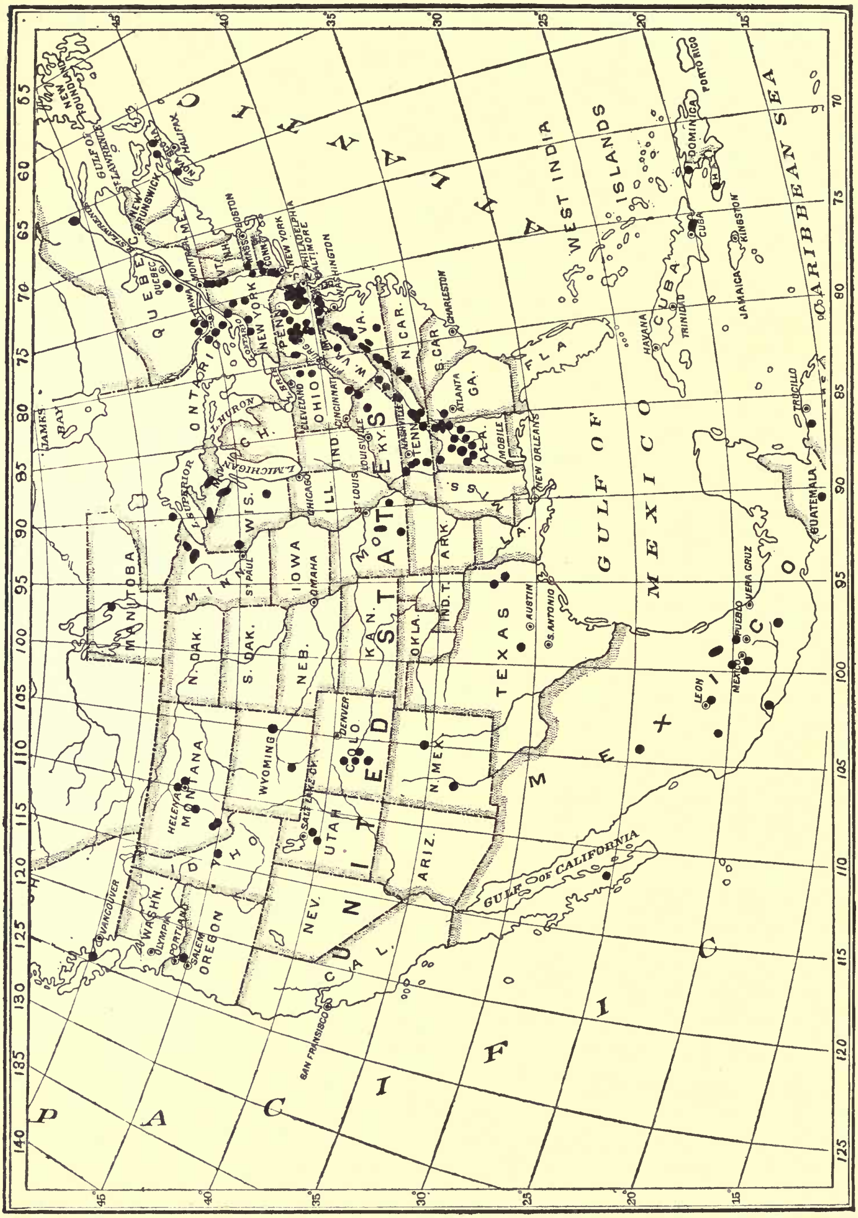

FIG. 7.—*Map showing the distribution of Iron Ores in North America. Adapted from Plate V.–XVI., Ann. Rep. Dir. U. S. Geol. Survey, Part III., p. 31.*

air is absent, ferrous carbonate and calcium sulphate, but on the admission of air, ferric hydrate soon forms.[1]

2.01.06. Bodies of limonite that become exposed to a reducing action from the favorable presence of decaying organic matter likewise furnish the protocarbonate. In general it may be stated that free oxygen must be absent or present only in small quantity where solution takes place. Sooner or later the ferruginous (or chalybeate) waters come to rest, especially in swamps. The protosalt is exposed to the evaporation of the excess of CO_2, that held it in solution, and also to the action of oxygen. Two molecules of carbonate, together with one atom of oxygen and some water, break up into CO_2, and the hydrated oxide $2\ Fe_2O_3,\ 3\ H_2O$, or some related molecule. The latter forms as a scum and then sinks to the bottom and accumulates in cellular masses. The sesquioxide is insoluble, and as against ordinary waters free from reducing agents it remains intact. Deposits of mud and peat forming above may cover the beds with a protecting layer. Hardly a bog exists which does not show, when cut in cross section, the bog ore beneath. Frequent associates of the ore are diatomaceous earth and shell marl, contributed by the remains of organisms which once inhabited the waters. At times excellent impressions of leaves and shells are preserved in the ore. Such ore bodies are not often practicably available on account of the low percentage in iron, due to the abundance of sand and silt washed in, and to the frequent large amounts of sulphur and phosphorus which they contain. The sulphur is present in pyrite and the phosphorus in vivianite, sometimes in sufficient quantity to be visible as at Mullica Hill, N. J., where the variety *Mullicite* is found. In certain parts of the country bog deposits have been utilized and under peculiar conditions others may yet be.

2.01.07. In eastern North Carolina bog-ore beds are frequent and are found lying just below the grass roots. Scattered nodules occur in the overlying soil, which are succeeded by a bed three feet or less in thickness, resting on sand.[2]

[1] F. P. Dunnington, *Amer. Jour. Sci.*, iii., XXXVI., 176. Experiments 10 and 11.

[2] W. C. Kerr, *Geology of North Carolina*, 1875, p. 218. B. Willis, *Tenth Census,* Vol. XV., p. 302. H. B. C. Nitze, *Bull. I. N. C. Geol. Survey,* 1893.

In Hall's Valley and Handcart Gulch, Park County, Colo., interesting and extensive deposits of limonite are in active process of formation. The iron comes from neighboring great beds of pyrite.[1]

Bog ore of good quality has recently been reported from the vicinity of Great Falls, Mont.[2]

At Port Townsend Bay, in the vicinity of Puget Sound, and at the Patton mines, near Portland, Ore., the ores are of such quality as to be available.[3]

Attention has been lately directed to the great deposits of bog ore in the Three Rivers district of the Province of Quebec in Canada. Three Rivers is on the St. Lawrence about midway between Montreal and Quebec, but the district which furnishes the bog ores extends from northeast of Quebec to a point west of Ottawa, an area stated by Griffin to be 400 miles long by 40 to 60 broad. The drainage of the old Archean heights of the Laurentides, the range that suggested the name Laurentian, crosses the belt, and being more or less laden with ferruginous solutions it deposits the ore in swamps, streams and lakes, wherever the water is for a time stationary or choked with vegetation. The ore beds furnish ideal illustrations of bog-ore deposits in all their forms. Beginning as a light film, the ore gradually accumulates on the bottom, where it hardens into thick crusts. These are exposed to the sun in the dry season in the shallower reaches, and become very hard cakes. During the succeeding wet season they are buried again under more ore, or sand and ore, until the thickness attained is very considerable. The ore is precipitated also in running water, and has been obtained from ravines in goodly amount. Even in the pipes used at the furnace at Radnor Forges for conveying the necessary water supply from the neighboring Riviere au Lard, the limonite deposits. The river flows from the swamp called Grand Plé, in the midst of which is a shallow lake called Lac a la Tortue. Ore is dug in the swamp and dredged in the lake. The

[1] R. Chauvenet, "The Iron Resources of Colorado." *Trans. Amer. Inst. Min. Eng.*, XVIII., 266. "Notes on Iron Prospects in Northern Colorado," *Ann. Rep. Colo. School of Mines*, 1886.

[2] *Mineral Resources, U. S. Geol. Survey*, 1888, p. 34.

[3] B. T. Putnam, *Tenth Census*, Vol. XV., p. 496.

supply is renewed after being removed. The deposits present many analogies with those of the Swedish lakes, later mentioned, but they supply caked ore rather than the oölitic form of the latter. The iron industry began in the region in 1730 and has continued more or less intermittently to date.[1] The iron furnished has especial excellence for car-wheels and chilled castings. The lake ores seem to run somewhat richer than those of the bogs. The latter contain about 42.5% Fe, the former 49%. Both have a little over 0.3% P and less than 0.1% S. These ore bodies are of great scientific interest, for they illustrate (as has been recognized for many years) the formation of bodies of other kinds of iron ores when in sedimentary series, and even when metamorphosed.

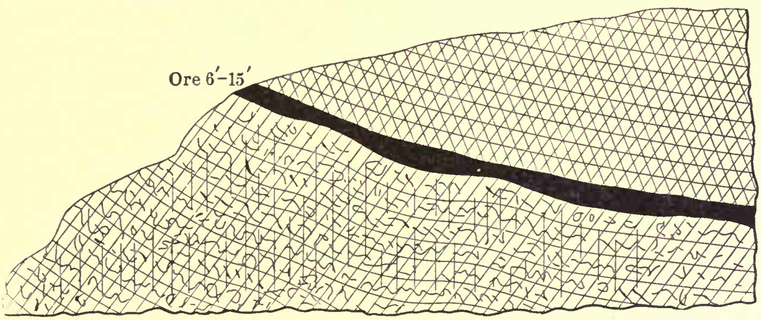

FIG. 8.—*Cross-section of the Prosser iron mine, near Portland, Ore., showing the bed of limonite between two sheets of basalt. After B. T. Putnam, Tenth Census, Vol. XV., p.* 496.

2.01.08. A somewhat different variety of Example 1 results when the ferruginous waters come to rest in the superficial hollows of the rock which has furnished the iron. Depressions in the serpentines of Staten Island, N. Y., contain such deposits, and the ore has been referred by N. L. Britton to the leaching of the underlying rock. It contains a notable percentage of chromium, which is known to be an element in the serpentine. The mines have been in former years quite large producers. Similar limonites occur at Rye, N. Y.[2]

[1] See especially, P. H. Griffin, "The Manufacture of Charcoal-iron from the Bog and Lake-ores of the Three Rivers District," *Trans. Amer. Inst. Min. Eng.*, XXI., 974. Also J. H. Bartlett, *Trans. Amer. Inst. Min. Eng.*, XIV., 508.

[2] N. L. Britton, *School of Mines Quarterly*, May, 1881. Compare also *Amer. Jour. Sci.*, iii., XX., 32, and XXII., 488.

At the Prosser mines, near Portland, Ore., deposits of limonite are found in the superficial hollows of a Tertiary basalt of the Cascade range. The ore contains roots and trunks of trees, and is covered by a later flow of basalt. Similar bodies of limonite resulting from basalt are known in the German province of Hesse, and in Ireland.[1]

2.01.09. The limonite sand, or oölite, that forms in the Swedish lakes about ten meters from the banks and in water up to ten meters in depth is another variety of this type. A layer half a meter and less in thickness accumulates every fifteen to thirty years, and is periodically dredged out. The ore is precipitated first as a slime that breaks up afterward into small concretions. It has been thought that the formation of these and similar bodies of limonite has been aided by small algæ and other plants or microscopic organisms.[2]

2.01.10. Example 2. Bodies of limonite in cavities of ferruginous rocks, on the outcrop, or below the surface, which have resulted either from the alteration of the rock *in situ* or from its partial replacement by limonite. Residual clay, quartz and other remains of alteration usually occur with the ore. Ferruginous limestones are the commonest sources of such deposits, but other rocks may afford them. The deposits are not limited to any one geological series, but in different parts of the country occur wherever the conditions have been favorable. Some of the ore may have been brought in by subterranean circulations which have leached the neighboring rocks. Considerable limonite has also resulted from the weathering of clay-ironstone nodules and black-band beds in the

[1] B. T. Putnam, *Tenth Census*, Vol. XV., p. 16, and J. S. Diller, "A Geological Reconnaissance in Northwestern Oregon," *Eighteenth Ann. Rep. U. S. Geol. Survey*, Part II., on the Oregon ore; Tasche, *Berg.- und Hütt. Zeit.*, 1886, p. 209; also Wurtemberger, *Neues Jahrb.*, 1867, p. 685, on the Hessian ores; Tate and Holden, "On the Iron Ores Associated with the Basalt of Northeastern Ireland," *Quar. Jour. Geol. Soc.*, XXVI., 151.

[2] F. M. Stapff, *Zeitschr. d. d. geolog. Gesellsch.*, 1866, Vol. XVIII., p. 8, on the geology of the ores. Sjogrun, *Berg.- und Hütt. Zeit.*, 1865, p. 116, on the agency of algæ. On the general formation of bog ores the following papers are of interest: G. J. Brush and C. S. Rodman, "Observations on the Natives Hydrates of Iron," *Amer. Jour. Sci.*, ii., XLIV., 219; J. S. Newberry, *School of Mines Quarterly*, November, 1880; J. Roth, *Chem. und Phys. Geologie*, I., pp. 58, 97, 221; F. Senft, *Humus, Marsch, Torf und Limonit-bildungen.*

Carboniferous system (to be mentioned later), and not infrequently from the alteration of nodular masses of pyrites. The limonite is in cellular lumps, in pipes, pots, and various imitative forms which often have a beautiful lustre. The hollow masses have in general resulted from the filling of reticulated cracks in shattered rock. The ore thus deposits around the cores of country rock, which afterward are removed, leaving a hollow shell, or geode. (See *Tenth Census*, Vol. XV., pp. 275, 369, 370.)

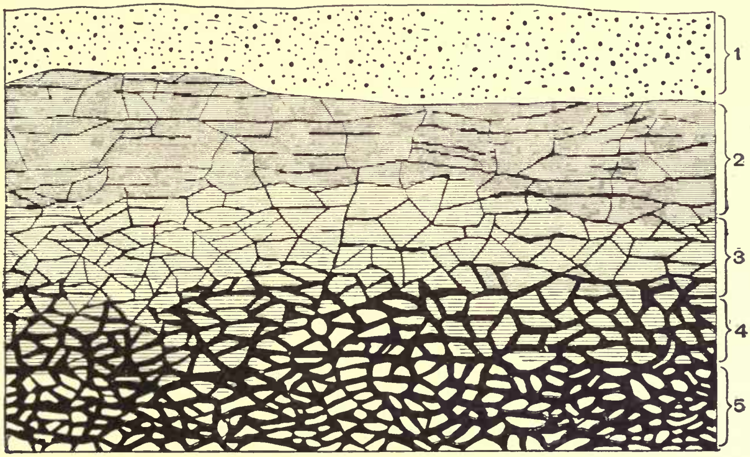

FIG. 9.—*Section of the Hurst limonite bank, Wythe County, Virginia, illustrating the replacement of shattered limestone with limonite and the formation of geodes of ore. After E. R. Benton, Tenth Census, Vol. XV., p.* 275.

2.01.11. Reserving the Siluro-Cambrian limonites for a subtype the ore bodies are described in order from east to west, taking up first the Allegheny region, then the Mississippi Valley, and lastly the Rocky Mountains. The limonites of New England and New York belong to the present subtype, as do those of eastern Pennsylvania and the more important ones in Virginia, Tennessee, Georgia and Alabama. In central and western Pennsylvania, however, not a small amount is obtained from the higher lying terranes. The Hudson River slates furnish small amounts in Franklin County, which are thought by McCreath to have resulted from the alteration of nodules of pyrites.[1] The Medina sandstones contain highly ferruginous portions in Huntingdon County.[2] The lower Helderberg and Oriskany are locally quite productive in Blair County, affording several great banks of ore.[3] The Oriskany is of greater importance in Virginia than in Pennsylvania. East of these last-mentioned exposures, and in southern Carbon County, in a bed of paint ore between the Oriskany and the Marcellus.[4] The Marcellus is the most productive of the Devonian stages. It affords considerable ore in Perry County,[5] Juniata County, Mifflin County, Huntingdon County.[6] Fulton County[7] and Franklin County.[8] All these are in southern Pennsylvania. Lesley states[9] that the ore is weathered carbonate. As shown under Example 4, beds of carbonate ore occur in Ulster County, New York, in the Marcellus. (Additional details on the above Pennsylvania deposits will be found in the geological reports on the particular counties.)

2.01.12. As already remarked, the greater part of the limonites in Virginia belong under the Siluro-Cambrian division and are there described, but in the James River Basin, on Purgatory and May's Mountains, there are deposits in sandstones of the Clinton.[10] Other limonite beds occur in the Oriskany on Brushy Mountain (Longdale mines), on Rich Patch Mountain (Low Moor mines, called by Lyman, Marcellus), on Warm Spring Mountain, and on Peter Mountain. In the Shenandoah Valley, on Massanutton Mountain, the limonite is referred by Prime to the Clinton stage.[11] On North Mountain it lies in the Oriskany, according to Campbell[12] and on the Great North Mountain in the Upper Silurian. Considerable oxide of zinc

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[1] *Second Penn. Geol. Survey*, M3, p. x.

[2] McCreath, *Second Penn. Geol. Survey*, MM, p. 198.

[3] Report MM, 196, M3, p. 33.

[4] C. E. Hesse, "The Paint-Ore Mines at Lehigh Gap," *Trans. Amer. Inst. Min. Eng.* XIX., 321.

[5] Report MM, p. 193; M3, p. 29.

[6] Report M, p. 66; MM, p. 194; M3, p. 140.

[7] Report M3, p. 42.

[8] Report M3, p. 1.

[9] *Iron Manufacturers' Guide*, p. 650.

[10] J. L. Campbell, *The Virginias*, July, 1880

[11] *The Virginias*, March, 1880, p. 35.

[12] *Ibid.*. January, 1880, p. 6.

FIG. 10.—*View of open cut, Low Moor Iron Mines, Va., looking S. 55 W. from summit of divide at head of McGraw's Gap. From a photograph by J. F. Kemp, July, 1898.*

collects in the tunnel heads of the furnaces running on Low Moor ores, indicating the presence of this metal in the limonite.[1]

The Oriskany ores (including those referred by Lyman to the Marcellus) were formerly the chief sources of Virginia iron, and at Longdale and Low Moor afforded very large amounts, but lately the Siluro-Cambrian have taken precedence. The Oriskany ores yield from 40 to 43% Fe in the furnace (Pechin), and were non-Bessemer. They have an excellent reputation for foundry and mill work. Another prominent source of brown hematite ores in Virginia has been of recent years the weathered and oxidized upper portions of the great pyrites deposits in Floyd, Grayson and Carroll counties, in the southwestern part of the State. This belt extends over 20 miles, and is known as the "Great Gossan Lead." Although uniformly pyrites or pyrrhotite below the water line, it is sufficiently oxidized above to yield an ore of about 40 to 41% Fe, with the sulphur not much over one per cent. The greatest depth is attained where the belt crossses the hills. The ores supply a useful mixture for the neighboring Siluro-Cambrian brown hematites.[2]

The iron ores in Kentucky are found in three widely separated districts, one near Greenup, in the northeastern corner of the State, known as the Hanging Rock region; the second near the central part along the Red and Kentucky rivers, known as the Kentucky and Red River region; and the third in the southwestern part near Lyon and Trigg Counties, known as the Cumberland River region. Although the first two contain much limonite, it has altered from nodules of carbonate, and the ores are therefore described under Example 5. One locality near Owingsville, in the second region, has limonites altered from the Clinton hematite. (See Example 6.) The Cumberland region affords limonites in the Subcarboniferous. They are in

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[1] B. S. Lyman, "Geology of the Low Moor, Va., Iron Ores," *Trans. Amer. Inst. Min. Eng.*, XIV., 801. E. C. Means, "Flue Dust at Low Moor, Va.," *Trans. Amer. Inst. Min. Eng.*, XVII., 129. E. C. Pechin, "Virginia Oriskany Iron Ores," *Engineering and Mining Journal,* August 13, 1892, p. 150; "Oriskany Iron Ores at Rich Patch Mountain," *Idem,* February 1, 8, and 15, 1896; "Iron Ores of Virginia," etc., *Trans. Amer. Inst. Min. Eng.*, XIX., p. 1016, 1890.

[2] E. C. Moxham, "The Great Gossan Lead of Virginia," *Trans. Amer. Inst. Min. Eng*, XXI., 133, 1892.

rounded masses, either solid or hollow, and are distributed through a red clay along with angular fragments of chert. The limonite pots are themselves filled with clay or water.[1]

2.01.13. In Tennessee the limonites of the eastern portion come mostly under Example 2*a*. In the west they are a southern extension of the pot-ore deposits of Kentucky, and show the same associated chert and clay. Safford has called the rocks containing them the Siliceous Group. The west Tennessee district projects into Alabama to a small extent.[2]

2.01.14. The principal limonite deposits of Alabama come under Example 2*a*, as do those of western North Carolina and Georgia. Some limonite is produced in Ohio, but it is all

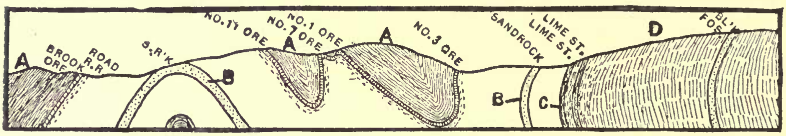

FIG. 11.—*Geological Section of the Low Moor, Va., Iron-ore Bed. After B. S. Lyman, Trans. Amer. Inst. Min. Eng., XIV.*, 801. *A—Marcellus Shale; B—Oriskany Sandstone; C—Lower Helderberg Limestone; D—Clinton Shales.*

weathered carbonate and is mentioned under Example 5. Hydrated ores are abundant in the Lake Superior region, but are mentioned in connection with hematite. (See also 2.01.22.) Deposits of brown hematite are worked in a small way in the southeastern part of Missouri, where they rest upon Cambrian strata and have a marked stalactitic character.[3]

Limonites referred to the Cretaceous by N. H. Winchell occur in western Minnesota.[4]

2.01.15. *The Annual Report of the Geological Survey of Arkansas*, Vol. I., consists of a report by R. A. F. Penrose on the "Iron Deposits of Arkansas." It at once appears that there is little prospect of Arkansas producing any notable

[1] W. B. Caldwell, "Report on the Limonite Ores of Trigg, Lyon, and Caldwell Counties," *Kentucky Geol. Survey*, New Series, Vol. V., p. 251.

[2] W. M. Chauvenet, *Tenth Census*, Vol. XV., p. 357; J. H. Safford, *Geology of Tennessee*, p. 350.

[3] P. N. Moore, *Geol. Survey of Missouri*, Report for 1874; F. L. Nason, *Mo. Geol. Survey*, 1892, II., p. 158.

[4] *Bull. VI., Minn. Geol. Survey*, p. 151.

amounts of iron ore. Such deposits as have been found are practically all limonite (brown hematite) and are generally very low in iron. The ores occur in five districts, viz.: Northeastern Arkansas, northwestern Arkansas, the valley of the Arkansas River, the Ouachita Mountains, and southern Arkansas. They are generally associated with sandstones or cherty limestones. The first-named district makes the best showing. In it the ores are in Lower Silurian (Calciferous or lower) sandstones, cherts and limestones. In the second district they are in Lower Silurian cherts, and Lower Carboniferous sandstones. In the third they occur with Carboniferous and Lower Carboniferous strata, but are also in the form of recent spring deposits. In the Ouachita Mountains they are with Lower Silurian shales and novaculites. In this district the magnetite or natural lodestone of Magnet Cove occurs, but it is only an interesting mineral, and of no practical importance. The last district has the ores in sands and clays of the Eocene. Its continuation in Texas and Louisiana is referred to below.

In eastern Texas, along the latitude of the northern boundary of Louisiana, extended beds of limonite are found capping the mesas or near their tops, and associated with glauconitic sands of Tertiary age. They are described by Penrose[1] as (1) brown laminated ores, (2) nodular or geode ores, (3) conglomerate ores. The first form extended beds whose firmness has prevented the erosion of the hills, and which are thought to have originated by the weathering of the pyrites in the greensands and from the iron of the glauconite itself. The second group occur just north of the last, and have probably resulted from the alteration of clay ironstone nodules (Cf. Example 5), while the third has formed in the streams by the erosion of the first two and from the smaller ore-streaks and segregations. Limonite also occurs in northwestern Louisiana.[2] Lawrence C. Johnson has also written of these ores,[3] but the most complete account has been given by W. Kennedy.[4] Mr. Kennedy speaks of the available ores as the "Laminated Ores" and the "Nodular Ores," both belong-

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[1] *First Ann. Rep. Texas Geol. Survey,* p. 66; also *Bull. Geol. Soc. Amer.*, III., 44. [2] *Mineral Resources,* 1887, p. 51.

[3] *Fiftieth Congress, First Session, Exec. Doc.* No. 195.

[4] "Iron Ores of East Texas," *Trans. Amer. Inst. Min. Eng.*, XXIV., 258, 862.

ing, in serious amount, to the greensand beds of the upper Eocene. An abundant series of analyses is given which shows the ores to be in general rather rich for limonites, and not high in sulphur or phosphorus. According to the grade of ore now demanded and obtained on Lake Superior, they are seldom Bessemer ores, but ought to yield excellent foundry irons. While the quantity is large, the situation precludes the use of any fuel but charcoal, and the remoteness of markets will mostly restrict the output to the comparatively limited local demand. The ore can be won by shallow stripping or from exposed beds, up to two feet or so in thickness. The geological relations of these ores are interesting and important in that they are derived from greensands, which consist so largely of glauconite, the double silicate of iron and potassium, and which are comparatively deep-sea deposits. The formation of glauconite by precipitation from sea-water, and as a filling of the small chambers in minute shells and organisms indicates[1] a marine method for the concentration of iron oxide. It is significant that J. E. Spurr has lately advocated a similar source for the ores of the Mesabi range, Minn. (See Example 9*e*.) Limonite is known in a number of localities in Colorado. The chief productive mines lie in Saguache County, near Hot Springs. They furnish a most excellent ore from cavities in limestones, which are generally, but with no great certainty, considered Lower Silurian. R. Chauvenet states that the ores yield about 43% Fe in the furnace.[2]

In Allamakee County, in the extreme northeastern corner of Iowa, important deposits of rich limonites have been discovered on Iron Hill near the town of Waukon[3] and elsewhere,

[1] On the formation of greensands, see W. B. Clark, *Journal of Geology*, II., 161, 1894.

[2] R. Chauvenet, "Preliminary Notes on the Iron Resources of Colorado," *Ann. Rep. Colo. State School of Mines*, 1885, p. 21; "Iron Resources of Colorado," *Trans. Amer. Inst. Min. Eng.*, XVIII., 266. F. M. Endlich, *Hayden's Reports*, 1873, p. 333. B. T. Putnam, *Tenth Census*, Vol. XV., p. 482. C. M. Rolker, "Notes on Certain Iron Ore Deposits in Colorado," *Trans. Amer. Inst. Min. Eng.*, XIV., 266. Rec.

[3] E. Orr, "Brown Hematite in Allamakee County, Iowa," *Amer. Geologist*, I., 129, 1888. W. J. McGee, "The Pleistocene History of Northeast Iowa," *Eleventh Ann. Rep. Dir. U. S. Geol. Survey*, 548, 1891. Samuel Calvin, "Geology of Allamakee Co.," *Fourth Ann. Rep. Geol. Surv. Iowa*, 97, 1894 Rec.

The superficial decay of the rocks in this unglaciated region has been extensive and has left a thick mantle of residual material. Calvin estimates that a total of about 800 feet of Trenton and Galena limestones, Maquekota shales and Niagara limestone have disappeared, leaving behind them the usual clays and the iron ore. The latter is in the form of nodules, pipes and pots, and is as much as 30 feet thick. It has less ocher and clay than is usual in residual deposits, and this fact, together with the amount of iron oxide, leads Calvin to infer more of concentration than would result by simple weathering. The known chemical composition of the beds which have disappeared indicates that the strata which were formerly over the area of the ore would have furnished but a fraction of it.

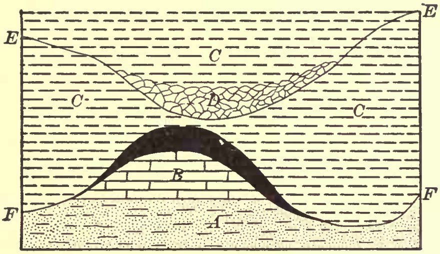

FIG. 12.—*Ideal cross-section of Iron Hill, near Waukon, Allamakee Co., Iowa. For explanation of letters, see text. Fourth Annual Report Iowa Geol. Survey, p.* 101, 1894.

Professor Calvin therefore suggests, as shown in the accompanying figure, that a depression first formed, into which the iron oxide drained from a wide area. Having once been concentrated, it then settled down and rested like a mantle upon the hilltop, which now stands in relief although it represents the rock formerly under the depression. In the accompanying Fig. 12, *A* is the St. Peter's sandstone; *B* the remaining Trenton limestone; the black area, the present ore; *CCC* the original geological section; *EE* the depressed outline after considerable weathering and erosion, with the production of the ore at *D*. *FF* is the present outline.

Much limonite occurs at Leadville in connection with the lead-silver ores, and is used as a flux by the lead smelters. Some grades low in silver and rich in manganese have even been used for spiegel at Pueblo. For the geological relations, see Example 30.

2.01.16. Limonites in supposed Carboniferous limestone occur in the East Tintic mining district in Utah, and seem to be associated with a decomposed eruptive rock, somewhat as at Leadville. The limonite is chiefly used as a flux by lead-silver smelters.[1]

2.01.17. Example 2*a*. *Siluro-Cambrian Limonites.*—Beds of limonite in so-called hydromica (talcose, damourite), slates and schists, often also with limestones of the Cambrian and Lower Silurian systems of the Appalachians. The great extent, the geological relations and the importance of these deposits warrant their being grouped in a subtype by themselves. They extend along the Appalachians from Vermont to Alabama, and are in the "Great Valley," as it was early termed, which

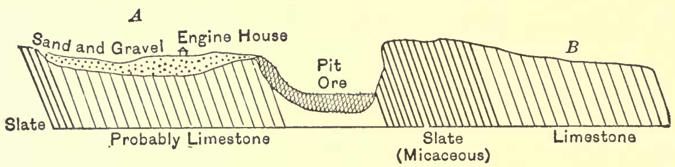

FIG. 13.—*Geological Section of the Amenia Mine, Dutchess County, New York, illustrating a Siluro-Cambrian limonite deposit. After B. T. Putnam, Tenth Census, Vol. XV., p.* 133.

marks the trough between the Archean on the east and the first corrugations of the Paleozoic rocks, often metamorphosed, on the west. The masses of limonite are buried in ochreous clay, and the whole often preserves the general structure of the schistose rocks which they have replaced. The original stringers of quartz remain, following the original folds. Dolomitic limestone often forms one of the walls, and still less often (but especially in New England) masses of siderite are found inclosed. Manganese is at times present, and in Vermont is of some importance of itself.

2.01.18. The deposits begin in Vermont, where in the vicinity of Brandon they have long been ground for paint. A curious pocket of lignite occurs with them, and affords Tertiary fossils. This prompted President Edward Hitchcock, about 1850, to refer all the limonites to the Tertiary, making

[1] B. T. Putnam, *Tenth Census*, Vol. XV., p. 490.

an instructive example of the occasional hasty generalizations of the early days. Lignite has also been found at Mont Alto, Pa. In northwestern Massachusetts, at Richmond and West Stockbridge; and just across the State line, in Columbia and Dutchess counties, New York, and at Salisbury, Conn., the mines are large, and were among the first worked in the United States. The limonite forms geodes, or "pots," pipes, stalactitic masses, cellular aggregates, and smaller lumps from which the barren clays and ochers are removed by washing. The ore is but a fraction of the material mined and occurs in irregular streaks through the clays, etc. It is mostly obtained by stripping and open cuts, and only rarely by underground mining, which would present difficulties with such poor material for walls.[1]

A gap occurs in the succession of the deposits across southern New York and New Jersey, although a few minor ones are known in the western part of the latter State, in the magnesian limestone of the valleys between the hills of gneiss.[2]

2.01.19. In Lehigh County and to the southwest through York County, in eastern Pennsylvania, the limonites are again

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[1] J. D. Dana, "Occurrence and Origin of the New York and New England Limonites," *Amer. Jour. Sci.*, iii., XIV., 132, and XXVIII., 398. Rec. E. Hitchcock, "Description of a Brown Coal Deposit at Brandon, Vt., with an Attempt to Determine the Geological Age of the Principal Ore Beds of the United States," *Amer. Jour. Sci.*, ii., XV., 95; *Hist. Geol. Survey of Vermont*, I., 233. See also Lesley, below. A. L. Holley, "Notes on the Salisbury (Conn.) Iron Mines and Works," *Trans. Amer. Inst. Min. Eng.*, VI., 220. J. P. Lesley, "Mont Alto (Pa.) Lignites," *Proc. Amer. Acad. Sci.*, 1864, 463–482; *Amer. Jour. Sci.*, ii., XL., 119. L. Lesquereux, "On the Fossil Fruits Found in Connection with the Lignite at Brandon, Vt.," *Amer. Jour. Sci.*, ii., XXXII., 355. H. Carvill Lewis, "The Iron Ores of the Brandon Period," *Proc. Amer. Assoc. Adv. Sci.*, XXIX., 427, 1880. J. F. Lewis, "The Hematite (Brown) Ore Mines, etc., East of the Hudson River," *Trans. Amer. Inst. Min. Eng.*, V., 216. J. G. Percival, *Rep. on the Geol. of Conn.*, p. 132; also, *Amer. Jour. Sci.*, ii., II., 268. R. A. F. Penrose, "Report on Manganese Ores," *Geol. Survey Ark.*, 1890, Vol. I. (Contains many valuable descriptions of Vermont limonites.) B. T. Putnam, *Tenth Census*, Vol. XV. C. U. Shepherd, "Notice, etc., of the Iron Works of Salisbury, Conn.," *Amer. Jour. Sci.*, i., XIX., 311. J. C. Smock, *Bull. VII. New York State Museum*, pp. 12, 52. N. H. and H. V. Winchell, "Taconic Ores of Minnesota and Western New England," *Amer. Geol.*, VI., 263. 1890.

[2] B. T. Putnam, *Tenth Census*, Vol. XX., p. 176. See also *Geol. Survey New Jersey*, 1880.

developed in great amount, and run southwesterly, with few gaps, to Alabama. It is in this portion that the "Great Valley" (called also the Cumberland Valley, or Valley of Virginia) is especially marked. Wherever the great limestone formation, No. II. of Rogers, is developed the ores are found. This corresponds to the Calciferous, Chazy, and Trenton of New York. Limonites also occur still lower in the Cambrian at about the horizon of the Potsdam sandstone or in the over lying slates. According to McCreath, they are divisible in Pennsylvania into ores at the top, ores in the middle, and ores at the bottom of the great limestone No. II. Those at the top form the belt along the central part of the valley where the Trenton limestone underlies the Utica or Hudson River slates. Those in the middle are connected with various horizons of ferruginous limestones in the Chazy and Calciferous. Those at the bottom along the north or west part of the South Mountain-Blue Ridge range are geologically connected with the Potsdam sandstone, or the slates which intervene between it and the base of the Calciferous.[1] Cobalt has been detected on those of Chester Ridge by Boye, but it is a rare and unique discovery.[2]

2.01.20. The Siluro-Cambrian limonites run across Maryland in Carroll and Frederick counties, and are mined to a small extent.[3]

These limonites are again strongly developed in the Shenandoah Valley along the western base of the Blue Ridge, and in southwestern Virginia in the Cripple Creek and New River

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[1] *Second Penn. Survey*, Rep. MM, p. 199.

[2] Dr. Boye, "Oxyd of Cobalt with the Brown Hematite of Chester Ridge, Penn., *Amer. Phil. Soc.*, January, 1846. P. Fraser, *Second Geol. Survey Penn.*, Reps. C and CC; "Origin of the Lower Silurian Limonites of York and Adams Counties," *Proc. Amer. Phil. Soc.*, March. 1875. See also, "Remarks on a Paper of F. Prime," *Idem*, December 21, 1877, 255. J. W. Harden, "The Brown Hematite Ore Deposits of South Mountain between Carlisle, Waynesborough, and the Southeast Edge of the Cumberland Valley," *Trans. Amer. Inst. Min. Eng.*, I., 136. J. P. Lesley, Summary, Final Report, Vol. I., 1892, pp. 205, 341. Rec. A. S. McCreath *Second Geol. Survey Penn.*, Vol. MM, 199. F. Prime, *Second Geol. Survey Penn.*, Reps. D and DD; "On the Occurrence of the Brown Hematite Deposits of the Great Valley," *Trans. Amer Inst. Min. Eng.*, III., 410; *Amer. Jour. Sci.*, ii., IX., 433; also, XI., 62, and XV., 261. Rec. B. T. Putnam, *Tenth Census*, Vol. XV., p. 181.

[3] E. R. Benton, *Tenth Census*, Vol., XV., p. 254.

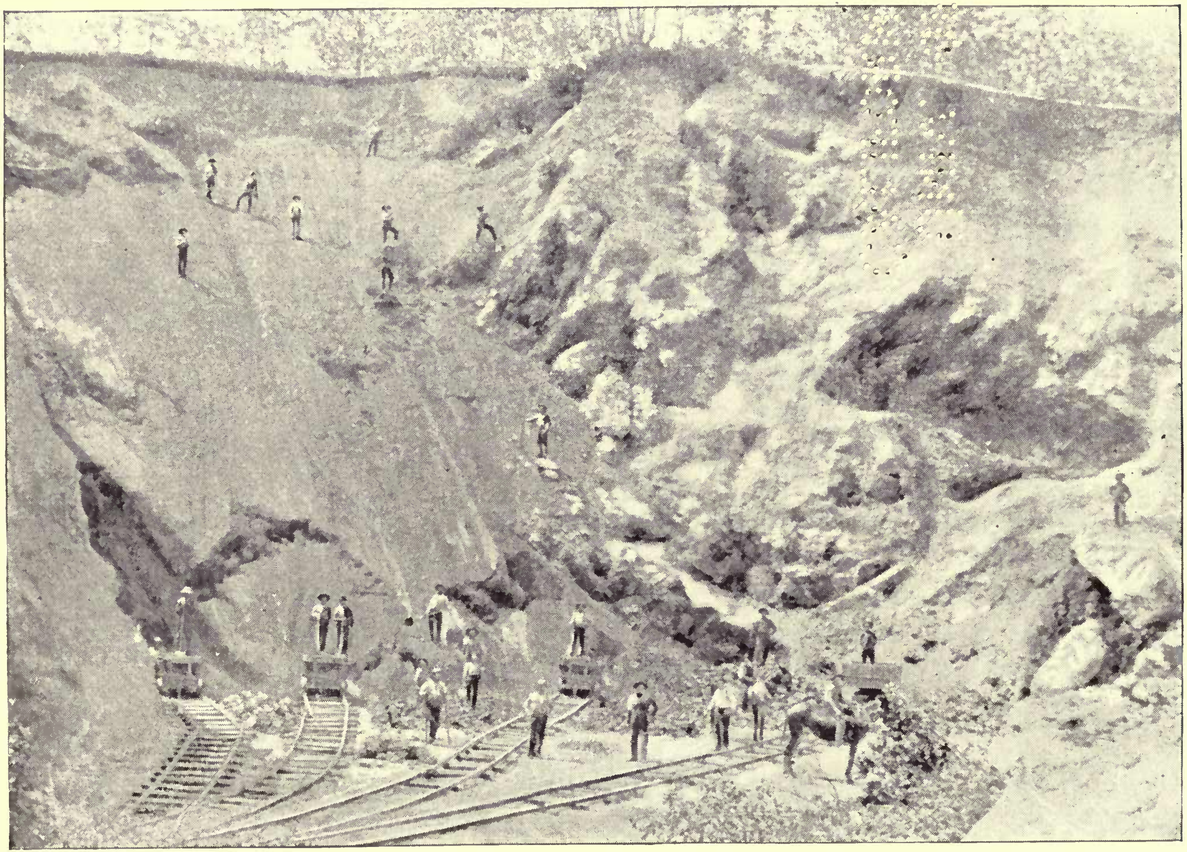

FIG. 14.—*View of the Siluro-Cambrian brown hematite bank at Baker Hill, Ala. From the Engineering and Mining Journal, January 28, 1893, p. 77.*

belt. The ores occur in connection with calcareous shales, calcareous sandstones, and impure limestones, but have not justified the expectations formed of them. The geological relations are similar to those of the zinc ores described under Example 26, and the pictures of the zinc mines will answer for those worked for limonite. In Carroll County, Virginia, the gossan of the great deposit of pyrite is dug for iron ore. The walls, however, are older than the Cambrian.[1]

2.01.21. The limonites of eastern Tennessee are the southern prolongation of the area of southwest Virginia. They lie betwen the Archean of the Unaka range on the east, and the Upper Silurian strata in the foot of the Cumberland tableland on the west. The ores outcrop in the longitudinal valleys or "coves." The bottoms of these valleys, according to Safford (p. 449), are formed by the shales, slates, and magnesian limestones of the Knox group, and in the residual clay left by their alteration the ore is found. The gossan of the neighboring veins of copper pyrites, best known at Ducktown (see Example 16), was originally exploited for iron.[2] The Tennessee limonite extends across northwestern Georgia, and still farther east

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[1] E. R. Benton, *Tenth Census*, Vol. XV., p. 261. J. L. Campbell, "Report on the Mineral Prospects of the St. Mary Iron Property," etc., *The Virginias*, February, 1883, p. 19. See also *The Virginias*, January, 1880, p. 4; March, p. 43. F. P. Dewey, "The Rich Hill Iron Ores," *Trans. Amer. Inst. Min. Eng.*, X., 77. W. M. Fontaine, "Notes on the Mineral Deposits of Certain Localities in the Western Part of the Blue Ridge," *The Virginias*, March, 1883, p. 44; April, p. 55; May, p. 73; June, p. 92. B. S. Lyman, "On the Lower Silurian Brown Hematite Beds of America," *Proc. Amer. Assoc. Adv. Sci.*, XVII., 114. A. S. McCreath, "The Iron Ores of the Valley of Virginia," *Trans. Amer. Inst. Min. Eng.*, XII., 103; *Engineering and Mining Journal*, June, 1883, p. 334. E. C. Moxham, "The Great Gossan Lead of Virginia," *Trans. Amer. Inst. Min. Eng.*, XXI., 133. E. C. Pechin, "The Iron Ores at Buena Vista, Rockbridge County, Virginia." *Engineering and Mining Journal*, Aug. 3, 1889, p. 92; "Mining of Potsdam Brown Ores in Virginia," *Engineering and Mining Journal*, Sept. 19, 1891, p. 337; "Iron Ores of Virginia and their Developments," *Trans. Amer. Inst. Min. Eng.*, XIX., 101; "Ore Supply for Virginia Furnaces," *Engineering and Mining Journal*, Vol. LI., 1891, pp. 322, 349. Rec.

[2] J. M. Safford, *Geol. of Tenn.*, p. 448, 1869. B. Willis, *Tenth Census*, Vol. XV., p. 331. The best works of reference are the recent folios of the U. S. Geological Survey, which cover a large part of southeastern Tennessee and the neighboring parts of Alabama and Georgia.

the so-called Huronian limestones of North Carolina also enter the State. But as even these so-called Huronian schists and associated marbles have been considered by F. P. Bradley to be metamorphosed Silurian (Cambrian), the ores may also belong under Example 2*a*. The well-determined Siluro-Cambrian rocks form but a narrow belt of no great importance in North Carolina.[1]

The limonites are again strongly developed in Alabama and furnish a goodly proportion of the ore used in the State. They form a belt lying east of the Clinton ores (Example 6), later described. As in Tennessee, they are associated with strata of the Knox group.[2]

2.01.23. *Origin of the Siluro-Cambrian Limonites.*—Dr. Jackson, of the First Pennsylvania Survey, argued in 1839[3] that they originated *in situ;* that is, by the alteration of the rocks in and with which they occur. Percival, in his report on the Geology of Connecticut in 1842 (p. 132), attributed them to the alteration of pyrite in the neighboring mica-slate. Prime, in Pennsylvania, in 1875 and 1878 (Reports D and DD), considers that the iron has been obtained by the leaching of the neighboring dolomites and slates, it being in them either as silicate, carbonate or sulphide; that the ore has reached its position associated with the slates, because, being impervious, they retained the ferruginous solutions; and that the potash abundantly present in the slates probably assisted in precipitating it.[4] Frazer, in 1876,[5] in studying the beds of York and Adams counties, Pennsylvania, found the hydromica slates filled with the casts of pyrite crystals, and held these to have been the sources of the iron, because they would afford ferrous sulphate and sulphuric acid. The latter reacted on the alkali of the

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[1] F. P. Bradley, "The Age of the Cherokee County Rocks, North Carolina," *Amer. Jour. Sci.*, iii., IX., 279, 320; B. Willis, *Tenth Census*, Vol. XV., p. 367.

[2] W. M. Chauvenet, *Tenth Census*, Vol. XV., p. 383. H. McCalley, "Limonites of Alabama Geologically Considered," *Engineering and Mining Journal*, Dec. 19, 1896, 583. For other references to Alabama iron ore deposits, see under Example 6. The folios of the U. S. Geological Survey bearing on this region should be consulted.

[3] *Ann. Rep. First Pa. Survey*, 1839.

[4] *Trans. Amer. Inst. Min. Eng.*, II. 410.

[5] *Second Pa. Survey*, Rep. C, p. 136.

slates, producing sodium sulphate. This, meeting calcium carbonate afforded calcium sulphate and sodium carbonate, which latter precipitated the iron. Calcium carbonate alone is, however, abundantly able to precipitate iron carbonate and oxide from both ferrous and ferric sulphate solutions (even when neutral) without the introduction of the alkali, although this might account for the alteration of the slates.[1]

2.01.24. J. D. Dana has written at length on the New England and New York deposits, and finds them always at or near the junction of a stratum of limestone, proved in many cases to be ferriferous, and sometimes entirely siderite, and one of hydromica slate or mica schist. In several mines bodies of unchanged spathic ore are embedded in the limonite. Hence Professor Dana explains the limonite as derived by the weathering of a highly ferruginous limestone, from which the limonite has been left behind by the removal of the more soluble elements, so as practically to replace the limestone in connection with other less soluble matter. The limonite has also at times replaced the schists, probably deriving its substance in part from iron-bearing minerals in them, and changing these rocks to the ochers and clays now found with the ores. These views are undoubtedly very near the truth for the region studied, and have been corroborated by observations of the writer. (Cf. also Example 4.) Weathering limestones do furnish residual clay, ocher, etc., as is shown by the deposits of western Kentucky and Tennessee under Example 2.

2.01.25. Another hypothesis early formulated and advocated by many is that the limonites have been derived from the surface drainage of the old Appalachian highlands, then have been precipitated in still water and have been buried up where they are now found. A precipitation around the shores of a ferruginous sea has also been urged on the analogy of certain explanations of the Clinton ore. (Example 6.) Their supposed Tertiary age has already been remarked. All these views are essentially hypothetical and have no good foundation.[2]

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[1] See F. P. Dunnington, "On the Formation of Deposits of Manganese," *Amer. Jour. Sci.*, iii., XXXVI., p. 175. (Experiments 10 and 11.)

[2] See H. D. Rogers, *Trans. Asso. Amer. Geol. and Nat.*, 1842, p. 345; E. Hitchcock, *Geol. Vt.*, Vol. I., p. 233; J. P. Lesley, *Iron Manufacturers' Guide*, p. 501; Rep. A, *Second Pa. Survey*, p. 83; J. S. Newberry, *International Review*, November and December, 1874.

ANALYSES OF LIMONITES.

2.01.26. All published analyses, except when forming a sufficiently large and continuous series from the output of any one mine, are to be taken with caution. Ores necessarily vary much, and a single analysis or a selected set may give a very wrong impression. The percentage in iron is different for different parts of the same ore body. The few that follow have been selected to show the range and the average. The highest are exceptionally good, the lowest less than the average, and the medium values indicate approximately the general run. Limonites afford from 40 to 50% Fe as actually exploited, but it is not difficult to find individual analyses that run higher. They are not, generally speaking, Bessemer ores.

ANALYSES OF LIMONITES.

	Fe.	P.	S.	SiO_2	Al_2O_3	H_2O.
Berkshire County, Mass.	47.52	0.187	......	......	......	......
Connecticut	50.48	0.353	......	......	......	......
Dutchess County, New York	46.45	0.370	......	14.100	3.056	......
Staten Island	39.72	0.059	0.391	14.190	3.590	12.41
Pennsylvania	56.30	0.125	0.020	5.165	......	......
Virginia (Low Moor)	43.34	0.636	......	......	......	......
Tennessee (Lagrange Furnace)	50.91	0.237	......	......	......	......
Alabama	50.89	0.225	......	......	......	......
Colorado	53.37	0.034	0.200	7.900	0.700	......
Colorado, average	43.00	0.030	......	20.000	......	13.00
Prosser mine, Oregon	44.71	0.666	......	......	......	......
Pure mineral	59.92	......	......	......	......	14.40

SIDERITE OR SPATHIC ORE.

2.01.27. Siderite is the protocarbonate of iron. As a mineral it often contains more or less calcium, magnesium, and manganese. When of concretionary structure, embedded in shales and containing much clay, the ore is called clay ironstone. When the concretions enlarge and coalesce, so as to form beds of limited extent, generally containing much bituminous matter, they are called black-band, and are chiefly developed in connection with coal seams.

2.01.28. Example 3. *Clay Ironstone.*—The name is applied to isolated masses of concretionary origin (kidneys, balls, etc.)

which may at times coalesce to form beds of considerable extent. They are usually distributed through shales, and on the weathering of the matrix are exposed and concentrated. They are especially characteristic of Carboniferous strata and differ from black-band only in the absence of bituminous matter and in the consequent drab color. They weather to limonite, generally in concentric shells with a core of unchanged carbonate within. Fossil leaves or shells often furnish the nucleus for the original concretion, and are thus, as at Mazon Creek, Ill., beautifully preserved. When in beds the ore is sometimes called flagstone ore; when broken into rectangular masses by joints, it is called block ore.

2.01.29. Example 3*a*. *Black-band.*—The name is applied to beds consisting chiefly of carbonate of iron with more or less earthy and bituminous matter. They are of varying thickness, though rarely more than six feet, and are almost invariably associated with coal seams. They are thus especially found in the Carboniferous system, and to a far less degree in the eastern Jura-Trias. They are also recorded with the Cretaceous coals of the West. It is not possible to separate the two varieties in discussing their distribution. The various productive areas are taken up geographically, beginning with the Appalachian region.

2.01.30. The carbonate ores are of great importance in the Carboniferous of western Pennsylvania and in the adjacent parts of Ohio, West Virginia and Kentucky. In these States the system is subdivided in connection with the coal, from above downward, as follows: I. The Upper Barren Measures, Permo-Carboniferous, or Dunkard's Creek Series; II. The Upper Productive Coal Measures, or Monongahela River Series; III. The Lower Barren Measures, or Elk River Series; IV. The Lower Productive Coal Measures, or Allegheny River Series; V. The Great or Pottsville Conglomerate. In the Upper Barren Measures of Pennsylvania, according to McCreath, there is hardly a stratum of shale or sandstone without clay ironstone nodules, but no continuous beds are known.[1] The deposits are not of great actual importance, and are worthy of only passing mention. In the Upper Productive Coal Measures some ore occurs associated with the Waynes-

[1] *Second Pa. Survey,* Rep. K, p. 386; MM, p. 159.

burg coal seam, and again, just under the Pittsburg seam there is considerable known as the Pittsburg Iron Ore Group. This latter ore becomes of great importance in Fayette County, and extends through several beds.[1] The Lower Barren Meas ures in Pennsylvania also contain carbonate ore in a number of localities. The most persistent is the Johnstown ore bed, near the base of the series. There are two additional beds just over the Mahoning sandstone.

The Lower Coal Measures are the chief ore producers in all the States. They furnish balls of clay ironstone in very many localities in western Pennsylvania, which will be found recorded with many additional references in Report MM, p. 174, *Pa. Geol. Survey.* The nodules are scattered through clay and shales. The so-called Ferriferous limestone, which lies a few feet below the Lower Kittanning coal seam, affords in its upper portion varying thicknesses of carbonate ore, known as "buhrstone ore," which is altered in large part to limonite. Some little carbonate ore was found in the early days in the anthracite measures of eastern Pennsylvania. Several beds of the same occur in the Great Conglomerate and its underlying (Mauch Chunk) shales. They are chiefly developed in southwestern Pennsylvania (Report KK), and may form either entire beds or disseminated nodules. The limonites of the Marcellus stage that pass into carbonates in depth in Perry and the neighboring counties have already been mentioned under Example 2. In West Virginia both Upper and Lower Measures afford the ore. From the latter black-band is extensively mined on Davis Creek, near Charleston.[2]

2.01.31. In Ohio a number of nodular deposits are known, but practically no ore is produced above the Mahoning sandstone of the Lower Coal Measures. Below this sandstone the ores are extensively developed. They extend up and down the eastern part of the State, and are both black-band and clay ironstone. Orton identifies twelve different and well-marked horizons distributed through the Lower Measures. He distinguishes the stratified ores, mostly black-band, and the concre-

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[1] Rep. MM, p. 162; KK, p. 111; L, p. 98.

[2] M. F. Maury and W. M. Fontaine, *Resources of West Virginia,* 1876. p. 247.

tionary ores, including kidney ores, block ores, and limestone ores.[1]

2.01.32. The general distribution of the iron ores of Kentucky has already been outlined under Example 2. The Hanging Rock region is a southern prolongation of the Ohio district of the same geological horizon. P. N. Moore has classified the local ores as limestone ores, which are associated with limestone, block ores, and kidney ores. The last two names refer to the fracture or shape of the masses. They occur associated with the usual clay and shale. Farther west, between the Kentucky and Red rivers, are the other deposits, the principal one of which comes low in the series, just over the Subcarboniferous limestone.[2]

2.01.33. Small quantities of black-band have been found in the Deep River coal beds, in North Carolina, associated with the Triassic coals.[3]

A large bed, or series of beds, has recently been reported from Enterprise, Miss., in strata of the Claiborne stage. They run from ten to eighteen feet in thickness, and extend for miles.[4] Scattered nodules have been noted at Gay Head, Martha's Vineyard.[5] Carbonate ores are as yet of no importance in the coal measures of the Mississippi Valley. They have been found associated with the Cretaceous coals of Wyoming and Colorado—and indeed the first pig iron of the latter State was made from them in Boulder County—but they are not an important source of ore.[6] An extended bed of very excellent carbonate has recently been discovered with coal near Great Falls, in the Sand Coulée region of Montana. Being near coal, limestone,

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[1] *Geol. of Ohio*, V., p. 378, and supplemental report on the Hanging Rock region in Vol. III.

[2] P. N. Moore, "On the Hanging Rock District in Kentucky," *Kentucky Geol. Survey*, Vol. I., Part 3.

[3] B. Willis, *Tenth Census*, Vol. XV., p. 306; W. C. Kerr, *Geology of North Carolina*, 1875, p. 225.

[4] A. F. Brainard, "Spathic Ore at Enterprise, Miss.," *Trans. Amer. Inst. Min. Eng.*, XIV., 146.

[5] W. P. Blake, "Notes on the Occurrence of Siderite at Gay Head, Mass.," *Trans. Amer. Inst. Min. Eng.*, IV., 112.

[6] R. Chauvenet, "Notes on the Iron Resources of Colorado," *Ann. Rep. Colo. School of Mines*, 1885, 1886; *Trans. Amer. Inst. Min. Eng.*, XVIII., 266.

and other iron ores, it promised to be of considerable importance.[1]

2.01.34. Example 4. Burden Mines, near Hudson, N. Y. Elongated lenticular beds of clay ironstone, passing into sub-

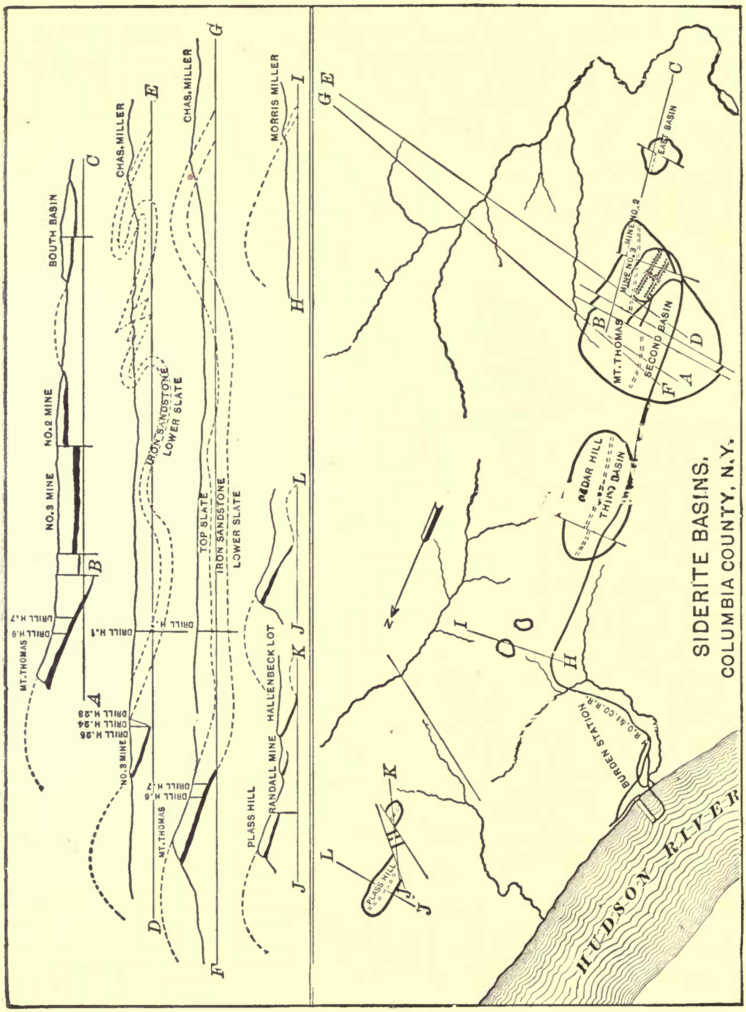

FIG. 15.—*Map and sections of the Burden spathic ore mines. After J. P. Kimball, Amer. Jour. Sci., August, 1890, p. 155.*

crystalline siderite, enclosed conformably between underlying slates, and overlying calcareous sandstone, of the Hudson River stage. The ore occurs in four "basins," which outcrop

[1] O. C. Mortson, *Mineral Resources U. S.*, 1888, p. 34.

along the western slope of a series of moderate hills, just east of the Hudson River. The hills have been shown by Kimball to be the eastern halves of anticlinal folds now reduced by erosion to easterly dipping monoclines. The western half of the ore bodies has been eroded away, leaving an outcrop 44 feet thick as a maximum, which pinches out along the strike and dip. The basins extend from southwest to northeast, parallel to the trend of the hills. The beds are more or less faulted. The southern part of the second basin affords Bessemer ores, but the others are too high in phosphorus. At this point the principal mining has been done. According to Olmstead, some varieties are richer in phosphorus than others, but they are so intimately mixed as not to be practicably separated. Up to 1889 the mines had produced 450,000 tons of roasted Bessemer ores.

2.01.35. In their geological relations the ores are of the greatest interest, as they occur in the western limit of the metamorphic belt, which forms the basis of the Taconic controversy, yet in strata which have been identified by fossils. Beds of limonite hitherto regarded as Siluro-Cambrian occur to the east; and should further study, on the lines developed chiefly by J. D. Dana, W. B. Dwight, and C. D. Walcott, clear up their stratigraphical relations, the work done in developing the structure of the siderite basins, as pointed out by Kimball, may be of great aid in explaining them. Very similar bodies of siderite occur with these limonites. (Example 2*a*.) The Burden ores are relatively high in magnesia, and this leads Kimball to suggest their original deposition from the off-shore drainage of the basic rocks of the Archean highlands. Further, it may be added that the ores in their lenticular shape are highly suggestive of a possible origin for magnetite deposits, and they are again referred to under "Magnetite." Other deposits of siderite in the shales of the Marcellus stage are known and were formerly worked at Wawarsing, Ulster County, across the Hudson River.[1]

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[1] J. P. Kimball, "Siderite Basins of the Hudson River Epoch," *Amer. Jour. Sci.*, III., xl. 155. I. Olmstead, "Distribution of Phosphorus in the Hndson River Carbonate," *Trans. Amer. Inst. Min. Eng.*, XVIII., 252. R. W. Raymond, "The Spathic Ores of the Hudson River," *Trans. Amer. Inst. Min. Eng.*, IV., 309. J. C. Smock, *Bulletin VII. of New York State Museum on Iron Ores*, p. 62.

2.01.36. Example 5. Roxbury, Conn. A fissure vein in gneiss, six to eight feet wide, of crystalline siderite, with which are asociated quartz and a variety of metallic sulphides, galena, chalcopyrite, zinc blende, etc. Although productive in former years, it is no longer worked, and is of scientific more than economic interest, being a unique deposit. It has furnished many fine cabinet specimens.[1]

2.01.37. The spathic ores are the lowest in iron of all, and in the raw state are often, if not always, far below the limit of profitable treatment. Calcination, however, drives off the carbonic acid and moisture and brings the percentage of iron up to a merchantable grade. The later development of the iron industry in this country has been unfavorable to spathic ores, and year by year their amount has decreased until now it is nearly obliterated, being only about one per cent of the total.

2.01.38. The subjects of limonite and siderite cannot well be passed without further reference to their genetic relations as connected with limestone. The processes involved concern not alone these ores, but also the more metamorphic forms—hematite and magnetite—into which they may pass by reason of subsequent changes. It was stated earlier (2.01.05) that calcium carbonate precipitated from ferric salts, ferric hydrate, and from ferrous salts, ferrous carbonate, which in the presence of oxygen quickly changed to ferric hydrate. J. P. Kimball[2] has recently added a note on the chemistry of the process which modifies it somewhat. He brings out the fact that it is the *hydrous* carbonate of iron which is precipitated from ferruginous salts by the various alkaline carbonates, and that, being an unstable salt, it quickly oxidizes to a hydrous oxide. From this the argument is made that bodies of siderite, or anhydrous ferrous carbonate, could not have originated by direct precipitation, but must have done so by pseudomorphous replacement of limestone. Dr. Kimball then follows out the possible metamorphism or changes of these bodies to other forms of iron ore,

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[1] J. P. Lesley, *Iron Manufacturers' Guide*, p. 649. C. U. Shepherd, "Report on the Geology of Connecticut," 1837, p. 30, *Amer. Jour. Sci.*, I., xix. 311.

[2] J. P. Kimball, "Genesis of Iron ores by Isomorphous and Pseudomorphous Replacement of Limestone," *Amer. Jour. Sci.*, September, 1891, p 231, and conclusion in the *Amer. Geol.*, December, 1891.

citing, however, among many that are unexceptionable, some instances as possible examples for which the field relations give but slight justification. The specular ores with the porphyries of Missouri are of this latter character, and the work of C. H. Smyth, Jr., later cited, on the oölitic Clinton hematites gives strong ground for thinking them accumulations in shallow waters as concentric layers upon original nuclei of quartz.

2.01.39. While the importance of limestone as a cause of the formation of bodies of iron ore cannot be too highly emphasized, and it is quite possible that some puzzling ones, such as many magnetite beds, have originated in this way, and that the limestone has so entirely disappeared as to give slight clue to its original presence; yet it must not be overlooked that siderite often does form in nature quite independently of calcite, and that conditions must be often such as to make this possible. If vuggs with free crystals, or if cleavage masses with the proper angle occur in a deposit, we must admit that the siderite is produced under circumstances not different from those which prevailed during the formation of the walls or of the massive mineral. Repeated experience indicates that these are not extraordinary.

CHAPTER II.

THE IRON SERIES CONTINUED—HEMATITE, RED AND SPECULAR.

2.02.01. The sesquioxide of iron, F_2O_3, is always of a red color when in powder. If it is of earthy texture, this color shows in the mass, and the ore is called red hematite; if the ore is crystallized, the red color is not apparent, and the brilliant luster of the mineral gives it the name specular hematite. The red hematites are first treated.

2.02.02. Example 6. *Clinton Ore.*—Wherever the Clinton stage of the Upper Silurian outcrops, it almost invariably contains one or more beds of red hematite, interstratified with the shales and limestones. These ores are of extraordinary persistence, as they outcrop in Wisconsin, Ohio and Kentucky in the interior, and then beginning in New York, south of Lake Ontario, they run easterly across the State. Again in Pennsylvania they follow the waves of the Appalachian folds and extend south into West Virginia and Virginia in great strength. They are found in eastern Tennessee and northwestern Georgia, and finally in Alabama are of exceptional size and importance. The structure of the ore varies somewhat. At times it is a replacement of fossils, such as crinoid stems, molluscan remains, etc. (fossil ore); again as small oölitic concretions, like flaxseed (flaxseed ore, oölitic ore, lenticular ore): while elsewhere it is known as dyestone ore. The ore in many places is really a highly ferruginous limestone, and below the water level in the unaltered portion it often passes into limestone, while along the outcrop it is quite rich.

2.02.03. In Dodge County, southeastern Wisconsin, the ore in 14 to 26 feet thick, and consists of an aggregate of small lenticular grains.[1] In Ohio it outcrops in Clinton, Highland

[1] T. C. Chamberlin, *Geol. Survey Wis.*, Vol. I., p. 179. R. D. Irving, "Mineral Resources of Wisconsin," *Trans. Amer. Inst. Min. Eng.*, VIII., 478; *Geol Survey Wis.*, Vol. I., p. 625.

and Adams counties, in the southwestern portion of the State along the flanks of the Cincinnati Arch, but it is thin and poor in iron, although rich in fossils.[1] A small area of the Clinton has furnished considerable ore in Bath County, Kentucky, where it is altered to limonite.[2]

2.02.04. Coming eastward, the limestones and the shales of the Clinton outcrop in the Niagara River gorge in New York, but show no ore. This appears first in quantity in Wayne County, a hundred miles east and just south of Lake Ontario. One bed reaches 20 to 22 inches. Farther east are the Sterling

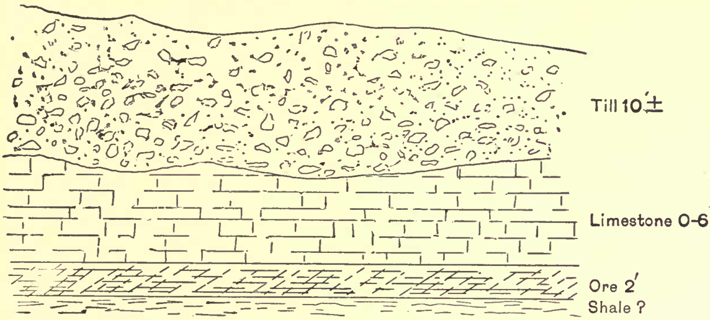

FIG. 16.—*Clinton Ore, Ontario, Wayne County, New York. After C. H. Smyth, Jr.*

mines, in Cayuga County; and again near Utica, in the town of Clinton, which first gave the ore its name, it is of great economic importance. There are two workable beds, the upper of which, with a thickness of about two feet, is the only one now exploited. Beneath this are 12 or 15 inches of shale, and then the second bed of 8 inches of ore.[3] Some 25 feet over the upper bed is still a third, which is too low grade for mining. It is four to six feet thick, and is locally called red flux. It consists of pebbles and irregular fragments of fossils, which are coated with hematite and cemented with calcite.

[1] J. S. Newberry, *Geol. of Ohio,* Vol. III., p. 7. E. Orton, *Geol. of Ohio,* Vol. V., p. 371.

[2] N. S. Shaler, *Geol. of Ky.*, Vol. III., 163.

[3] A. H. Chester, "The Iron Region of Central New York," address before the Utica Merchants and Manufacturers' Association, Utica, 1881 J. C. Smock, *Bull. VII. of N. Y. State Museum,* June 1889. C. H. Smyth, Jr., "On the Clinton Iron Ore," *Amer. Jour. Sci.*, June, 1892, p 487. *Zeitschr. für prakt. Geologie,* 1894, 304.

2.02.05. The rocks of the Clinton thicken greatly in Pennsylvania and run southwestward through the central part of the State. Six different ore beds have been recognized, of which the lower are probably equivalent to the southern dyestone ores.[1]

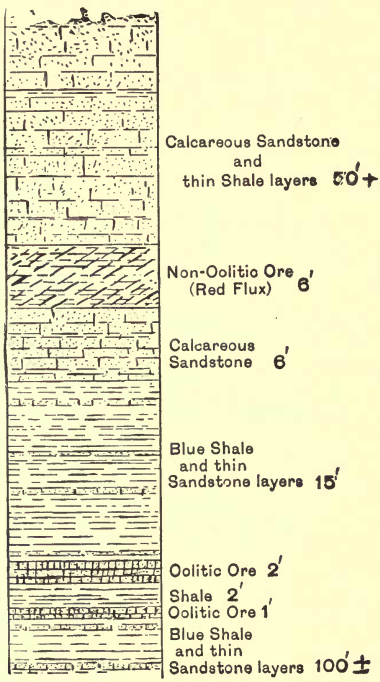

FIG. 17.—*Clinton Ore, Clinton, New York. After C. H. Smyth, Jr.*

The ores are of chief importance in the Juniata district. The belt extends southwestward across Maryland and eastern West Virginia, where the beds are quite thick, although as yet not much developed, and appears in the extreme southwest corner of Virginia. Thence it runs across eastern Tennessee, and is of very great importance. The lines of outcrop are

[1] J. H. Dewees, "Fossil Ores of the Juniata Valley," *Penn. Geol. Survey*, Rep. F. E. d'Invilliers, *Ibid.*, Rep. F3 (Union, Snyder, Mifflin, and Juniata counties). A. S. McCreath, *Ibid.*, Rep. MM, p. 231. J. J. Stevenson, *Ibid.*, Reps. MM and T2 (Bedford and Fulton counties). I. C. White, *Ibid.*, Reps. MM and T3 (Huntingdon County). H. H. Stoek, "Ores at Danville, Montour County," *Trans. Amer. Inst. Min. Eng.*, XX., 369.

known as "dyestone ranges." They lie west of the Siluro-Cambrian limestones (Example 2*a*) and in the edges of the Cumberland tableland. Four or five are known, of which the largest extends across the State. This ore is more fossiliferous

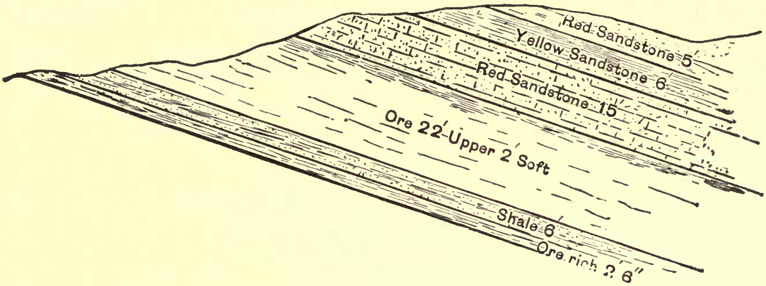

FIG. 18.—*Clinton Ore, Eureka Mine, Oxmoor, Ala. After C. H. Smyth, Jr.*

toward the south and more oölitic toward the north. It is very productive in the Chattanooga region.[1]

2.02.06. The Clinton just appears in northwestern Georgia, and continues thence into Alabama, where it is again of great

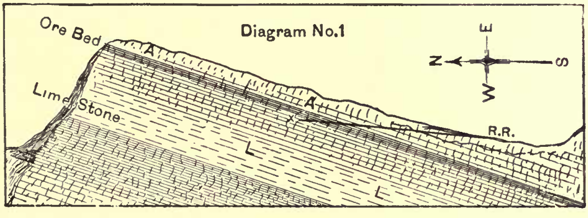

FIG. 19.—*Cross-section of the Sloss Mine, Red Mountain, Ala.*

importance, and, with the less productive Siluro-Cambrian limonites, furnishes practically all the ore of the State. The outcrop can be traced almost continuously for 130 miles. The ore is rich in fossils and occurs in several beds, which, although averaging much less, may aggregate, as at the Eureka furnace, as much as 34 to 37 feet. The chief mines are in Red Mountain,

[1] Killebrew and Safford, *Resources of Tennessee*. E. C. Pechin, "The Iron Ores of Virginia," etc., *Trans. Amer. Inst. Min. Eng.*, XIX., 1016. J. B. Porter, "Iron Ores, Coal, etc., in Alabama, Georgia, and Tennessee," *Trans. Amer. Inst. Min. Eng.*, XV., 170. J. M. Safford, *Geol. of Tenn.* P. N. Moore, *Virginias*, May, 1880, p. 78.

a local name for the northeast and southwest ridges, in which the ore outcrops, east and south of Birmingham. Folds and faults have brought the beds into close proximity with the coal and limestone of the region, and thus into a position very favorable for economic working.[1]

The accompanying map, Fig. 20, illustrates the geography and economic geology of the Birmingham district. In explanation it may be said that the three coal fields, the Warrior, the Cahaba, and the Coosa, make three elevated basins, formed in part by synclinal foldings and in part by faulting. The intervening strips are relatively depressed and constitute the so-called valleys, each of which has its own name. Thus there is a long valley in which Birmingham is situated and which forks at the northeast corner of the map. The central portion of it consists of Cambrian and Lower Silurian rocks, which yield brown hematite ores, as indicated on the map. They, however, are a minor feature and do not form over 10% of the total furnace supply. On each side of the valley there is a ridge called Red Mountain, mostly formed by Clinton strata, with Trenton limestone beneath and black Devonian shale above. The Clinton reaches a thickness of 150 feet, but is quite variable in character. It may contain as many as five or more beds of ore of differing thicknesses and somewhat contrasted composition and structure. The best of these are worked. The Clinton beds in Red Mountain dip on each side away from the center of the valley, and really are the remains of an anticline eroded at its crest. The anticline is of the usual Appalachian type with steeper dips on one flank, in this case the northwestern, than on the other, and the crest is nearer the northwest side than the northeast. The dip at one important mine is shown in Fig. 18. The most productive points are east and south of Birmingham, and along this line the largest mines are situated. The ore is chiefly won by open cuts, and is laid bare by stripping off the hanging. Curiously enough,

[1] A. F. Brainerd, "On the Iron Ores, Fuels, etc., of Birmingham, Ala.," *Trans. Amer. Inst. Min. Eng.*, XVII., 151. "The Sloss Iron Ore Mines," *Engineering and Mining Journal*, Oct. 1, 1892, p. 318. T. S. Hunt, "Coal and Iron in Alabama," *Trans. Amer. Inst. Min. Eng.*, XI., 236. J. B. Porter, "Iron Ores, Coal, etc., in Alabama, Georgia, and Tennessee," *Trans. Amer. Inst. Min. Eng.*, XV., 170. E. A. Smith, *Alabama Geol. Survey*, 1876; also *Proc. Amer. Assoc. Adv. Sci.*, XXVII., 246.

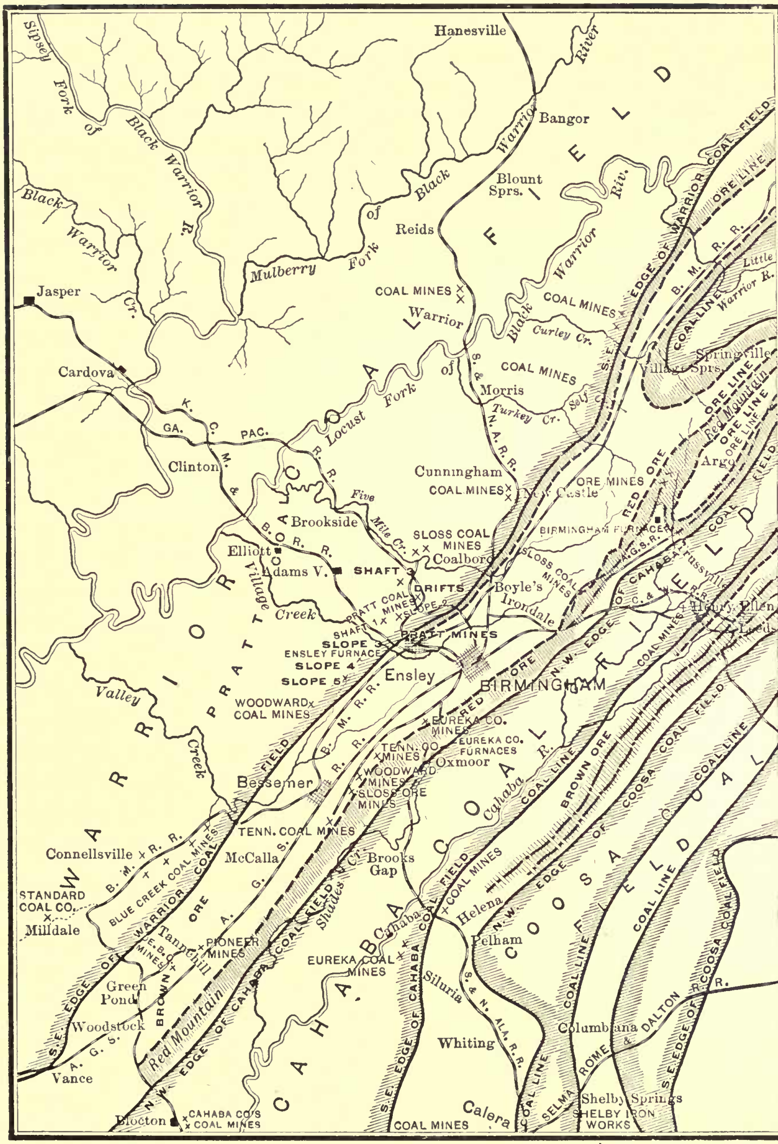

FIG. 20.—*Map of the Vicinity of Birmingham, Ala. From the Transactions of the American Institute of Mining Engineers, Vol. XIX., Plate IV.*

for an ore in the midst of limestone and limey shales, it is prevailingly siliceous, so that non-siliceous or calcareous varieties are much-sought-for mixtures. The red hematites are also exposed in Murphrees Valley and are developed in some large and productive openings. While on the west this valley has the normal and anticlinal flank, it is faulted along the east so that the Clinton measures lie against the Cambrian shales and are overthrown to a steep northwesterly dip.

2.02.07. Red hematite, supposed to be of the Clinton stage, occurs in Nova Scotia in very considerable amount, in Pictou and Antigonish counties.[1]

2.02.08. In general the Clinton ore is characterized by a high percentage of phosphorus, and is seldom, if ever, available for Bessemer pig. It is chiefly employed for ordinary foundry irons. The percentage in iron varies much. Experience at Clinton, N. Y., shows that it averages about 44% Fe in the furnace. These hematites have undoubtedly originated in some cases by the weathering of ferruginous limestones above the water level. I. C. Russell has shown that the unaltered limestones at the bottom of a mine in Atalla, Ala., 250 feet from the surface, contained but 7.75% Fe, while the outcrop afforded 57.52%. J. B. Porter has recorded the gradual increase of lime also in another Alabama mine from a trace at the outcrop to 30.55% at 135 feet. Other writers have explained these beds as due to the bringing of iron in solution into the sea of the Clinton age and to its deposition as small nodules, etc., or as ferruginous mud (Roger, Lesley, Newberry). In this way an oölitic mass has originated, as in the modern Swedish lakes (Newberry). (See Example 1.) N. S. Shaler has argued, on the basis of the Kentucky beds, that the iron has been derived from the overlying shales, and descending in solution has been precipitated by the lower-lying limestones. As the shales are themselves calcareous, this seems improbable. A. F. Foerste has shown that the ore is very often deposited either in the interstices of fragments of bryozoans or as replacing their substance. The rounded, water-worn character of the original fragments is regarded as occasioning the apparent concretionary character. Admirable work upon the origin of the ore has

[1] Sir J. W. Dawson, *Acadian Geology*, p. 591. Fletcher, *Can. Geol. Survey*, 1886.

also been done by C. H. Smyth, Jr. He finds that the small oölites, or concretions, as they occur at Clinton, N. Y., and many other localities, have a water-worn grain of quartz as a nucleus. The character of the grain is such that it has evidently been derived from granitoid or schistose rocks. The hematite comes off at times in concentric layers, when tapped gently. It may also be dissolved away so as to leave a siliceous cast or skeleton of the spherule. Dr. Smyth thus makes a strong argument that the ores in such cases are concretionary, and that they were formed in shallow waters around the nuclei of sand. But he also admits, as others quoted above have indicated, that the replacement of bryozoa and the weathering of ferruginous limestone have in many localities played their part. The iron ore is in the latter case a residual product, but now the mine waters are depositing calcium carbonate rather than removing it.[1]

2.02.09. Glenmore Estate, Greenbrier County, West Virginia. A bed of red hematite in Oriskany sandstones. Limonites are abundant in the Oriskany of Virginia, and the hematite may have been derived from some such original.[2]

2.02.10. Mansfield Ores, Tioga County, Pennsylvania. Three beds of ore are found in the strata of the Chemung stage of Tioga County, Pennsylvania. They are known as (1) the Upper or Spirifer Bed, (2) the Middle or Fish Bed, and (3) the Lower Ore Bed. No. 1 is full of shells and is about 200 feet below the Catskill red sandstones, and at Mansfield is two to three feet thick. No. 2 is oölitic, resembles the Clinton ore, and affords fish remains. It lies about 200 feet below No. 1

[1] A. F. Foerste, "Clinton Group Fossils, with Special Reference to Collections from Indiana, Tennessee, and Georgia," *Amer. Jour. Sci.*, iii., XL., 252. (Abstract; original not cited.) "Clinton Oölitic Iron Ores," *Amer. Jour. Sci.*, iii., XLI., 28. Rec. "Notes on Clinton Group Fossils, with Special Reference to Collections from Maryland, Tennessee, and Georgia," *Proc. Bost. Soc. Nat. Hist.*, XXIV., 263. J. P. Lesley, *Iron Manufacturers' Guide*, p. 611. J. S. Newberry, "Genesis of the Ores of Iron," *School of Mines Quarterly*, November, 1880, p. 13. Rec. H. D. Rogers, *Geol. of Penn.*, Vol. II., p. 127. N. S. Shaler, *Geol. of Ky.*, Vol. III., p. 163. C. H. Smyth, Jr., "On the Clinton Iron Ore," *Amer. Jour. Sci.*, June, 1892, p. 487. Rec. "Die Haematite von Clinton in den oestlichen Vereinigten Stachin," *Zeitscher. für prakt. Geologie*, 1894, 304.

[2] W. N. Page, "The Glenmore Iron Estate, Greenbrier County, West Virginia," *Trans. Amer. Inst. Min. Eng.*, XVII., 115.

and varies up to six or seven feet thick. No. 3 is 100 to 200 feet lower, and contains small quartz pebbles.[1] The ore is not rich, and but little has been mined. It is a brownish red hematite.[2]

2.02.11. Beds of red hematite are reported by Schmidt in the Lower Carboniferous of western central Missouri.[3]

2.02.12. Example 7. Crawford County, Missouri. Bodies of finely crystalline specular hematite, associated with chert, sandstone fragments, residual clays and some pyrite in conical or rudely cylindrical depressions in the Cambrian (Ozark) Series. A broad area of upheaval runs across central Missouri from the east, near St. Louis, to the southwestern part of the State. In the eastern and central portions it is chiefly composed of Cambrian and Silurian strata, but to the southwest Lower Carboniferous come in (see 2.06.06). The hematites here considered belong in the Cambrian. In the region of the mines there is a heavy sandstone stratum, earlier called the "Second Sandstone," but in the later reports described as the Roubidoux. It is underlain by a heavy limestone stratum locally called the Gasconade. The Ozark uplift was formed at the close of the Lower Carboniferous and has remained exposed to atmospheric agencies ever since. Their effects are shown in the great mantles of residual clay, which are widely distributed, and in the phenomena of the hematite deposits. Dr. A. Schmidt, of the *Missouri Survey* of 1872 (Report on Iron Ores, p. 66), wrote that these had replaced the pre-existing rock, or had been deposited in hollows in the then existing surface. Pumpelly, however, in 1885,[4] advanced a more probable hypothesis, which is strongly supported by F. L. Nason. The region is and has long been one of sink-holes caused by subterranean drainage through the Gasconade limestone and the caving in, at times, of the overlying sandstone. Cavities were thus afforded in which ferruginous waters might stand and precipitate their dissolved burden of ore. Nason shows that

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[1] A. S. McCreath, Rep. MM, *Second Penn. Survey*, p. 231.

[2] J. P. Lesley, *Geol. of Penn.*, 1888, Vol. I., p. 311. A. Sherwood, Rep. G, *Second Penn. Survey*, pp. 33, 37, 41, 42, 67. A. S. McCreath, Rep. MM, *Second Penn. Survey*, p. 251.

[3] A. Schmidt, "Iron Ores and Coal Fields," *Missouri Geol. Survey*, 1872, p. 169.

[4] *Tenth Census*, Vol. XV., p. 12.

FIG. 21.—*View in Cherry Valley Mine, showing sandstone with underlying cherty clay. The sandstone dips southeast inward toward the ores. After F. L. Nason, Report on Iron Ores of Missouri, p.* 125. *Plate VI.*

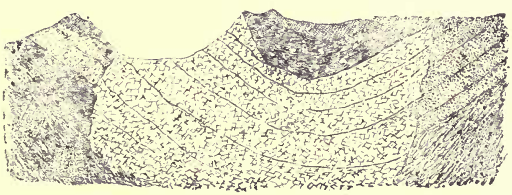

FIG. 22.—*Section of the northern end of the Cherry Valley Mine.* 1, *Clay detritus;* 2, *Sandstone;* 3, *Cherty and slaty clay;* 4, *Ores;* 5, *Blocks of sandstone. After F. L. Nason, Report on Iron Ores of Missouri, p.* 131.

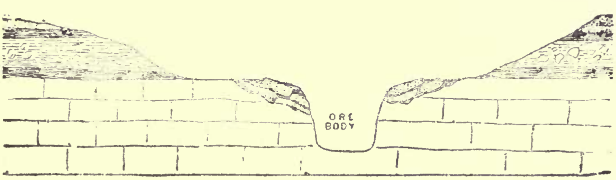

FIG. 23.—*Cross section of the Cherry Valley Mine.* 1. *Sandstone;* 2, *Clay and chert;* 3, *Sandstone dipping inward;* 4, *Magnesian limestone. After F. L. Nason, Report on the Iron Ores of Missouri, p.* 134.

several of the largest mines are along lines of old drainage valleys. The edges or walls of the pits are formed by the sandstone which dips inward, as shown in the accompanying figures. Just how much overlying rock has washed away does not appear with all desirable certainty, but the presence of large amounts of chert mixed with the ore indicates that the cap must have been to a great extent limestone with interbedded layers of this rock. As Nason states[1] the limestone that fell into the cavities has been replaced with ore. It is very probable that the former was an important precipitating agent to the latter. A fossil crinoid was found at Cherry Valley, replaced by hematite, giving evidence that even Lower Carboniferous strata had been present. The leaching of these old, overlying beds and the superficial drainage seem to indicate the method of derivation of the ore.

The most productive counties are Crawford, Phelps and Dent, but smaller deposits occur in several others. The largest mines are the Cherry Valley, with a total product of over half a million tons, the Simmons Mountain, which has yielded about half as much, and the Meramec with 375,000.

The total product of all the mines is computed by Nason at about two and one-quarter millions of tons. A sample from a stockpile made up at St. Louis furnaces from several mines, yielded Fe 56.43, P 0.065 (Nason, *l. c.* p. 157), but many are much lower in iron. In former years 100,000 to 200,000 tons were annually produced; recently, however, much less. Some anomalous features are presented by these ores in that they are specular hematite in a practically unmetamorphosed sandstone, whereas some less crystalline form would naturally be expected. Nason believes that they were originally sulphides, and that the heat generated by the decomposition of this mineral has effected the change to specular.[2]

2.02.13. Example 8. Jefferson County, New York. Large but irregular bodies of red hematite associated with crystalline

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[1] "Iron Ores of Missouri," p. 138, *Mo. Geol. Sur.*, 1892.

[2] W. M. Chauvenet, *Tenth Census*, Vol. XV., 1885, p. 403. F. L. Nason, "Report on Iron Ores," pp. 119–156, 218–231. *Missouri Geol. Survey*, 1892. Rec. R. Pumpelly "On the Origin of the Ore," *Tenth Census*, Vol. XVI., p. 12. Rec. A. Schmidt, "Iron Ores and Coal Fields," *Missouri Geol. Survey*, 1872, p. 124.

limestone, serpentine, and pyritous gneiss and overlain by Potsdam sandstone. The crystalline limestone is certainly pre-Cambrian, and would be called Algonkian in the later use of this term, and later Laurentian in the earlier nomenclature.[1] In a recently issued report to James Hall, State Geologist, C. H. Smyth, Jr., has named the limestone series the Oswegatchie. The ore bodies occur along a northeast belt, from Philadelphia, Jefferson County, to Gouverneur, St. Lawrence County. They range up to 30 or 40 feet in thickness and consist of red, earthy hematite in porous or cellular masses, with some specular. Many interesting minerals, including siderite, millerite, chalcodite, quartz, etc., are found in cavities. The alignment of the mines along a marked belt has given some ground for thinking them interbedded deposits, and their association with Potsdam sandstone has created the impression that they are of Cambrian (or, as it was then called, Lower Silurian) age.[2] J. P. Kimball has stated that they are replacements of Calciferous limestone.[3] E. Emmons in the "Report on the Second District" of the early New York Survey, regarded the associated crystalline limestone as an intruded igneous mass, and the same method of origin was applied to the ores and accompanying so-called serpentine. The latter was called rensselaerite by Emmons. Brooks gave the following section, taken at the Caledonia Mine: 1. Potsdam sandstone, 40 feet. 2. Hematites, 40 feet. 3. Soft, schistose, slaty, green, magnesian rock with pyrite and graphite, 90 feet plus. 4. Granular, crystalline limestone, with phlogopite and graphite. 5. Sandstone (like 1), 15 feet. 6. Crystalline limestone with beds and veins of granite. C. H. Smyth, Jr., has recorded the stratigraphical observations, cited earlier, and has formulated the following explanation of origin. The lineal arrangement of the ore-bodies is referred to their association with a great stratum of pyritous gneiss belonging to the Oswegatchie Series. This weathers deeply and becomes light and porous (constitut-

[1] C. H. Smyth, Jr., "Geological Reconnaissance in the Vicinity of Gouverneur, N. Y.," *Trans. N. Y. Acad. Sci.*, XII., 97, 1893. "Report on Jefferson and St. Lawrence Counties," *Rep. of N. Y. State Geol.*, 1893, 493. Also 1895, 481.

[2] See T. B. Brooks, *Amer. Jour. Sci.*, iii., IV., 22.

[3] J. P. Kimball, *Amer. Geologist*, December, 1891, p. 368.

ing thus a "fahlband"). It contains considerable disseminated magnetite. The so-called serpentine or rensselaerite only occurs in association with ore, and itself varies in character, so that one is justified in regarding it as an altered form of several different kinds of rocks. Smyth infers that the decay of the ferruginous minerals, but especially of pyrite in the pyritous gneiss, has furnished the iron-bearing solutions, which following down the dip have replaced the crystalline limestone where the presence of intruded granites or the flattening of the dip checked the circulations. The action of the acidulated ferruginous waters has altered the granites and gneisses in the limestone series to the so-called serpentine.[1] These views are fortified by microscopic study of the rocks, and though advanced only as an hypothesis are worthy of great confidence.

The mines have afforded in the past a moderately rich (50 to 55% Fe), non-Bessemer ore. The best known and largest producers are the Old Sterling, the Caledonia and Kearney properties, but they are not now operated and are not likely to be reopened in the immediate future.

2.02.14. Example 9. Lake Superior Hematites. Bodies of hematite, both red and specular, soft and hard, anhydrous and somewhat hydrated, associated with jaspers and cherts, and deposited by the replacement of cherty iron carbonate with iron oxide, in troughs formed by some relatively impervious rock. The impervious rock is usually a decidedly altered igneous dike, now hornblendic and dioritic, but one that has been originally diabase. The trough may be formed by a folded dike; by two or more intersecting dikes; by the intersection of a dike and a compact, sedimentary stratum; or less commonly by a folded bed of slate. All of these varieties are known in one place and another. Increasing study has shown that the parallelism in the structure of the several districts, in the associates of the ore, and in the geological horizons at which the ore

[1] T. B. Brooks, "On Certain Lower Silurian Rocks in St. Lawrence Co., New York," *Amer. Jour. Sci.*, iii., IV., p. 22. Rec. G. S. Colby, *Jour U. S. Assoc. Charcoal Iron Workers*, XI., p. 263. E. Emmons, *N. Y. Geol. Survey, Second District*, p. 93. T. S. Hunt, "Mineralogy of the Laurentian Limestones of North America," *21st Ann. Rep. Regents N. Y. State Univ.*, 1871, p. 88. J. C. Smock, *Bull. N. Y. State Mus.*, No. 7, 1889, p. 44. Rec. C. H. Smyth, Jr., in *Report of N. Y. State Geologist* for 1894, and *Journal of Geology*, II., 678, 1894. Rec.

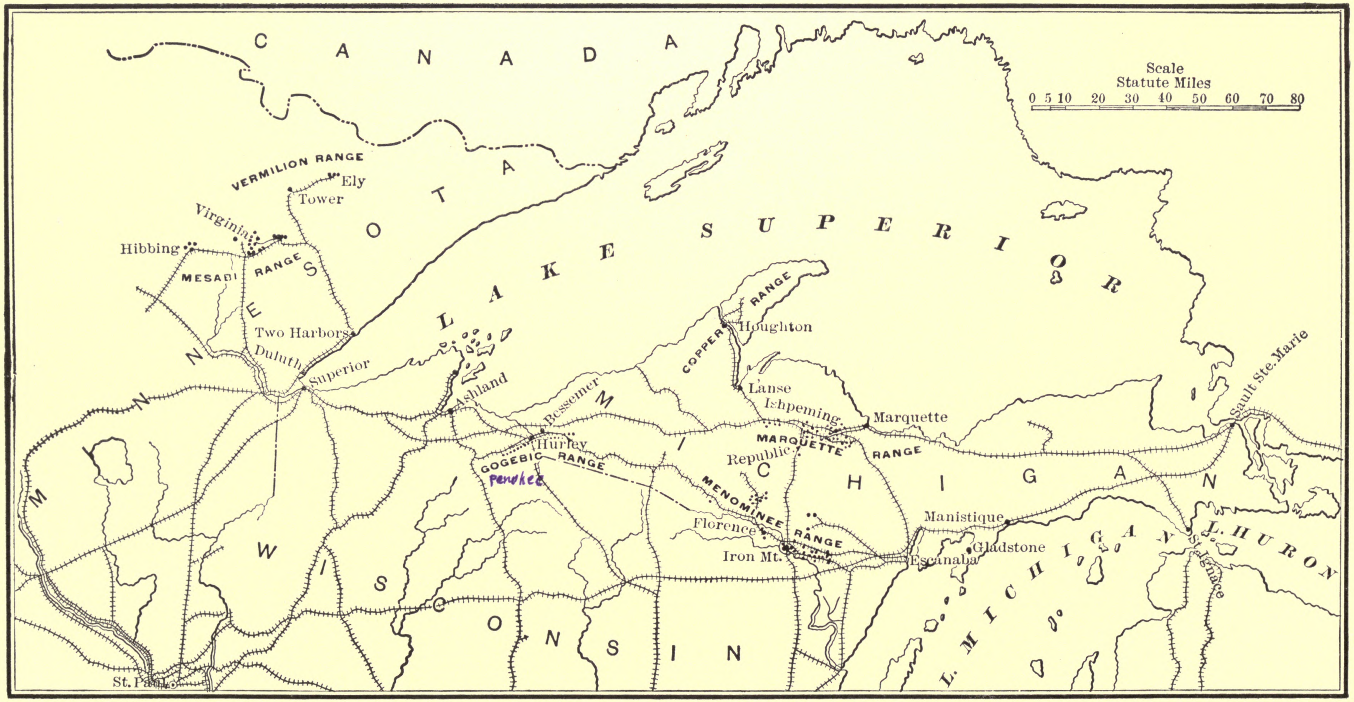

FIG. 24.—*Map of the Lake Superior region, showing the location of the iron-ore districts. Reduced from the Serenteenth Ann. Rep. Dir. U. S. Geol. Survey, Part III., Plate I.*

occurs, is pronounced. Magnetite is at times present and limonites have been mined to a limited degree. There are five principal ore-producing belts or districts, which are also called in instances "ranges," as they follow ranges of low hills. They are, in the order of their chronological exploitation, the Marquette, just south of Lake Superior, in Michigan; the Menominee, on the southern border of the Upper Peninsula and partly in Wisconsin; the Gogebic or Penokee-Gogebic, on the northwestern border between Michigan and Wisconsin; the Vermilion Lake, in Minnesota, northwest of Lake Superior; and the Mesabi (Mesaba), in the same general region as the last.

2.02.15. The geology of these districts has been a subject of much controversy, not alone in the relations of the separate areas, but in the subdivisions of a single one. The ever-present difficulty of classifying and correlating metamorphic rocks has here been very great. Moreover, there are other separate districts, of related geological structure, which ought also to be brought into harmony, and only at a very recent date has this been even partially attained.

2.02.16. The ores and their inclosing rocks have usually been called Huronian, as this is the name formerly applied to the schistose and metamorphic rocks overlying what was conceived to be the basal, gneissic Laurentian. The geologists of the United States Geological Survey have essentially modified this nomenclature, and have restricted Archean to the earliest crystalline or metamorphosed, igneous rocks that precede the first sediments. Algonkian is then employed for the first and subsequent sedimentary rocks, and for the igneous intrusions that followed the first sediments up to the opening of the fossiliferous Cambrian. The difficulty of correctly correlating these strata with the original Huronian prompted the step, but Huronian is still in very general use and Algonkian and the new meaning of Archean have received but moderate support outside of the Survey. In later years, however, the exceptionally difficult geological problems in the iron ore districts on the south side of Lake Superior have been especially solved by the geologists of the U. S. Survey, Irving, Van Hise, Bayley, H. L. Smyth, and others, and it is upon their work that the following descriptions for the three districts in question are based. The references in the footnote following will place any reader in touch with the earlier literature, reviews of which will be found in the citations from Van Hise, A. Winchell and Wadsworth.[1] The north shore districts are also closely related, and as a geological problem account must be taken as well of the original Huronian area, north of Lake Huron, and of the Kaministiquia and Rainy Lake regions north of Lake Superior, although they contain no iron ores.[2]

2.02.17. The oldest or pre-sedimentary rocks (Archean) consist of massive granites, gneissoid granites, syenites, peridotites, greenstone schists, and other schists that are sheared and metamorphosed igneous rocks and tuffs of various kinds. They were called the "Fundamental Complex" by Irving, and the name in the form of "Basement Complex" has been retained in the later work. Further investigation may clear up its stratigraphical relations to a certain extent. The Archean is succeeded by the formations of the Algonkian, which involve or succeed undoubted sediments. In the south shore iron ranges the Algonkian has been quite uniformly found to be divisible into two series, which are separated by an unconformity and a considerable period of erosion. The lower is called Lower Huronian, Lower Marquette, Keewatin, Lower Vermilion, and Menominee proper in the different exposures, and probably the great cherty limestone of the Penokee-Gogebic series is its local equivalent. In the Marquette district Wadsworth has recently divided it still further into the Republic and Mesnard formations. The upper part follows an unconformity and is called in the different regions Upper Huronian, Animikie, Upper Vermilion, Upper Marquette, Western Menominee, and

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[1] C. R. Van Hise, "An Attempt to Harmonize Some Apparently Conflicting Views on Lake Superior Stratigraphy, *Amer. Jour. Sci.*, ii., XLI., 117; *Tenth Annual Report Director U. S. Geol. Survey.* Van Hise, Bayley and Smyth, *Monograph XXVIII. of U. S. Geological Survey* on the Geology of the Marquette Iron District. A. Winchell, "A Last Word with the Huronian," *Bull. Geol. Soc. Amer.*, II., 85. M. E. Wadsworth, "Notes on the Geology of the Iron and Copper Districts," 1880.

[2] The following papers deal with the ores in general: D. N. Bacon, "The Development of Lake Superior Iron Ores," *Trans. Amer. Inst. Min. Eng.*, XXVII., 341; John Birkinbine, "The Resources of the Lake Superior Region," *Idem*, XVI., 168, 1887; "The Iron Ore Supply," *Idem*, XXVII., 519: H. V. Winchell, "Historical Sketch of the Discovery of Mineral Deposits in the Lake Superior Basin," *Proc. Lake Superiar Min. Inst.*, II., contains a bibliography. See also *Amer. Geologist*, XIII., 164.

Penokee-Gogebic proper. For the Marquette region this has also been further divided by Wadsworth into two, the Holyoke and the Negaunee formations. It is much less metamorphosed than the lower member, and in the Marquette district contains some ore. In the Menominee region of Wisconsin it affords the deposits there wrought and carries the ore in the Gogebic range. Higher in the section, after another unconformity follows the Keweenawan (Keweenian) or Nipigon. This closes the Algonkian. Still above is the Cambrian (Eastern, Western or Potsdam) sandstone.

2.02.18. Example 9*a*. Marquette District. The Marquette

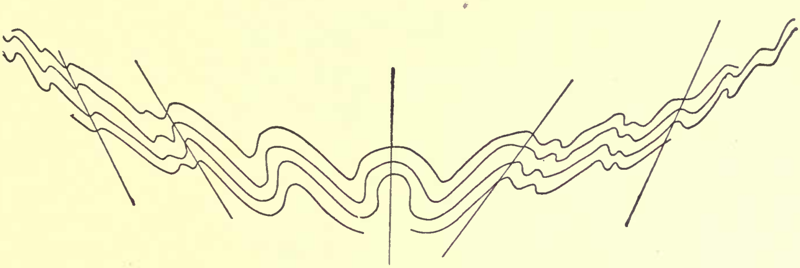

FIG. 25.—*Generalized section across the Marquette Iron Range, to illustrate the type of folds. After C. R. Van Hise, Fifteenth Ann. Rep. Dir. U. S. Geological Survey, p.* 485.

district was earliest known and has been most thoroughly studied; but owing to the confused geological structure, there has been, as already remarked, much discordance of interpretation. The remarkably careful and systematic work of Van Hise and Bayley[1] has, however, cleared up the greatest difficulties. In the Marquette district the Algonkian (or Huronian) rocks form a synclinorium or synclinal trough, resting in the older Archean crystallines and extending from Marquette on Lake Superior, westward in a nearly east and west line. While the axis of the main syncline runs east and west, there are many minor folds parallel with this, which are overturned outwardly from the

[1] C. R. Van Hise and W. S. Bayley, "Preliminary Report on the Marquette Iron-bearing District of Michigan," with a Chapter on the Republic Trough, by H. L. Smyth, *Fifteenth Annual Report Director U. S. Geol. Survey*, 485–650. This report should be in the hands of every one interested in the region. See also Monograph XXVIII., which with its atlas is the fullest exposition of the subject.

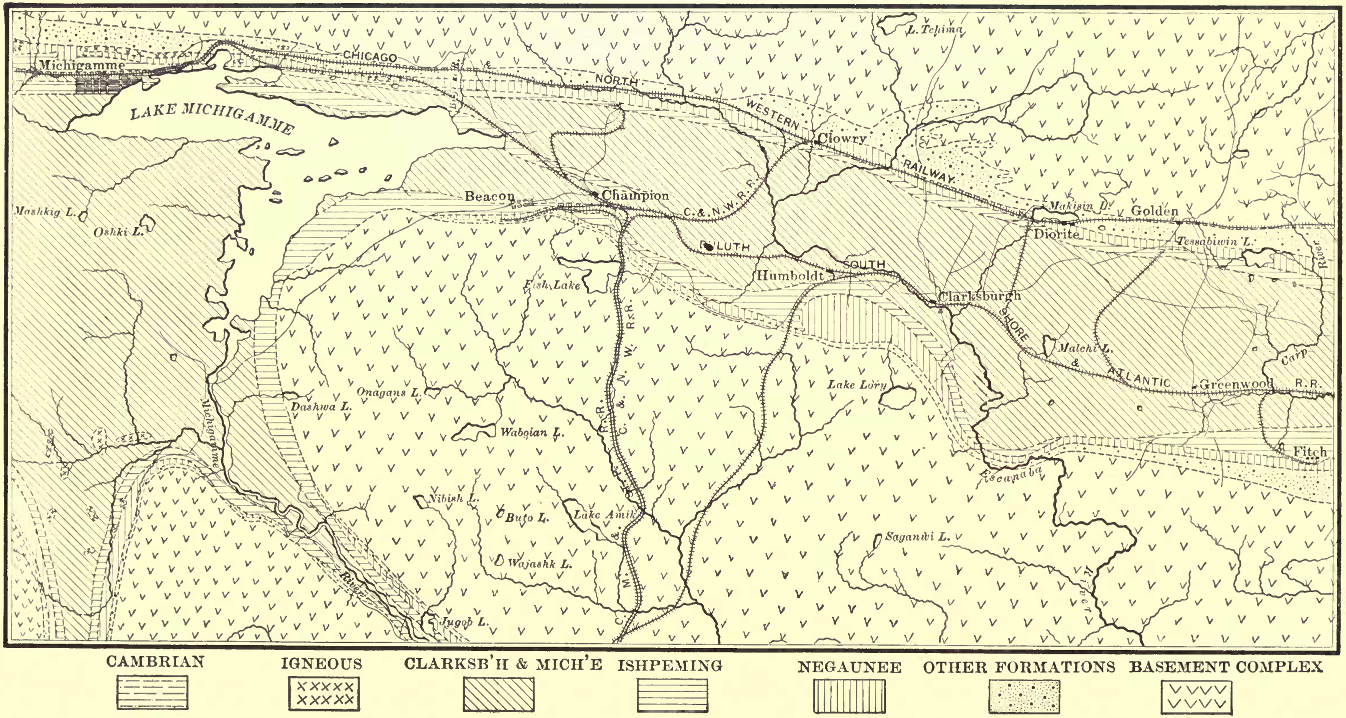

FIG. 26.—*Geological map of the western portion of the Marquette iron range. Scale 2.7 miles to the inch. Reduced and condensed from a colored map by* **Van Hise and Bayley**, *Fifteenth Ann. Rep. Dir. U. S. Geol. Survey. (Plate XIII.)*

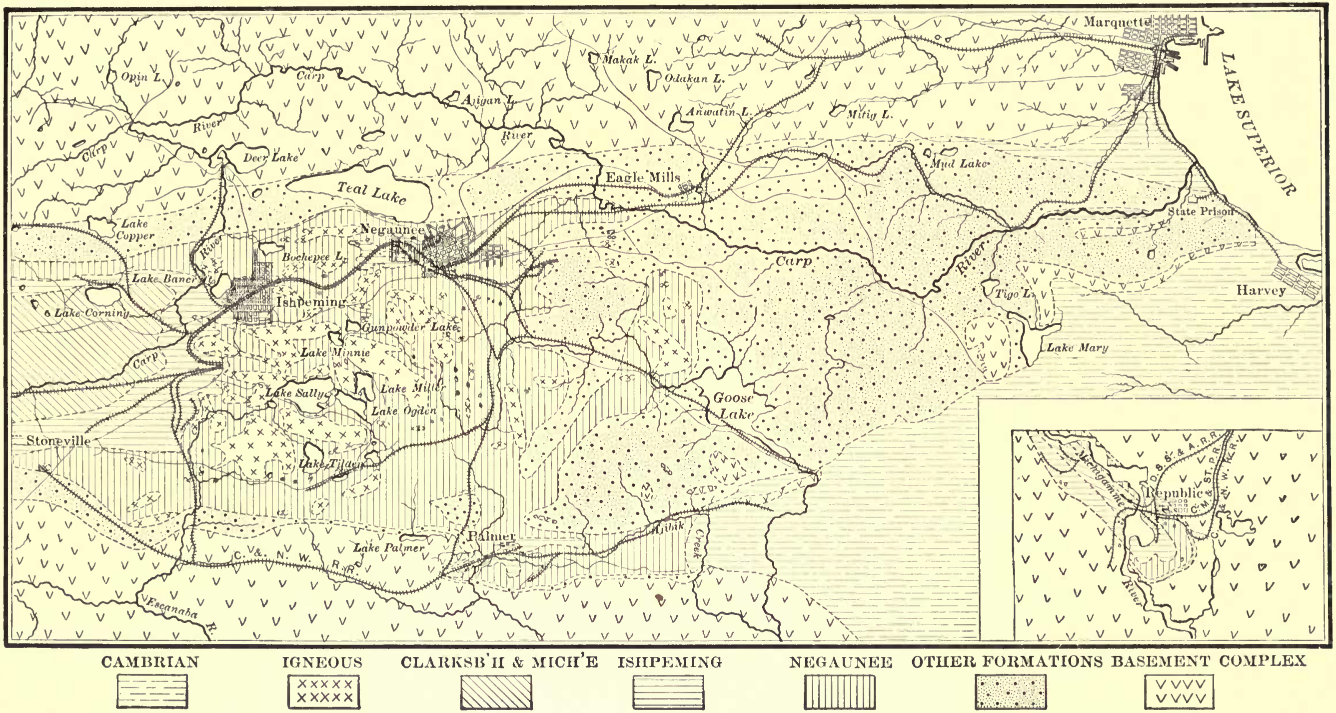

FIG. 27.—*Geological map of the eastern portion of the Marquette iron range.* (*See Fig.* 26.)

center as in the accompanying figure, after Van Hise. Some marked folding has also occurred at right angles to the east and west axis. Faulting is almost entirely lacking, and the topographic relief is quite entirely due to the relative resistances presented by the several rocks to erosion. All are more or less metamorphosed and have evidently suffered severely from pressure and shearing stresses. The Lower Marquette is chiefly developed at the eastern end and around the rims of the synclinorium, as it was from this end that the shore-line seems to have advanced upon the ancient land. It begins with the Mesnard quartzite, 110 to 670 feet thick. Above come in order the Kona dolomite, 425 to 1,375 feet; the Wewe slate, 550 to 1,050 feet; the Ajibik quartzite, 700 to 900 feet; the Siamo slate, 200 to 625 feet; and the Negaunee iron formation, 1,000 to 1,500 feet. In Figs. 26 and 27 all these except the Negaunee are grouped under one sign. The total thickness varies from 2,975 to 6,120. The Upper Marquette includes from below upward, the Ishpeming formation, including the Goodrich quartzite and the Bijiki schist; the Michigamme formation of slates and mica schist; and the Clarksburg formation of more or less altered volcanic rocks. Upon Figs. 26 and 27 the Ishpeming has one sign and the Michigamme and Clarksburg another. In the mining district the total thickness of the Upper Marquette is less than 5,000 feet. Except as regards the Goodrich quartzite of the Ishpeming and some small limonite deposits in the Michigamme formation the divisions have no economic importance. In the Lower Marquette the economic interest centers in the Negaunee formation, which is much the most important of all. Later than all these just cited are intrusions of basic dikes that have been prime factors in the ore deposition.

The Negaunee formation in its completest section consists from below upward of sideritic slate and grünerite-magnetite[1] slate; ferruginous slate; ferruginous chert; and at the top of jasperite or jasper-rock; but not all of these are necessarily present in any one section. The ores are either "soft ores" or "hard ores." The former are blue, red or brown, earthy and somewhat hydrated varieties of hematite, and resemble ordi-

[1] Grünerite is a variety of amphibole or hornblende. It is an iron amphibole.

FIG. 29.—*Open cut in the Republic mine, Marquette range, showing a horse of jasper. From a photograph by H. A. Wheeler.*

nary dirt of these colors, with small lumps of ore scattered throughout. They strongly simulate, limonite but are not so hydrated. The soft ores are now the main object of mining, but they were earlier looked upon with disfavor and only the hard ores were sought. The hard ores are mas-

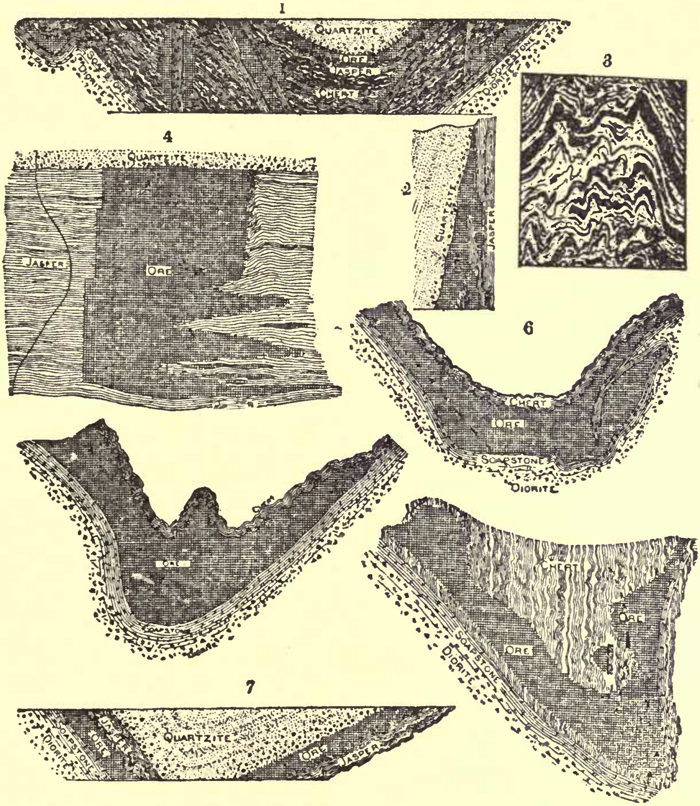

FIG. 28.—*Cross-sections to illustrate the occurrence and associations of iron ore in the Marquette district, Michigan. After C. R. Van Hise, Amer. Jour. Sci., February,* 1892; *Engineering and Mining Journal, July* 9, 1892.

sive or micaceous specular hematite, rarely magnetite, and are blasted out in lumps. Van Hise makes three classes of deposits: (1) Those at the bottom of the iron-bearing formation; (2) those within it; and (3) those at its top, including also some that run up into the Goodrich quartzite, the lowest stratum of the overlying Ishpeming formation. The hard ores belong to the third class. All these classes rest upon an impervious rock of some sort, and lie in a pitching trough formed by it. The trough may be a fold in the Siamo slate, and often is for ores of the first class. It may be a single folded dike, which is an altered diabase, now called soapstone or paint-rock by the miners. These are shown in the cuts of Fig. 28. The trough may result from the intersection of two or more dikes, as is more fully illustrated under the Vermilion district. In all cases it seems evident that after the close of the time-period represented by the Upper Marquette, and after the intrusion of the basic dikes, the overlying ferruginous rocks were subjected to extensive leaching of their iron, by descending atmospheric waters, charged with carbonic acid. When these came to rest in the troughs, or met other descending currents, which were charged with oxygen, and which had percolated downward along the dikes, the dissolved proto-salt of iron was oxidized and precipitated as ferric oxide, replacing the cherts or other siliceous rock that had previously filled the trough. The silica is thought to have been in large part removed by alkaline solutions emanating from the diabase. These changes were facilitated by the fact that the brittle cherts had been much shattered during the folding, and this condition contributed to the formation of the soft ores in their fragmental condition. The hard ores appear to owe their condition to the dynamic metamorphism that has been particularly strong along the contact line of the Upper and Lower Marquette. The micaceous ores certainly owe their structure to shearing. The magnetites are supposed to be former hematites, that have suffered partial reduction by infiltrating solutions charged with organic matter. They are best developed in the Republic tongue of the main trough.

2.02.21. The origin of these ore bodies has been a subject of much controversy. A review of the various hypotheses up to 1880 is given in Wadsworth's monograph[1] and a still later one is given in the monograph of Van Hise, Bayley and Smyth.[2]

[1] M. E. Wadsworth, "Notes on the Iron and Copper Districts of Lake Superior," *Bull. Mus. Comp. Zöol.*, Vol. VII., No. 1, July, 1880.

[2] Van Hise, Bayley and Smyth, "The Marquette Iron-bearing District of Michigan," *Monograph XXVIII. U. S. Geological Survey*, pp. 3–148, 1897.

The early survey of Foster and Whitney (1851) attributed an eruptive origin to them and the same difficult thesis has been supported by Wadsworth (1880). Others formerly regarded them as old limonite beds in a sedimentary series that was subsequently metamorphosed. Credner (1869), Brooks (1873), and others saw reason for it; but there is little doubt that the origin outlined above is correct. While the present text follows the recent work of the U. S. Geological Survey, because it is more detailed, comprehensive and really accurate than any other available, and because space is necessarily limited, yet the reader who would thoroughly acquaint himself with the questions under discussion should consult the citations given below, especially those from Brooks, Irving, Wadsworth and Rominger.

2.02.22. It was in the forties that the importance and extent of the ore bodies were first vaguely suspected. The trouble that they made with the compasses of the early land surveyors indicated their existence. Important mining began in 1854. Somewhat over 100,000 tons were produced in 1860, over 800,000 in 1870, nearly 1,500,000 in 1880. In 1877 the Menominee region was opened, and in 1885 the Penokee-Gogebic and Vermilion districts began to ship. The total shipments from the Lake Superior region in 1890 were 8,982,531 tons. The total production through 1897 of the Marquette district was 49,253,222 tons. A quite complete citation of the literature is to be found in Wadsworth's monograph, already referred to; in Irving's "Copper-bearing Rocks of Lake Superior," *Monograph V., U. S. Geol. Survey;* and in Van Hise, Bayley and Smyth, *Monograph XXVIII.* See also under Examples 9*b*, 9*c*, and 9*d*. Only the most important or most recent papers are mentioned here.[1]

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[1] J. Birkinbine, "Resources of the Lake Superior District," *M. E.*, July, 1887. T. B. Brooks, *Geol. Survey of Michigan*, Vol. I., 1873; *Geol. Survey of Wisconsin*, Vol. III., p. 450. H. Credner, "Die vorsilurischen Gebilde der oberen Halbinsel von Michigan in Nord Amerika," *Zeitsch. d. d. Geol. Ges.*, 1869, XXI., 516; also *Berg- und Hütt. Zeit.*, 1871, p. 369. Foster and Whitney, *Geol. of the Lake Superior District*, Vol. I., "Iron Lands," 1851. R. D. Irving, "On the Origin of the Ferruginous Schists and Iron Ores of the Lake Superior Region," *Amer. Jour. Sci.*, iii., XXXII., 263; "Preliminary Paper on an Investigation of the Archean of the Northwestern States," *Fifth Ann. Rep. Director U. S. Geol. Survey,* p. 131;

2.02.23. Example 9*b*. Menominee District. The Menominee River, which gives the district its name, forms the southeasterly boundary between the Upper Peninsula of Michigan and Wisconsin. The mines are situated about forty miles south of the Marquette group, and the same distance west of Lake Michigan. The larger number are in Michigan, but the productive belt extends also into Wisconsin. They lie along the south side of an east and west range of hills, which rises from 200 to 300 feet above the surrounding swampy land. Beginning with the base and included in the lower Menominee according to H. L. Smyth, the geological section is as follows, all of

Seventh Ann. Rep., p. 431; also Administrative Reports in subsequent volumes. J. E. Jopling, "The Marquette Range: Its Discovery, Development, and Resources," *Trans. Amer. Inst. Min. Eng.*, XXVII., 541. J. P. Kimball, "The Iron Ore of the Marquette District," *Amer. Jour. of Sci.*, ii., XXXIX., 290. H. S. Munroe, *School of Mines Quarterly*, II., p. 43. E. Reyer, "Geologie der Amerikanischen Eisenerzlagerstätten (insbesonden Michigan)." *Oest. Zeitsch. f. Berg- u. Hütt.*, Vol. XXXV., pp. 120, 131, 1887 C. Rominger, *Geol. Survey of Michigan*, Vol. IV., 1884. "Report on the Iron and Copper Regions, 1881–84, *Idem*, Vol. V., 1895. C. R. Van Hise, "An Attempt to Harmonize Some Apparently Conflicting Views of Lake Superior Stratigraphy," *Amer. Jour. Sci.*, iii., XLI., p. 117, February, 1891; *Tenth Ann. Rep. Director U. S. Geol. Survey*; ' The Iron Ores of the Marquette District of Michigan," *Amer. Jour. Sci.*, February, 1892, p. 115. *15th Annual Report Director U. S. Geol. Survey*, pp. 485–657. Van Hise, Bayley and Smyth. "The Marquette Iron-bearing District of Michigan," *Mono. XXVIII. and Atlas U. S. Geol. Survey.* M. E. Wadsworth, "Notes on the Iron and Copper Districts of Lake Superior," *Bull. Mus. Comp. Zöol.*, VII., 1, 1880; "On the Origin of the Iron Ores of the Marquette District, Lake Superior," *Proc. Bost. Soc. Nat. Hist.*, Vol. XX., p. 470; *Engineering and Mining Journal*, Oct. 29, 1881, p. 286; *Ann. Rep. Mich. State Geologist*, 1891–92. "The Geology of the Lake Superior Region," in a pamphlet issued by the Duluth, South Shore & Atlantic R. R., 1892. Dr. Wadsworth announces a new subdivision of Formations in this and in *Amer. Jour. Sci.*, January, 1893, p. 73. H. Wedding, *Zeitsch. f. Berg-, Hütt-, und Salinenwesen in Preus. Staat.*, XXIV., p. 339. C. E. Wright and C. D. Lawton, *Reps. of the Commissioners of Mineral Statistics of Michigan*, 1880, and annually to date. G. H. Williams, "Greenstone Schist Areas of the Menominee and Marquette Regions of Michigan," introduction by R. D. Irving, *Bull. 62, U. S. Geol. Survey.* H. V. Winchell, "Historical Sketch of the Discovery of Mineral Deposits in the Lake Superior Region, *Proc. Lake Superior Mining Inst.*, II. 3.

A careful compilation of analyses of ores from all the larger mines of the four older ranges is given by Geo. W. Goetz, *Trans. Amer. Inst. Min. Eng.*, XIX., 59, 1890.

which rests on the Archean crystallines: 1. A basal quartzite, rarely conglomeratic, 1,000 feet thick as a maximum, and at least 700 feet over wide areas. 2. A crystalline limestone, 700 to 1,000 feet thick, and possibly reaching 1,500 to 2,000 on the Fence River. This was earlier called by Rominger the Norway limestone. 3. Red, black and green slates that are not known to exceed 200 to 300 feet. The slates here and there contain the iron formation that affords the rich ores of Iron Mountain and Norway. In the southern portion the horizon of the slates is in part occupied by altered eruptives, which may thicken up to 2,000 feet on the Fence River. 4. The Michigamme jasper, a greatly altered ferruginous rock, usually carrying apparently

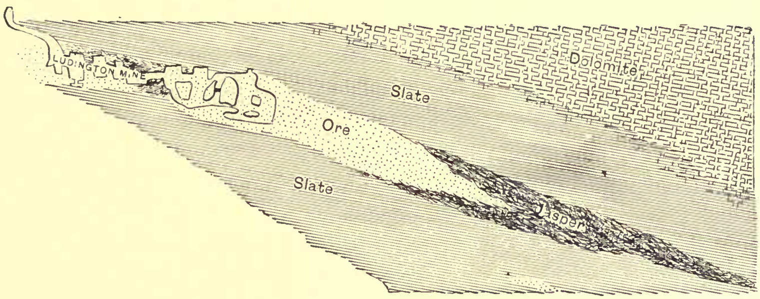

FIG. 30.—*Plan of the Ludington ore body, Menominee district, Michigan. After P. Larsson, Trans. Amer. Inst. Min. Eng., XVI.*, 119.

fragmental quartz grains. The rock is best developed at Michigamme Mountain, S. 4, T. 43 N., R. 31 W. It is variable but appears to have originally been, in part at least, a clastic sediment. Infiltrating iron salts and the formation of cherty silica have brought about the alteration of the rock.

Iron ores are met at three horizons in this section. The lowest is in the quartzite. No. 1, not far from its junction with the limestone. It has yielded but one workable deposit The great majority of the ore bodies is in the slates, No. 3. They occur as local concentrations in a ferruginous rock composed of banded jasper and iron ore. The ferruginous rock is met at various horizons in the slates. The third ore-bearing formation is the Michigamme jasper, but the ore bodies are small.[1]

[1] The above is condensed from H. L. Smyth, "Relations of the Lower Menominee and Lower Marquette Series in Michigan (Preliminary)," *Amer. Jour Sci.*, March, 1894, 216. Further correlative notes are given in

The Michigamme jasper is correlated by Smyth with the Negaunee formation of the Marquette district, and this brings the principal ore bearing stratum of the Menominee range below the ore-bearing formations in the Marquette.

In the black slates of the Upper or Western Menominee there are still other ore bodies, such as those of the Commonwealth and Florence mines, and at the Quinnesec mines. A goodly mass of soft blue ore was obtained in the Potsdam sandstone, which had evidently been eroded from the older ores during the deposition of the Potsdam. Great geologic interest has been felt in the metamorphism of the eruptive rocks in the Menominee district, and although remotely related to the geology of the ores, attention should be directed to the valuable paper of G. H. Williams cited below.

Since 1890 W. S. Gresley of Erie, Pa., has been collecting from the ore piles in that city most extraordinary slabs of ore, chiefly from the Chapin mine, of the Menominee range, that contain impressions bearing the closest resemblance to algæ, or other low forms of plant life. They may be the long-sought fossils of Huronian times.[1]

The Menominee ores are generally soft, blue-earthy hematites, which give a red powder and consist of finely divided particles of specular. Brown hematites are very limited. A lenticular shape is more pronounced than in the Marquette district and the concentration of the ore has not been shown to be connected with intruded dikes as elsewhere, although the chemical reactions involved are doubtless the same. The general strike is about N. 75° W., and the dip 70° to 80° N. They also pitch diagonally down on the dip. (Cf. New Jersey Magnetites, Example 13*d*.) There has been produced including 1897 a grand total of 24,931,441 tons since mining began.[2]

C. R. Van Hise's paper on the Marquette range, in *15th Ann. Rep. Dir. U. S. Geol. Survey*, p. 647. Smyth has also given an excellent short sketch at the close of his paper on "Magnetic Observations in Geological Mapping," *Trans. Amer. Inst. Min. Eng.*, XXVI., 640–709, 1896.

[1] W. S. Gresley, "Traces of Organic Remains from the Huronian (?) Series at Iron Mountain, Mich.," etc., *Trans. Amer. Inst. Min. Eng.*, XXVI., 527. See also *Science*, April 24, 1896, 622; *Amer. Geologist*, August, 1896, 123.

[2] T. B. Brooks, *Geol. Survey of Wisconsin*, Vol. III., 430–663. D. H. Brown, "Distribution of Phosphorus in the Ludington Mine," *M. E.*, XVI.,

Some fifteen miles north of the Menominee range, and between it and Negaunee in the Marquette range, is a narrow, closely folded syncline, called the Felch Mountain district. It contains a series of strata closely parallel to the Lower Menominee, and apparently an outlier cut off by erosion. H. L. Smyth has also traced out by means of magnetic observations a northwesterly extension of the Menominee range, in a drift-covered district, so as almost to connect with the Marquette area west of the Republic trough. From 20 to 30 miles of concealed rocks have thus been shown that may prove productive, although the cheap ores of the Mesabi range have made their immediate future uncertain.[1]

2.02.24. Example 9*c*. Penokee-Gogebic District. This lies in an east and west range of hills, which crosses the westerly boundary of the Upper Peninsula and Wisconsin, and is from ten to twenty miles south of Lake Superior, and eighty to one hundred miles west of the Marquette mines. The rocks are less metamorphosed than in the previous two districts. The strata run east and west with a northerly dip of 60° to 80° (65° in the larger mines), and with no subordinate folds. The geological series is now generally called the Penokee, following the usage of Irving and Van Hise, to whose labors we owe our accurate knowledge of the district and from whose papers the following is taken. It rests upon the southern complex of Archean crystallines and forms a narrow belt, over 70 miles long, and from half a mile to three miles broad. The geological structure and relations are much simpler than in the other districts, and have afforded the key for the solution of problems elsewhere. The strata are divided into an upper and a lower series, of which the former is much the larger in amount, but the latter is the

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525. J. Fulton, "Mode of Deposition of the Iron Ores of the Menominee Range, Michigan," *Trans. Amer. Inst. Min. Eng.*, XVI., 525. N. P. Hulst, "The Geology of that Portion of the Menominee Range East of the Menominee River, *Proc. Lake Superior Mining Institute*, March, 1893, p. 19. Per Larsson, "The Chapin Mine," *Trans. Amer. Inst. Min. Eng.*, XVI., 119. C. E. Wright, *Geol. Survey Wisconsin*, III. ,666–734. G. H. Williams, "Greenstone Schist Areas of the Menominee and Marquette Regions of Michigan, with an Introduction by R. D. Irving," *Bull. 62, U. S. Geol. Survey.*

[1] H. L. Smyth, "Magnetic Observations in Geological Mapping." *Trans. Amer. Inst. Min. Eng.*, XXVI., 640, 189 6.

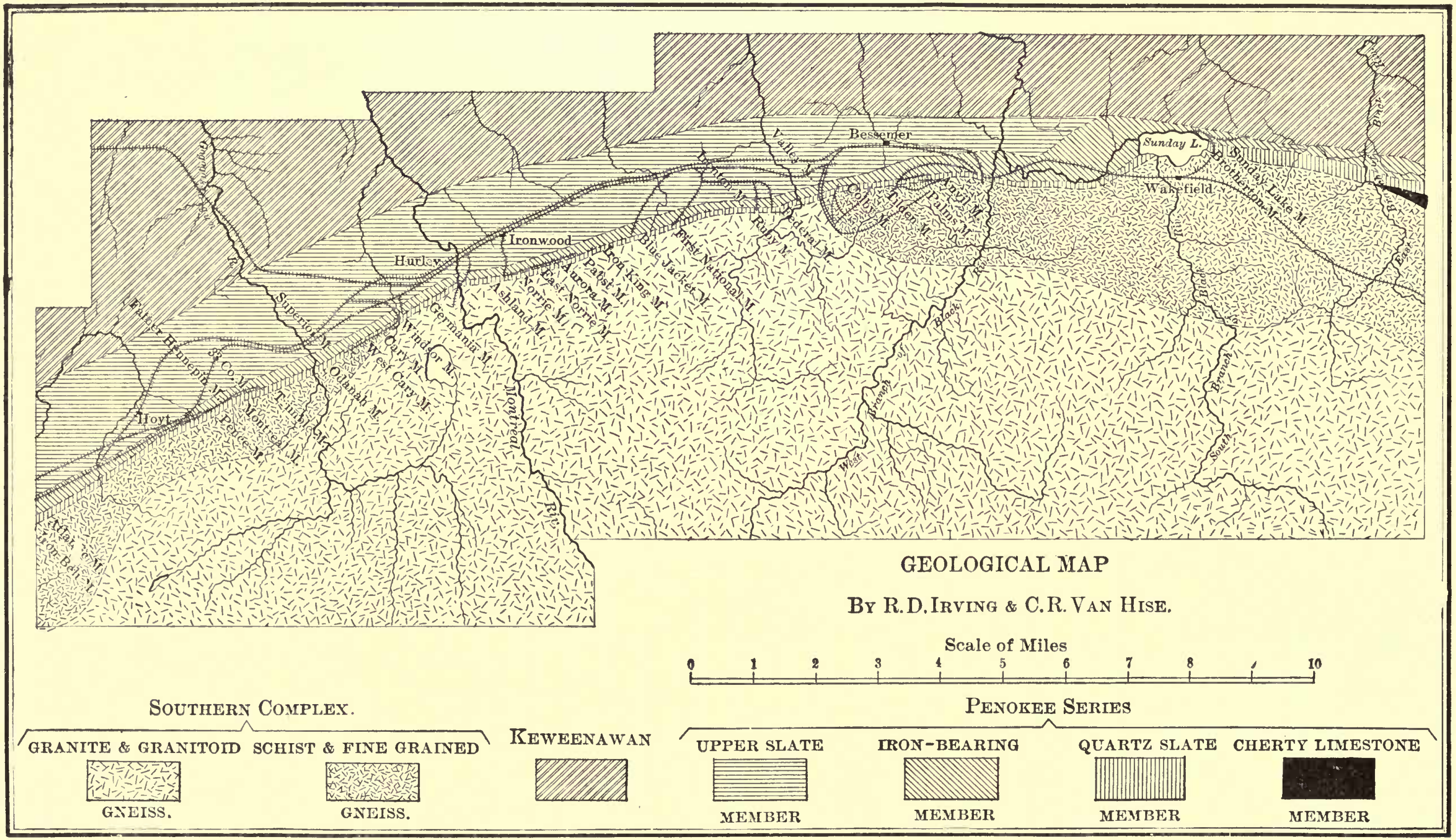

FIG. 31.—*Geological map of the Penokee-Gogebic iron range. Reduced from a colored map by Irving and Van Hise, Monograph XIX., Plate II., U. S. Geological Survey.*

one that is of economic importance. At the base is a cherty dolomitic limestone 300 feet and less thick. It outcrops chiefly at the extreme west and the extreme east, and has no immediate connection with the ores. Over this lies a quartz-slate or quartzite that is extremely persistent throughout the entire area. It is 500 feet and less thick, and forms the usual footwall of the large ore bodies. Above the quartz slate is the iron-bearing member, 800 to 1,000 feet thick. It is not clastic, but consists of cherty carbonates of iron, with some magnesium and calcium, or of derivatives from these carbonates and cherts. Three types of rock have been established: (1) The slaty and often cherty iron carbonate, more or less analogous to siliceous iron carbonates in the Carboniferous and other later systems. It is regarded as of organic origin. (2) Ferruginous slates and cherts. The iron of the siderite in type one has been more or less moved and redeposited as oxides, and rearrangement and recrystallization of the silica have also transpired. (3) Actinolite and magnetite schists have resulted by the change of much of the iron carbonate to magnetite and by the combination of the remainder with lime, magnesia and silica to yield actinolite. This last-named type is especially abundant west of Tyler's Fork, *i.e.*, in the western third and beyond the productive mining region. The upper Penokee consists of slate, with quartzites, graywackes and schists, 12,800 feet thick and less. It has no connection with the ores, and is succeeded by the Keweenawan traps and sandstones on the north. All the Penokee strata are cut by dikes and sheets of diabase, some of which in the iron-bearing formation have played an important part in the production of the ore bodies.

The ores are found in the lower portion of the iron-bearing member, and either on or near the underlying quartz-slate. The northerly dipping quartz-slate with the overlying cherty carbonates and ferruginous slates is cut by southerly dipping diabase dikes, so as to form a trough with sides nearly at right angles. The troughs themselves pitch downward to the west, and in them, as illustrated by the accompanying figures (Figs. 32 and 33) are found the ore bodies. The ores are soft blue, brown and black earthy hematites, and often contain notable percentages of manganese. There is little doubt that they have been derived from the cherty carbonates in the overlying iron-

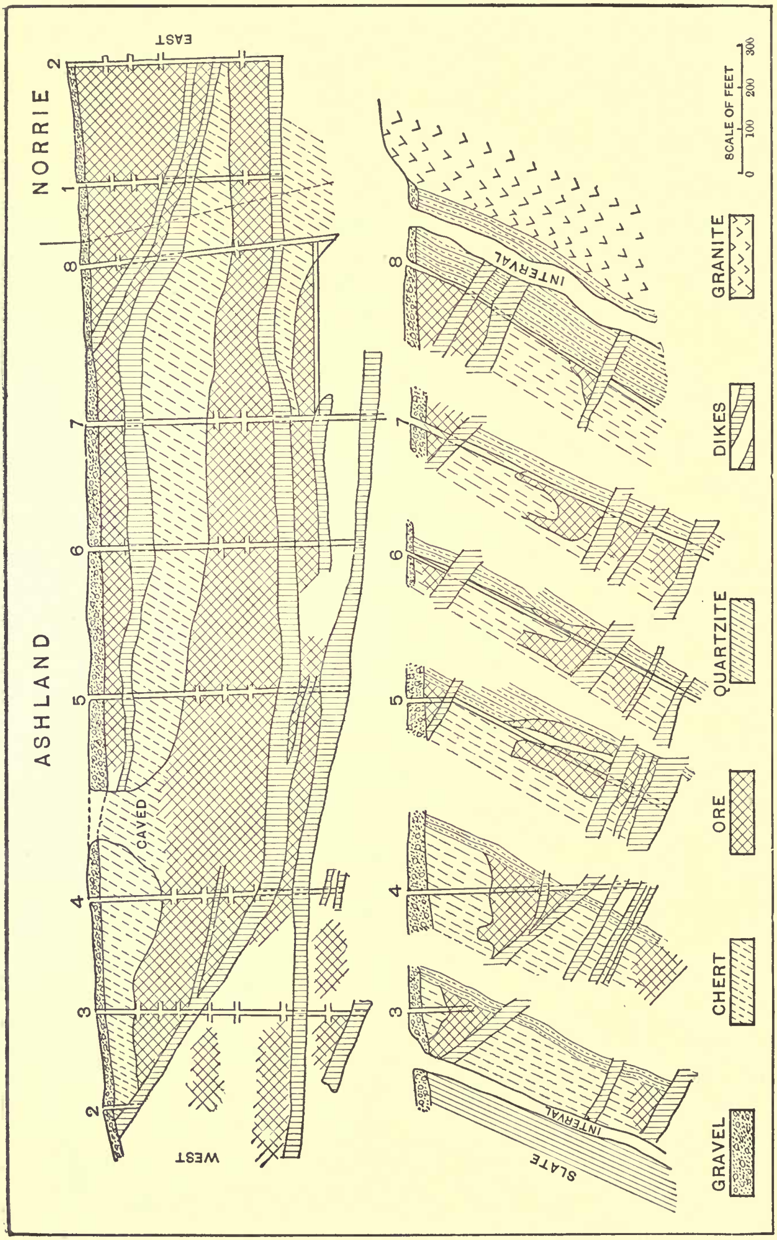

FIG. 32.—*Longitudinal and cross-sections of the Ashland Mine, Ironwood, Mich., redrawn from mine maps. The figure illustrates the occurrence and method of formation of the ores.*

bearing formation, which in the long run of weathering and erosion has yielded its iron oxide to descending atmospheric waters, more or less charged with carbonic acid. The iron-bearing solutions filtering downward have come to comparative rest in the troughs, where they have met other waters, presumably charged with oxygen. The iron oxide has been precipitated and at the same time the silica has been removed by carbonated waters or by those which have been rendered alkaline by the leaching of the neighboring dikes. The latter are excessively altered and are locally called soapstone or soap-rock in description of their condition. It is impossible to state how much of the iron-bear-

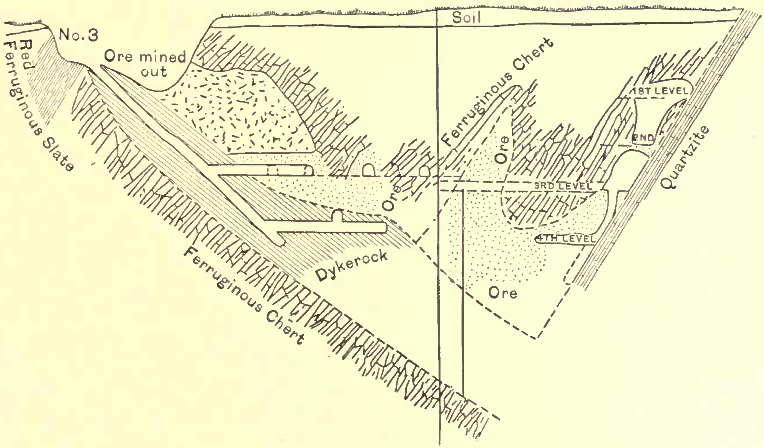

FIG. 33.—*Cross-section of the Colby mine, Penokee-Gogebic district, Michigan, to illustrate occurrences and origin of the ore. After C. R. Van Hise, Amer. Jour. Sci., January,* 1891.

ing formation has disappeared in the protracted process of superficial erosion, but probably some thousands of feet. The depth to which the ore will be found in the troughs is also problematical. It is now known to extend to 800 feet on the dip. The solution of the question of the origin of these ores has been one of the most valuable of the additions to our knowledge in recent years, and has proved suggestive and fruitful for all the other Lake Superior districts.

The range became productive in 1885, and including 1897 there has been shipped a total of 23,047,023 tons of ore.[1]

[1] C. M. Boas, "Some Dike Features of the Gogebic Iron Range," *Trans. Amer. Inst. Min. Eng.*, XXVII., 556. R. D. Irving, *Geol. Survey of Wis*

2.02.25. Example 9*d*. Vermilion Range, Minnesota. Bodies of hard specular ores at Vermilion Lake, and soft ores at Ely, deposited in troughs as in the preceding examples, formed by folded or intersecting dikes, which penetrate the iron-bearing formation. The district is situated in northeastern Minnesota, and lies northwest from Lake Superior. Two Harbors, the shipping point, is twenty-six miles east of Duluth, and from Tower, the principal town near the Vermilion Lake mines, it is sixty-seven miles to the docks. Ely is twenty-three miles northeast of Tower. Leaving the lake the railroad first crosses with heavy grades the northwestern flank of the Lake Superior synclinal, chiefly consisting of the southeasterly dipping trap sheets of the Keweenawan. Underlying these is a series of gabbros and augite syenites—the former of which contain some titaniferous magnetites, similar to those in the Adirondacks. The Mesabi range of hills succeeds on the north, but although ore-bearing further west, as described under the next example, it is barren at this point, and consists chiefly of black slates, referred to the Animikie. Sedimentary, gneissic and eruptive rocks, regarded as Laurentian by the Minnesota geologists, succeed, and give place finally to the metamorphic rocks of the Vermilion range, that contain the ore. Still further north are the Laurentian rocks again. This whole region needs further and very detailed mapping to accurately bring out its geological structure, although the main points mentioned above serve to outline it. The immediate geological relations of the ores have been elucidated, however, by the recent careful work of H. L. Smyth and J. R. Finlay,

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consin, III., pp. 100–167, 1880. "Origin of the Ferruginous Schists and Iron Ores of the Lake Superior Region," *Amer. Jour. Sci.*, iii., XXXII., 263, 265; see also under Van Hise. C. D. Lawton, "Gogebic Iron Mines," *Engineering and Mining Journal*, Jan. 15, 1887, p. 42. C. R. Van Hise, "On the Origin of the Mica Schists and Black Mica Slates of the Penokee-Gogebic Iron-bearing Series," *Amer. Jour. Sci.*, iii., XXXI., 453–459. "The Iron Ores of the Penokee-Gogebic Series in Michigan and Wisconsin, *Amer. Jour. Sci.*, iii., XXXVII., 32. Irving and Van Hise, "The Penokee Iron-bearing Series of Northern Michigan and Wisconsin," *Monograph XIX., U. S. Geological Survey*, 1892. Rec. An abstract of the monograph will be found in the *Tenth Annual Rep. Director U. S. Geol. Survey*, 341. Rec. C. Whittlesey, "The Penokee Mineral Range, Wisconsin," *Proc. Bost. Soc. Nat. Hist.*, IX., July, 1863. C. E. Wright, *Geol. Survey of Wisconsin*, III., pp. 239–301.

FIG. 34.—*Map of the Minnesota Iron Ranges. After F. W. Denton, Trans. Amer. Inst Min. Eng., XXVII., 344.*

to which the subsequent description is chiefly due. For a thorough reading up upon the district, the references given below will suffice.[1]

The Vermilion Lake mines are situated on the top of an abrupt hill above the town of Soudan. Some ore appears in Lee Hill, a mile or two southeast, near Tower, but the deposits are not known to be large. The mines at Soudan extend for about a mile along a main belt in a direction a little north of east, and upon a more or less parallel minor belt that lies a short distance north. This alignment is due to the intrusion of a great mass of greenstone, with many ramifying dikes, but all on this general line, which is also the strike of the jasper.

On the northern side of the mines the surface slopes somewhat sharply to Vermilion Lake. The general relations are illustrated by the accompanying Fig. 35. Smyth and Finlay have shown that stratigraphically there are two series of sedimentary rocks, both of which have been penetrated by abundant intrusions of quartz porphyry and diabase. The lower series consists of slates and graywackes, not excessively metamorphosed. The slates are at times carbonaceous and occasionally charged with pyrites. Above the slates lies the iron-bearing formation, consisting of quartz, variously intermingled with hematite or magnetite, or quite free from either. The

[1] A. H. Chester, *Eleventh Ann. Rep. Minn. Geol. Survey*, 155, 167. T. B. Comstock, "Vermilion Lake District in British America," *Trans. Amer. Inst. Min. Eng.*, July, 1887. F. W Denton, "Methods of Iron Mining in Northern Minnesota," *Idem*, XXVII., 344. R. D. Irving, *Seventh Ann. Rep. U. S. Geol. Survey*, 1885-86, 435. H. L. Smyth and J. R. Finlay, "The Geological Structure of the Western Part of the Vermilion Range, Minnesota," *Trans. Amer. Inst. Min. Eng.*, XXV., 595–645, 1895. Rec. C. R. Van Hise, *Bull. 86, U. S. Geol. Survey.* Various references in chapter ii. Bailey Willis, *Tenth Census*, XV., 457. Alexander Winchell, *Fifteenth Ann. Rep. Minn. Geol. Survey*, 174. Also "Some Results of Archean Studies," *Bull. Geol. Soc. Amer.*, I, 357. H. V. Winchell, "Diabasic Schists, Containing the Jaspilyte Beds of Northeastern Minnesota," *Amer. Geol.*, II., 18. "The Iron Ranges of Minnesota," *Proc. Lake Superior Mining Inst.*, III., 1895. Rec. N. H. Winchell: Many references to the region by N. H. Winchell are to be found in the reports of the *Minn. Geol. Survey.* They are practically summarized in the next reference. N. H. and H. V. Winchell, "The Iron Ores of Minnesota," *Bull. 6, Geol. Survey of Minn.* Rec. "On a Possible Chemical Origin of the Iron Ores of the Kewatin in Minnesota," *Amer. Geol.*, IV., 291, 389. "The Taconic Iron Ores of Minnesota and Western New England," *Amer. Geol.*, VI., 263.

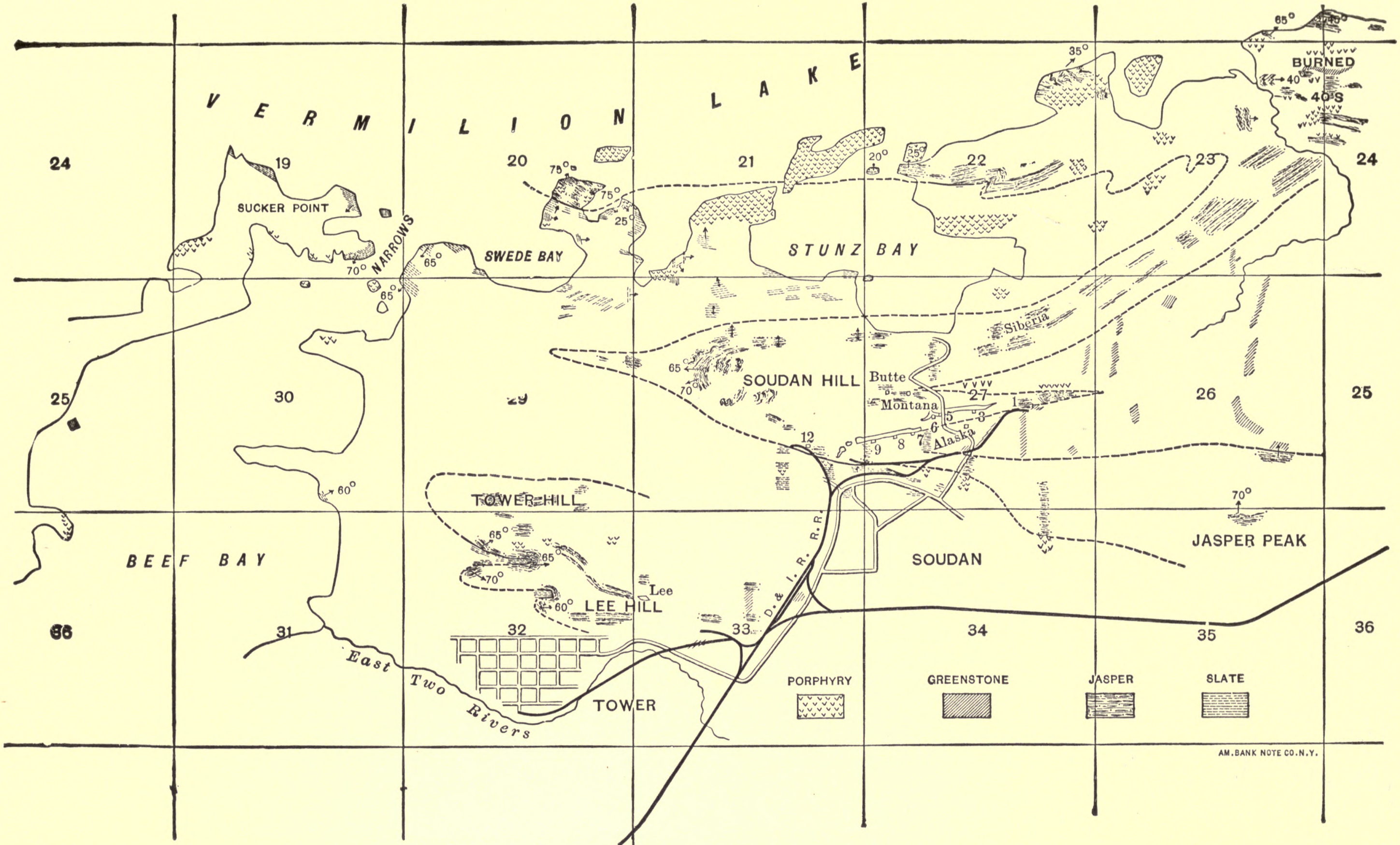

FIG. 35.—*Geological Map of the vicinity of Tower and Soudan, Minn. After Smyth and Finlay, Trans. Amer. Inst. Min. Eng, XXV., 595, 1895.*

varieties occur in parallel but narrow bands, never over three or four inches across, and doubtless represent the original beds of the sediment, but just what the character of the original sediment was, whether the cherty carbonates of the south shore or the probable glauconites of the Mesabi range is hopelessly destroyed by metamorphism. These sediments each form three belts, as shown in Fig. 35, which are repeated because of sharply compressed and pitching folds. After the formation of the sediments, but before the folding, intrusions of quartz porphyry and diabase took place, as dikes and sheets, some large, others of excessive thinness. Subsequently all suffered severely from compression. A larger series of folds was developed along an east and west line, and a smaller series at right angles to this. This severe compression and shearing changed the quartz porphyries in large part to conglomerate breccias, and to sericite schists, while the diabases passed into chlorite or actinolite schists or conglomerate breccias. The breccias first resulting from the crushing have had their fragments so rubbed upon one another that they are stretched and rounded and have their interstices filled with sericite schist or chlorite schist, as the case may be. The brecciation took place on the anticlinal crests, but in the synclinal troughs schists resulted. These foldings also formed troughs especially from the corrugated greenstone dikes and from the intersections of the same, and when the iron-bearing formation stood over such a trough, it passed through the same series of changes that have been earlier outlined under the Marquette range, so that the iron oxide became concentrated along the sides and on the bottoms, while the silica was removed. The accompanying figures exhibit cross-sections in all respects like those on the south shore. The ores are all hard, dense, specular, and are about half of bessemer and half of non-bessemer grade.

2.02.26. The geological relations at Ely are practically the same, but the ore body as displayed in the Chandler and Pioneer mines is larger than at Vermilion Lake. It rests, however, on a greenstone dike, which is folded into a syncline with a minor roll in the bottom of the trough which, as shown in Fig. 38, makes it a double one. The ores are soft hematites of extraordinary richness and purity, and are all of very high bessemer grade. Indications of ore are strong still further east, and

FIG. 37.—*Open cut at Minnesota Iron Company's Mine, Soudan, near Tower, in south view looking west. Photograph by J. F. Kemp,* 1894.

FIG. 39.—*Sunken ground over the Chandler iron mine, Ely, Minn. The depression is the result of mining by the caving system. From a photograph by J. F. Kemp,* 1894.

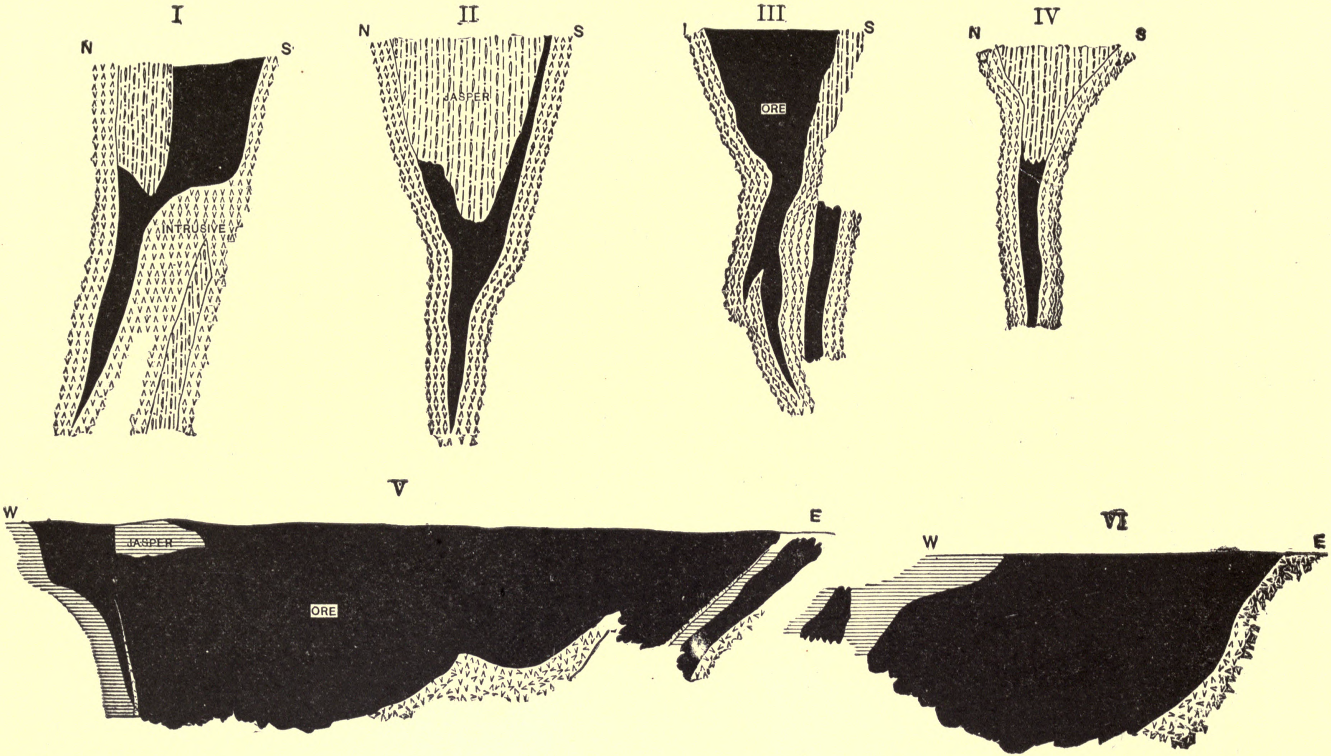

FIG. 36.—*Cross-sections of the ore bodies at Soudan, Vermilion Range, Minn. After Smyth and Finlay, Trans. Amer. Inst. Min. Eng., XXV.*, 595, 1895.

developments have now proved important. The combined output of the mines at Ely and Vermilion Lake is from 800,000 to over 1,000,000 tons annually, about equally divided between them. The total shipments up to the close of 1897 have been 10,498,716 tons.

The work of H. L. Smyth and Finlay has demonstrated what many observers have felt from more cursory examination—that the geological relations of these ores are essentially the same as those on the south shore. Different explanations have, however, been advanced, and great uncertainty has surrounded the geology, on account of the excessively metamorphosed and

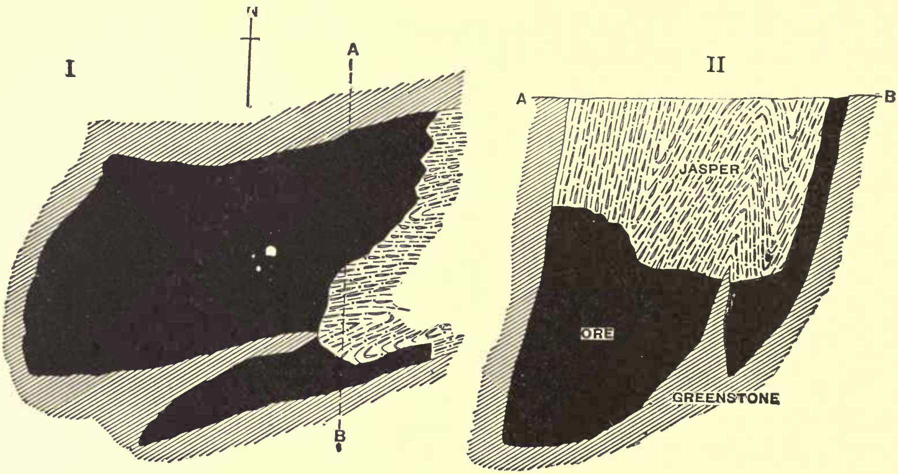

FIG. 38.—*Horizontal and vertical cross-sections of the Chandler ore body at Ely, Minn. After Smyth and Finlay, Trans. Amer. Inst. Min. Eng., XXV., 595, 1895.*

obscure igneous rocks. N. H. and H. V. Winchell have argued that the ores were submarine precipitates from volcanic lapilli, furnished by submarine eruptions. From the lapilli the sea water was thought to have extracted the iron and silica. There seems, however, little reason to question the results of Smyth and Finlay.

2.02.27. Example 9*e*. Mesabi Range. Of much more recent development than the other districts is the Mesabi range of Minnesota. The mines began to make important shipments of ore in 1893. The indications are that the deposits are not less extensive than those in any other of the Lake

Superior localities, and that they are even larger and of a character to be more easily mined. The present developments are situated southwest of Vermilion Lake, and nearer Duluth and Lake Superior. They cover a stretch of about 30 miles, from Biwabik on the east, through McKinley, Virginia, Eveleth, Mountain Iron and smaller towns to Hibbing on the west. Little ore is known beyond Hibbing. The ore bodies are all south of the granite ridge. The ore lies under the black slates called Animikie in the section given in Paragraph 2.02.25, and over the quartzite, there called the Pewabic; but they are situated twenty miles or so west of the line of that section. The

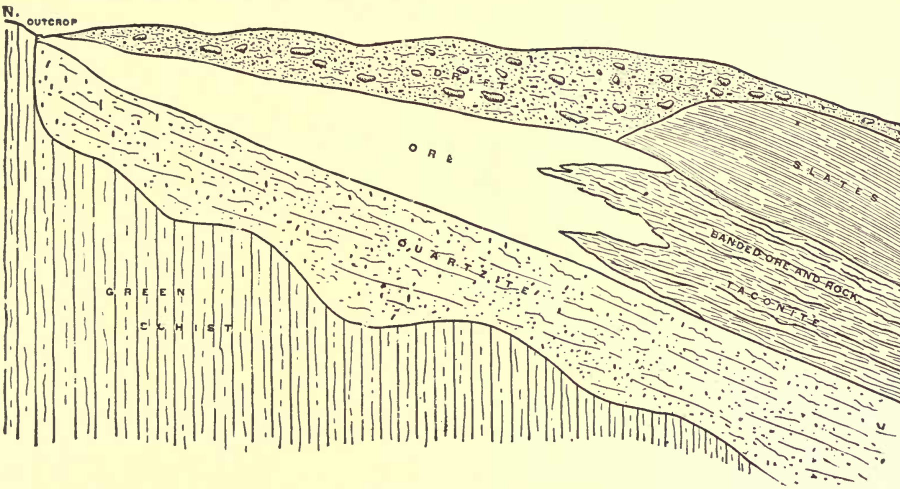

FIG. 40.—*General cross-section of ore body at Biwabik, Mesabi Range, Minn. After H. V. Winchell, Twentieth Ann. Rep. Minn. State Geologist.*

ore bodies are all south of the granite ridge called the Giants' Range. Upon the southern slopes of this range lie the green schists of the Keewatin, which are unconformably overlain by the Pewabic quartzite. On this rests the ore-bearing rock, which is a jaspery or cherty siliceous variety called taconyte by H. V. Winchell. Over this, in order, come greenish siliceous slates and cherts, black slates (referred to the Animikie), and great masses of gabbro. On the flanks of the Giants' Range the dip is steep, but it flattens out nearly to horizontality away from the granite. All the formations above the Keewatin are called Taconic by the Winchells.

2.02.28. The ore bodies lie on the southerly slopes of low hills, and are found immediately below the mantle of glacial drift, which varies up to 200 feet in thickness. Ore indications have long been known on the range, and various reports have been made in former years, although always unfavorably. The indications then available showed only siliceous limonites of low grade. Deep test pits, however, which penetrated these caps and the drift, have revealed enormous ore bodies and have rewarded persistent prospecting. The ores are blue and brown and of soft, earthy texture, with occasional hard streaks. They lie from 10 to as much as 180 feet below the surface as now mined, and where the stripping is sufficiently thin it is removed with steam shovels, and then after being shaken up with black powder the ore is excavated in the same way. The ore bodies are lenses. which at times, as at the Mesaba Mountain or Oliver mine in Virginia, appear to form a basin. In the central part of this mine a drill hole is stated to have shown 335 feet of ore, but the general run is less. The ore bodies have usually a southeasterly trend, and are longer than wide. The blue ores are richest in iron and purest as regards phosphorus, and they are the ones specially desired. Ores for foundry iron also occur in large amount, but are at present less sought for. The rock most intimately associated with them all is the chert, called taconyte. The underlying quartzite is occasionally shown in the mines as well as the overlying slates, but the whole region is so completely buried in drift that outcropping rock is a rare thing.

The ores are thought by H. V. Winchell to have originated by replacement of the taconyte. The rock contains calcareous streaks which have perhaps aided in furnishing the carbonic acid, which, it is thought, has dissolved the silica of the taconyte in the replacement process. Recently, valuable observations on the geology of the ores have been accumulated by J. E. Spurr, while in the field for the Minnesota Geological Survey, in whose *Bulletin X.* the detailed report has appeared. A preliminary paper in the *American Geologist* for May, 1894, gives an abstract of the results. As in the Penokee-Gogebic and Marquette districts, the western end of the Mesaba range is least disturbed and metamorphosed. The stratigraphy is the same as that already outlined in preceding paragraphs, but the

FIG. 41.—*View of the Mesaba Mountain or Oliver Mine, Virginia, Minn., looking southeast. The view shows the overlying gravels and the ore. From a photograph by J. F. Kemp, 1894.*

quartzite is simply called by Spurr, Animikie, and not Pewabic. The iron-bearing series is stated to be from 500 to 1,000 feet thick, with an average of 800 feet. The unaltered rock is described as consisting of "cryptocrystalline, chalcedonic or finely phenocrystalline silica" thickly "strewn with rounded or subangular bodies made up chiefly of a green mineral," regarded as glauconite, the hydrated silicate of protoxide of iron and potash. Analyses of the rock corroborate this determination, because they indicate a constant but small percentage of potash. Layers of the rock, rich in calcite (probably magnesian) also occur. Spurr is thus led to regard the rock as an altered greensand, to which view similar conclusions regarding the much more recent and unmetamorphosed ores of Texas and Louisiana (see 2.01.15) give support. The chemistry of the deposition is considered by Spurr to be the following: Atmospheric waters, with dissolved carbonic acid, and some alkaline salts have filtered into the cracks and become charged with ferrous carbonate, where the conditions prevented oxidation. The greater solubility of the ferrous salt led to its solution before the alkali attacked the silica.

Later, reaching more open and fissured portions, the ferrous salt was oxidized and deposited, while the silica was attacked and removed by the alkali. In time, thus the iron oxide was concentrated along fissured strips, near faults, and the like, whereas the silica was removed. It is recognized as well that the ferrous salt was precipitated as carbonate, amid deoxidizing conditions. The change from silicate or carbonate to hydrous oxide of iron led to shrinkage and shattering, and the passage from hydrous oxide to carbonate, where such occurred, to expansion and shattering. It follows from the explanation that the regions of rich ore bodies would be those of notable geological disturbances, so that faults are presumed near Virginia, Biwabik and elsewhere.[1]

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[1] C. E. Bailey, "Mining Methods on the Mesabi Range," *Trans. Amer. Inst. Min. Eng.*, XXVII., 529. F. W. Denton, "Open-pit Mining with Special Reference to the Mesabi," *Proc. Lake Superior Mining Inst.*, III., 1896. "Methods of Iron Mining in Northern Minnesota," *Trans. Amer. Inst. Min. Eng.*, XXVII., 344. E. P. Jennings, "The Mesabi Range," *Science*, XXIII., 73. E. J. Longyear, "Explorations on the Mesabi Range," *Trans. Amer. Inst. Min. Eng.*, XXVII., 537. J. E. Spurr, "The Mesabi

2.02.29. Hematites apparently much like those of Lake Superior have been reported from the Hartville iron district in Laramie County, Wyoming. The ores, according to W. C. Knight, constitute irregular zones in Carboniferous rocks and are associated in many cases with copper deposits. (See 2.04.28.) The published analyses show rich ores of bessemer grade.[1]

2.02.30. The explorations of Mr. A. P. Low, of the Geological Survey of Canada, have shown extensive developments of iron carbonates, and magnetite and hematite, associated with jasper, and with cherty carbonate of lime, along the east side of Hudson Bay, and in the valleys of the Koksoak (called also Ungava) and Hamilton rivers. Mr. Low describes the enclosing strata as Cambrian. The samples brought back proved rather low in iron (30 to 54% Fe), but the geological relations are extraordinarily like those of Lake Superior.[2]

2.02.31. Example 10. James River, Virginia. Specular hematite in narrow beds (lenses), interstratified with quartzites and slates of metamorphic character and Archean age. They run four to six feet, or less, in thickness, with prevailingly vertical dip, but they also pitch diagonally down on the dip like the lenses of magnetite, later described. They furnish a very excellent grade of ore. The ore bodies are found along both sides of the James River, a few miles above Lynchburg. Some magnetite also occurs in the region, and some limonite. More or less clay accompanies the ore.[3]

Iron-bearing Rocks," *Bulletin 10, Minn. Geol. Survey*, 1894. Rec. "The Iron Ores of the Mesabi Range," *Amer. Geologist*, XIII., May, 1894, 335. H. V. Winchell, *Twentieth Ann. Rep. Minn. State Geol.*, 112, 1892. "Iron Ores of Minnesota," *Bull. 6, Minn. Geol. Survey*. H. V. Winchell and J. T. Jones, "The Biwabik Mine," *Trans. Amer. Inst. Min. Eng.*, XXI., 951. For an early account of the Mesabi Range see New York *Times*, December 14, 1892.

[1] W. C. Knight, *Bulletin 14*, Wyoming Experiment Station, Laramie, Wyo., pp. 135 and 176. A large series of analyses appears in the prospectus of the Wyoming Railway and Iron Co. E. P. Snow, "The Hartville Iron Ore Deposits in Wyoming," *Engineering and Mining Journal*, October 5, 1895, p. 320.

[2] The above note is due to the courtesy of Dr. George M. Dawson, Director of the Geological Survey of Canada, who kindly gave the writer an abstract of Mr. Low's report in advance of its publication.

[3] E. B. Benton, *Tenth Census*, Vol. XI., p. 363 (on Virginia). J. L. Campbell, *Geology and Resources of the James River Valley*, p. 49, New

2.02.32. Similar lenses of specular ore and magnetite are found in central North Carolina, in schistose rocks, which have been referred to the Huronian.

As stated under 2.02.29, lenses of specular hematite of very excellent quality are found also in metamorphic rocks, north of Fort Laramie, Wyoming, which may prove productive in time.

2.02.33. Example 11. Pilot Knob, Missouri. Two beds of hard specular hematite separated by a thin seam of so-called slate (possibly volcanic tuff), and interstratified with breccias and sheets of porphyry. Along the eastern limit of the Ozark uplift of Missouri and Arkansas a series of knobs of granite and porphyritic rocks project through the Cambrian limestones and sandstones. They are older than the limestones, and clearly were not intruded through them. The limestones and sandstones lie up against the porphyry and in the valleys between. The underlying porphyry has been found in the valley near Pilot Knob, after penetrating four hundred feet of sedimentary rocks. The porphyry and ores have often been called Huronian, but in view of the recent reorganization of the Huronian (see Example 9), this is not done, nor ever has been, on any accurate grounds. Pilot Knob is formed by one of these eruptive knobs. It consists of sheets of porphyries that are capped by porphyry breccia, and two ore beds, and the intervening slaty rock which may be a tuff. The beds strike and dip 13° S. S. W. The hill is over 600 feet high. The lower bed has furnished most of the ore, running from 25 to 40 feet thick, and affording a dense bluish, specular hematite of from 50 to 60% Fe, siliceous and very low in phosphorus. The upper bed is irregular and of lower grade, and runs from 6 to 10 feet thick. The Pilot Knob mines in this solid ore are now substantially exhausted.

Recent drill holes on the northerly slope and below the outcropping face of ore have shown that under the Cambrian strata of the valley there is a great bed of ore boulders or breccia in clay, much as is the case at Iron Mountain, later described. Analyses of these latter ores were not, however,

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York, 1882. H. B. C. Nitze, "On North Carolina," *Bulletin No. 1, North Carolina Geol. Survey,* 1893. B. Willis, *Tenth Census*, Vol. XV., p. 301. *The Virginias*, a monthly, formerly published by Jed. Hotchkiss, at Staunton, contains much information on Virginia in general.

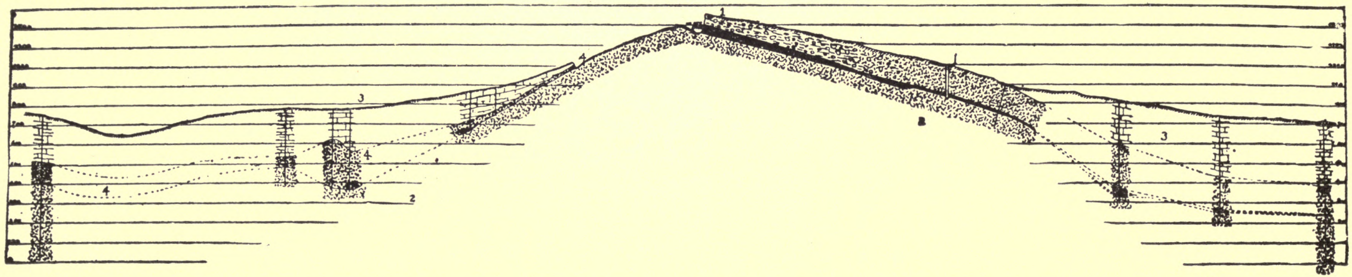

FIG. 42.—*Cross-section of Pilot Knob, Mo.* *From a drawing by W. B. Potter, in Nason's Report on the Iron Ores of Missouri, p.* 95, *Mo. Geol. Survey, Vol. II.*, 1892.

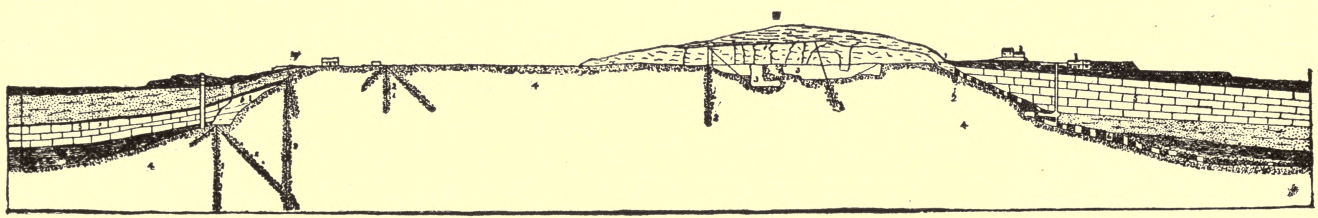

FIG. 45.—*Cross-section of Iron Mountain, Mo., showing the knob of porphyry, with the veins of ore, and the mantling succession of ore-bearing conglomerate, sandstone, and limestone. From a drawing by W. B. Potter in Nason's Report on the Iron Ores of Missouri, p.* 29, *Mo. Geol. Survey, Vol. II.*, 1892.

sufficiently encouraging for development during the recent low prices for iron. Doubtless the bed will afford important reserves.

2.02.34. Near Pilot Knob are two other hills of porphyry, Shepherd Mountain and Cedar Mountain, whose ores are structurally more related to Example 11*a*. The first contains three veins, the Champion, the North, and the South. They are long and narrow (4 to 10 feet) strike north 60° to 70° east, and dip 70° north. The Champion vein contained a little streak of natural lodestone, but the ore is mostly specular.

The North vein shows a good breast of ore five feet wide, but too full of pyrite to be available. Cedar Mountain has a vein of specular ore. Neither hill has been an important producer. Minor veins have been found on neighboring porphyry hills (Buford, Hogan, and Lewis mountains), some of which contain much manganese.

2.02.35. Example 11*a*. Iron Mountain, Missouri. Veins of hard, specular hematite irregularly seaming a knob of porphyry. Iron Mountain is five or six miles north of Pilot Knob, and is a low hill with a westerly spur called Little Mountain. It has also a northerly spur. It consists of feldspar porphyries, more or less altered. These are seamed with one large, and on the west somewhat dome-shaped, parent mass of ore and innumerable minor veins that radiate into the surrounding rock. Upon the flanks of the porphyry hill rests a mantling succession of sedimentary rocks, that dip away on all sides. The lowest member is a conglomerate of ore fragments, weathered porphyry, and residual clay left by its alteration. It is regarded by Pumpelly as formed by pre-Silurian, surface disintegration and not by shore action, inasmuch as sand does not fill the interstices, while white clay from decomposed porphyry does. It is, however, overlain by a thin bed of coarse, friable sandstone, which marks the advance of the sea, and whose formation preceded the limestones. This conglomerate was in later years the principal source of the ore, but the mines are now considered to be worked out. It was mined underground, hoisted and washed by hydraulic methods, like those employed in the auriferous gravels of California, and then jigged. The apatite has largely weathered out of it. The rock of the mountain itself, in the cuts of the mines, is largely kaolinized, and exhibits everywhere the effects of extreme alteration. The smaller veins that penetrate the porphyry show at times casts or much altered cores of apatite crystals.

2.02.36. The porphyries of Pilot Knob and Iron Mountain, in thin section, are seen to belong to quartz porphyries, feldspar porphyries, and porphyrites. Both orthoclase and plagioclase are present in them, and many interesting forms of structure. One significant fact is that they are everywhere filled with dusty particles of iron oxide, probably magnetite. An eruptive origin was originally assigned to these ores by J. D. Whitney (*Metallic Wealth of the United States*, p. 479, 1854), just as to the Lake Superior hematites. The later investigations of Adolph Schmidt for the Missouri Survey in 1871 arrived at a different conclusion. Dr. Schmidt considered them, whether occurring in an apparent bed, as at Pilot Knob, or in various more or less irregular veins, as at Iron Mountain, to have been formed either by a replacement of the porphyries with iron oxide deposited from solution, or by a filling in the same way of fissures, probably formed by the contraction of the porphyry in cooling. In the valuable report on iron ores by F. L. Nason in the *Missouri Geological Survey* a sedimentary origin is advocated for the Pilot Knob beds. They are conceived to have been deposited in a body of water in a hollow, between formerly existing porphyry hills, which rose above. In the course of weathering, the hills became the valleys, and the early sedimentary beds the hilltop. It is, however, somewhat difficult to understand how the more or less incoherent sediments withstood degradation better than the hard, firm, porphyry hills. Some such origin as sedimentation or replacement is, however, the only reasonable one. It is not improbable that the Pilot Knob ores originated in the saturation and more or less complete replacement of layers of tuffs with infiltrating iron oxide.

An extended table of analyses of Iron Mountain ores will be found in *Mineral Resources of the United States*, 1889-90, p. 47.[1]

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[1] G. C. Broadhead, "The Geological History of the Ozark Uplift," *Amer. Geol.*, III., 6. J. R. Gage, "On the Occurrence of Iron Ores in Missouri," *Trans. St. Louis Acad. Sci.*, 1873, Vol. III., p. 181. E. Harrison, "Age of the Porphyry Hills, *Ibid.*, Vol. II., p. 504. E. Haworth, "A Contribu-

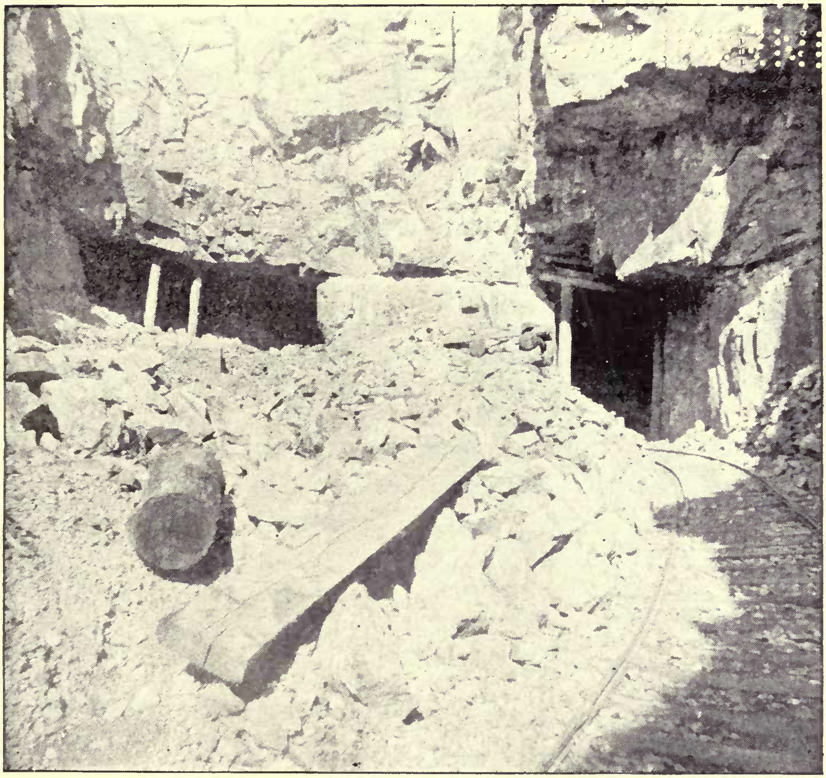

FIG. 43.—*View of open cut at Pilot Knob, Mo., showing the bedded character of the iron ore. From a photograph by J. F. Kemp, 1888.*

FIG. 44.—*View of Iron Mountain, Mo., from the east. From a photograph by H. A. Wheeler.*

ANALYSES OF HEMATITES, RED AND SPECULAR.

(The same discrimination must be employed in looking over these analyses that was emphasized under limonite.)

	Fe.	P.	S.	SiO_2.	Al_2O_3	H_2O.
Clinton, N. Y. (fossil ore)........	44.10	0.650	0.230	12.63	5.45	2.77
Wisconsin (fossil ore)............	51.75	1.392	......	......	......	......
Pennsylvania (Mifflin ore).......	44.40	0.115	0.028	......	......	......
Tennessee (Meigs County).......	51.63	0.345	......	......	......	......
Birmingham, Ala................	56.40	0.340	......	16.80	0.50	......
Antwerp, N. Y..................	46.32	0.883	......	......	......	......
Missouri (Crawford County).....	59.41	0.085	......	......	......	......
Marquette dist., Mich. (specular)	68.40	0.530	......	2.07	......	......
" " " "	64.83	0.067	......	3.60	2.03	......
Menominee district, Michigan. ..	60.47	0.009	......	3.38	......	......
Iron Mountain, Mo..............	65.50	0.040	0.010	5.75	......	......
Pilot Knob, Mo.................	59.15	0.015	......	13.27	2.19	......
James River (Maud vein)........	49.89	0.139	......	......	......	......
Elba	61.81	0.020	0.170	5.97	3.47	......
Pure mineral...................	70.00	......	......	......	......	......

These analyses are mostly taken from State reports and from *Mineral Resources of the United States.* They are intended to illustrate he general run of compositions, but for Birmingham and Marquette are high. Analyses vary widely.

tion to the Archæan Geology of Missouri," *Amer. Geol.*, I., 280–363; "Age and Origin of the Crystalline Rocks of Missouri," *Bull. 5, Mo. Geol. Survey,* 1891. A. V. Leonhard, "Notes on the Mineralogy of Missouri," *Trans. St. Louis Acad. Sci.*, Vol. IV., p. 440. F. L. Nason, "Report on the Iron Ores of Missouri," *Mo. Geol. Survey,* II. Rec. R. Pumpelly, "Geology of Pilot Knob and Vicinity," *Mo. Geol. Survey,* 1872, p. 5; see also remarks on Iron Mountain, *Bull. Geol. Soc. Amer.*, Vol. II., p. 220. Rec. W. B. Potter, "The Iron Ore Regions of Missouri," *Journal U. S. Asso. Charcoal Iron Workers,* Vol. VI., p. 23. Rec. F. A. Sampson, "A Bibliography of the Geology of Missouri," *Bull. 2, Mo. Geol. Survey,* 1890. (This is a valuable book of reference.) F. Shepherd, *Ann. Rep. Mo. Geol. Survey,* 1853–54. Hist. A. Schmidt, "Iron Ores of Missouri," *Mo. Geol. Survey,* 1872, p. 45, and especially p. 94. Rec. J. D. Whitney, *Metallic Wealth of the U. S.*, p. 479. Of more recent issues are the following: E. Haworth, "The Crystalline Rocks of Missouri," *Eighth Ann. Rep. Mo. Geol. Survey,* 1894, p. 81. C. R. Keyes, "Geographic Relations of the Granites and Porphyries in the Eastern Part of the Ozarks," *Bull. Geol. Soc. Amer.*, VII., 363, 1896. "Report on the Mine la Motte Sheet," *Geol. Survey of Mo.*, IX., Sheet Report 4. Arthur Winslow, E. Haworth and F. L. Nason, "Report on the Iron Mountain Sheet," *Idem,* Sheet Report 3. Rec. This last is the best work of reference as regards the mines. Further details will be found in Winslow's Bulletin 132 of the *U. S. Geol. Survey,* on "The Disseminated Lead Ores of Southeastern Missouri."

CHAPTER III.

MAGNETITE AND PYRITE.

2.03.01. Example 12. Magnetite Beds. Beds of magnetite, often of lenticular shape, interfoliated with Archean gneisses and crystalline limestones. They are extensively developed in the Adirondacks, in the New York and New Jersey Highlands, and in western North Carolina. The presence of magnetite in Michigan (Example 9*a*), in Minnesota (Example 6*b*), on Shepherd Mountain in Missouri (Example 11), and in Virginia (Example 12) has already been referred to. Other magnetite bodies are known in Colorado, Utah, California and Wyoming, and will be mentioned subsequently. Titanium is often present, but the titaniferous ores are made a special example. The same is true of pyrite and pyrrhotite. Apatite is always found, although it may be in very small quantity. Chlorite, hornblende, augite, epidote, quartz, feldspar, and a little calcite are the common associated minerals. In New Jersey the beds occur in several parallel ranges or belts.

2.03.02. Example 12*a*. The Adirondacks. Deposits of magnetite are extensively developed in the crystalline area of the Adirondacks, and they show some interesting relationships between the character of the ore and the nature of the country rock. The titaniferous varieties to be later described favor the interior, mountainous core, but the nontitaniferous are especially found on the flanks and in the foothills. The region is in large part an eruptive area of plutonic rocks representing various members of the great gabbro family whose chief minerals are labradorite and some form of pyroxene. There are members which are little else than labradorite and which are called anorthosites; there are others containing labradorite and hypersthene, the norites; still others are dark and basic, and consist of little else than labradorite, augite, hypersthene, ilmenite and garnets, the last-named having been formed by metamorphism.[1] Augite syenites of massive character have recently been recognized by H. P. Cushing, and the discovery has thrown much light on many rocks only known before as gneisses. All these eruptives have suffered greatly from dynamic metamorphism, and are now as a rule decidedly gneissoid in structure. In addition to the eruptives there are white, crystalline, graphitic marbles, usually charged with pyroxenes; black, hornblendic schists; quartzites; and quartzose gneisses that represent a series of sedimentary rocks of Algonkian age, but that are now much broken by the eruptives above mentioned. The Algonkian sediments are most satisfactorily exhibited on the western side of the mountains.

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[1] The general geology of the Adirondacks is described by E. Emmons in his "Report on the Second District of New York," *N. Y. Natural History Survey*, 1842. The later papers of importance are the following, and a general review of work that had been done up to 1892 is given by J. F. Kemp, "A Review of Work Hitherto Done on the Geology of the Adirondacks," *Trans. N. Y. Acad. of Sciences*, XII., 19, 1892. H. P. Cushing, "Report on the Geology of Clinton Co.," *13th Ann. Rep. State Geologist*, 1893, 473; *15th Idem*, 499. "Report on the Boundary Between the Potsdam and Pre-Cambrian Rocks North of the Adirondacks," *16th Annual Report State Geologist*, 1896. An additional report on Franklin Co. is in press (1899). "Augite-syenite Gneiss near Loon Lake, N. Y.," *Bull. Geol. Soc. Amer.*, X., 177–192. J. F. Kemp, "Gabbros on the Western Shore of Lake Champlain," *Idem*, V., 213, 1894. "Crystalline Limestones, Ophicalcites and Associated Schists of the Eastern Adirondacks," *Idem*, VI., 241. "Preliminary Report on the Geology of Essex Co.," *Rep. N. Y. State Geologist* for 1893, 79, 1894; continued in the *15th Ann. Rep.*, *Idem*, 1895, 575. A report on Warren Co. is in press. "The Geology of Moriah and Westport Townships, Essex Co.," *Bull. N. Y. State Museum*, III., 325, 1895. "The Geology of the Magnetites near Port Henry, N. Y., *Trans. Amer. Inst. Min. Eng.*, XXVII., 146, 1897. "The Geology of the Lake Placid Region," *Bull. N. Y. State Museum*, V., 51, 1898. C. H. Smyth, Jr., "A Geological Reconnoissance in the Vicinity of Gouverneur, N. Y., *Trans. N. Y. Acad. Sci.*, XII., 203, 1893. "Petrography of the Gneisses of the Town of Gouverneur, N. Y.," *Idem*, XII., 203, 1893. "Report on the Geology of Four Townships in St. Lawrence and Jefferson Counties," *13th Ann. Rep. N. Y. State Geologist*, 491. "Crystalline Limestones and Associated Rocks of the Northwestern Adirondack Region," *Bull. Geol. Soc. Amer.*, VI., 263, 1895. "Report on the Crystalline Rocks of St. Lawrence Co.," *15th Ann. Rep. N. Y. State Geologist*, 1895, 477. Additional reports on the western Adirondacks are in press.

2.03.03. The magnetites are found in the form of lenticular masses that correspond perfectly to the foliation of the gneisses. They may extend long distances on the strike, as at Lyon Mountain, where the Chateaugay ore is said to be traceable four or five miles, but it is lean over most of the distance. Belts more or less continuous for a mile are opened up in several places. The ore may be in gneiss that is practically quartz and microperthite as at Hammondville; or in pyroxenic gneisses as at Lyon Mountain; or on the contact of gneiss like that which forms the wall-rock at Hammondville just mentioned, and dark, basic, hornblendic gneiss, derived from intruded gabbro; or on the contact of gabbro like the last and gneisses which are involved with crystalline limestones, as at the Cheever mine; or finally, in the crystalline limestones near gabbro intrusions, as at the Weston mines, Keene Center. The ores at

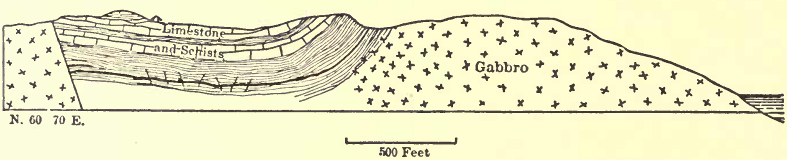

FIG. 47.—*Cross-section of the Cheever iron mine, near Port Henry, N. Y., showing the occurrence of the ore in pyroxene gneiss, just over gabbro. Lake Champlain terminates the section at the right. After J. F. Kemp, Bull. N. Y. State Museum, Vol. III., p.* 346.

Mineville have been regarded as contact deposits by J. F. Kemp, and as having been developed by the neighboring gabbro. As will appear from the accompanying map and sections, Figs. 48 and 49, there are two groups of mines. One on Barton Hill is based on a long series of pods or lenses that occur between an underlying gabbro and gabbro-gneiss, and an overlying gneiss, called the Orchard. The Orchard gneiss consists almost entirely of quartz and oligoclase. Above it is the Barton gneiss, containing some quartz with abundant microperthite, plagioclase, orthoclase, brown hornblende, augite and hypersthene. The lower group embracing the Miller pit, Old Bed and "21," have the "21" gneiss, an aggregate of quartz and microperthite, exposed on the surface. Diamond drill cores have, however, revealed the gabbro-gneiss beneath the ore in depth. The map brings out the parallel pod-like shape of the

FIG. 46.—*View of open cut and underground work in Mine 21, Mineville, near Port Henry, N. Y. Photographed by J. F. Kemp, 1892*

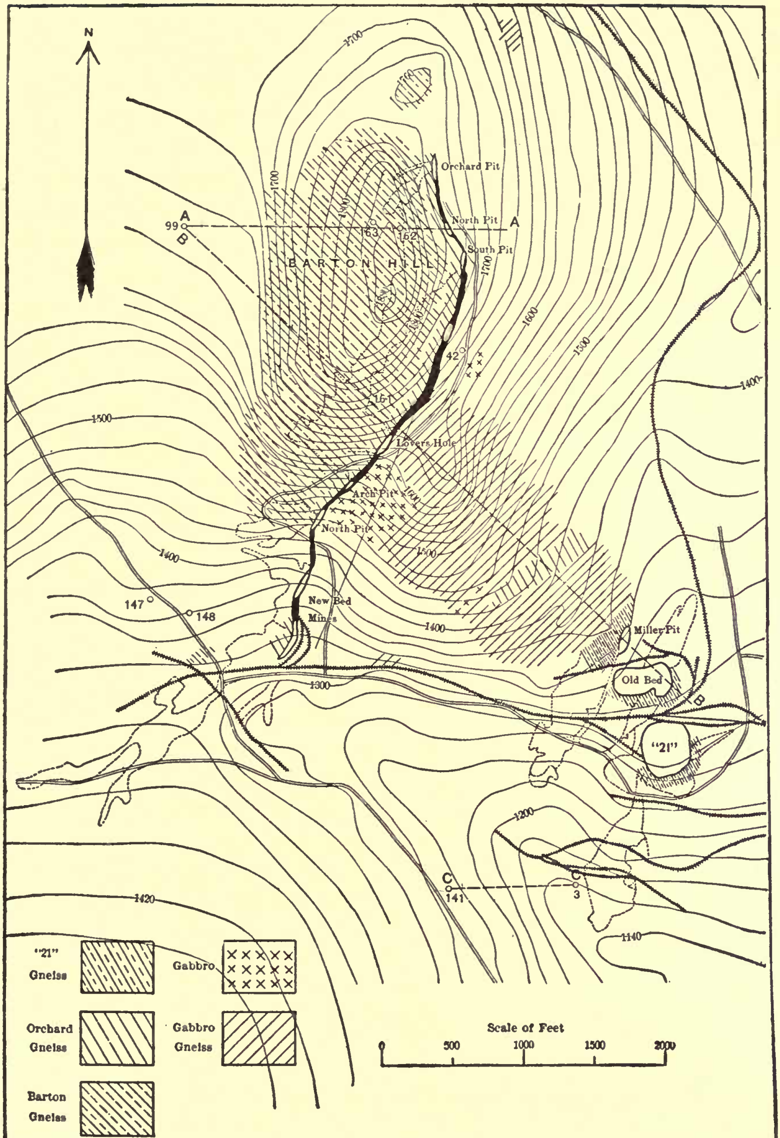

FIG. 48.—*Geological map of the iron mines at Mineville, near Port Henry, N. Y. For details of formations see text. After J. F. Kemp, Trans. Amer. Inst. Min. Eng., XXVII.*, 146.

ores. In one instance, the New Bed mines, the workings have followed a pod over 2,000 ft. The magnetites have not yet been described in the same detail at other localities, but data are at hand which give ground for similar inferences regarding several additional ones. Gabbros are usually in the vicinity of the ore even when it does not occur on the contact. Nevertheless some mines give no immediate evidence of the influence of any rock except that of the walls, as for instance the Palmer Hill workings near Ausable Forks; and the ore appears to be a great, basic segregation, drawn out into a band, parallel

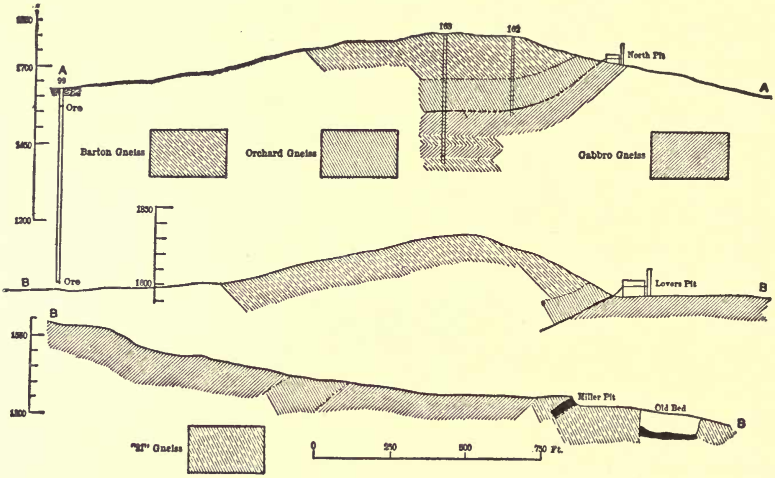

FIG. 49.—*Cross-section of ore-bodies at Mineville, near Port Henry, N. Y., to accompany map*, FIG. 48. *After J. F. Kemp, Trans. Amer. Inst. Min. Eng., XXVII.*, 146.

with the foliation. At Palmer Hill the walls are a siliceous gneiss, consisting of quartz, microperthite, microcline and augite.

The ores follow all the foldings and flowing curves that are exhibited in the foliation of the gneisses, and because of this they exhibit many peculiar shapes. They swell and pinch, roll and fold and feather out. Still, at Mineville they show a marked parallelism in the long axes of the pods or lenses, and while these tongue out into the walls, they do so with a general parallel alignment. Faults are common and in instances have sharply cut off the ore. Dark, brecciated strips may mark the fault line and may resemble trap dikes, as in No. 7 slope at Hammondville. Small gulches are frequently over the places where the ore is lost, and serve to mark the fault line. Trap dikes are frequent in the mines, and hardly a solitary one fails to show them. They may fault the ore for a few feet.[1]

2.03.04. In their metallurgical relations the ores may be classified, following the example of B. W. Putnam in his report for the Tenth Census, into (1) those high in phosphorus, but low in sulphur (Mine 21, Mineville); (2) Bessemer ores, low in both phosphorus and sulphur (Barton Hill mines, Hammondville mines); (3) pyritous ores (Buck Mountain, Ticonderoga).

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[1] The following papers relate especially to the ores as distinguished from the geology: L. C. Beck, *Mineralogy of New York*, Part I., 1–38, 1842. J. Birkinbine, "Crystalline Magnetite in the Port Henry (N. Y.) Mines," *Trans. Amer. Inst. Min. Eng.*, XVIII., 747, 1890. Rec. "Note on the Magnetic Separation of Iron Ore at the Sanford Ore-bed, Moriah, Essex Co., N. Y., 1852, *Idem*, XXI., 378, 1892; see also p. 157. H. Credner, *Zeitsch. d. d. g. Gesell*, 1869, XXI., p. 516; *B. und H. Zeit.*, 1871, 369. J. D. Dana "On the Theories of Origin," *Amer. Jour. Sci.*, iii., XXII., 152, 402. E. Emmons, *Geology of New York, Second District*, pp. 87, 98, 231, 255, 291, 309, 350. Hist. C. E. Hall, "Laurentian Magnetite Ore Deposits of Northern New York," *32d Ann. Rep. State Museum*, 1884, p. 133. Rec. Hanns Hoefer, "Die Kohlen- und Eisenerzlagerstätten Nord Amerikas," 175, 1878. J. F. Kemp, "Notes on the Minerals Occurring near Port Henry, N. Y.," *Amer. Jour. Sci.*, iii., XI., 62, and *Zeitsch. f. Kryst.*, XIX., 183. "The Geology of the Magnetites near Port Henry, N. Y.," *Trans. Amer. Inst. Min. Eng.*, XXVI., 146, 1897. G. W. Maynard, "The Iron Ores of Lake Champlain," *Brit. Iron and Steel Inst.*, Vol. I., 1874. F. L. Nason, "Notes on Some Iron-bearing Rocks of the Adirondack Mountains," *Amer. Geologist*, XII., 25, 1893. B. T. Putnam "Notes on the Iron Mines of New York," *Tenth Census*, XV., 89, 1885. Rec. B. Silliman, "Remarks on the Magnetites of Clifton, St. Lawrence County, N. Y.," *Trans. Amer. Inst. Min. Eng.*, I., 364. J. C. Smock, "Iron Mines of New York," *Bull. VII., N. Y. State Museum.* Rec. J. Stewart, "Laurentian Low Grade Phosphate Ores," *Trans. Amer. Inst. Min. Eng.*, XXI., 176, 1892. Wedding, *Zeitschr. f. B., H., und S. im. p. St.*, XXIV., 330, 1876. See also the general works on Iron Ores cited at beginning of Part II. On Canadian magnetites the following papers may be mentioned: F. P. Dewey, "Some Canadian Iron Ores," *Trans. Amer. Inst. Min. Eng.*, XII., 192. B. J. Harrington, "On the Iron Ores of Canada," *Can. Geol. Survey*, 1873-74. T. S. Hunt, *Can. Geol. Survey*, 1866–69, pp. 261, 262. T. D. Ledyard, "Some Ontario Magnetites," *Trans. Amer. Inst. Min. Eng.*, XIX., 28, and July, 1891. W. H. Merritt, "Occurrence of Magnetite Ore Deposits in Victoria County, Ontario," *Proc. Amer. Asso. Adv. Sci.*, XXXI., 413, 1882.

On the western side of the mountains some extensive mining has also been done. The Benson mines at Little River are based upon a broad, mineralized zone whose ore is inclined to be lean, and to be a subject for magnetic concentration. There are numerous deposits of magnetite in Canada, to the north of Lake Ontario, whose geological relations are similar to those above described.

2.03.05. Example 12*b*. New York and New Jersey Highlands, and the South Mountain of Pennsylvania. Lenticular or pod-like masses of magnetite in Archean gneiss and crystalline

FIG. 50.

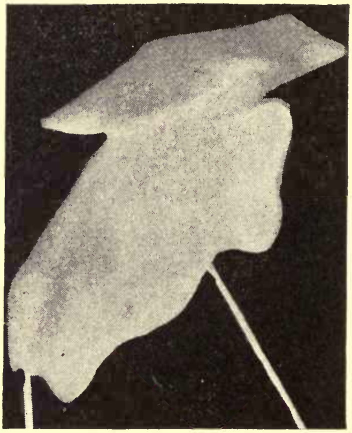

FIG. 51.

FIGS. 50 *and* 51.—*Model of the Tilly Foster ore body.* 50. *Side view, showing faulted shoulder. After F. S. Ruttmann, Trans. Amer. Inst. Min. Eng., XV.*, 79. 51. *View of bottom of same. Photographed by J. F. Kemp from the model now at the School of Mines, Columbia College.*

limestone. From Putnam County, New York, a ridge of Archean rocks runs southwest across the Hudson River, traversing Orange County, New York, and northern New Jersey, and running out in Pennsylvania. Lenses of magnetite occur throughout its entire extent. They are not as large as some in the Adirondacks, but they are more regularly distributed. East of the Hudson, in Putnam County, the Tilly Foster mine is the most important, and the descriptions and figures of it are the best illustrations of the shape of lenses published. West of the Hudson, in Orange County, the Forest of Dean mine affords considerable ore yearly. It is cut by an interesting trap dike. As the results of study of the Archean of this region, N. L. Britton has divided it into a Lower Massive group, a Middle Iron Bearing, and an Upper Schistose. (*Geol. of N. J.*, 1886, p. 77.) F. L. Nason has also sought to classify it on the basis of rock types, of which he makes four, named, from their typical occurrences, Mount Hope type, Oxford type, Franklin type, and Montville type. They are arranged in their order of probable age. They correspond in some respects to Britton's grouping, but differ materially in others. (*Geol. of N. J.*, 1889, p. 30.) Four courses, or mine-belts, have been recognized in New Jersey—the Ramapo, the Passaic, the Musconetcong, and the Pequest—in order from east to west. The lenses strike northeast with the gneisses, and usually have, like them, high dips. In addition they have also a so-called "pitch" along the strike, so that they run diagonally down the dip. They have been observed to pitch northeast with an easterly dip and southwest with a westerly. Either by the overlapping of lenses or by an approximation to an elongated bed, they sometimes, as at Hibernia, extend a mile or more in unbroken series. Again, they may be almost circular in cross section (Hurd mine). At Franklin Furnace one is found in crystalline limestone.[1]

[1] E. S. Breidenbaugh, "On the Minerals Found at the Tilly Foster Mine, New York," *Amer. Jour. Sci.*, iii., VI., 207. J. F. Kemp, "Diorite Dike at the Forest of Dean Mine," *Idem*, iii., XXXV., 331. F. H. McDowell, "The Reopening of the Tilly Foster Mine," *Trans. Amer. Inst. Min. Eng.*, XVII., 758; *Engineering and Mining Journal*, Sept. 7, 1889, 206. F. S. Ruttman, "Notes on the Geology of the Tilly Foster Ore Body, Putnam County, New York," *Trans. Amer. Inst. Min. Eng.*, XV., 79. Rec. J. C. Smock, *Bull. VII., N. Y. State Museum.* Rec. A. F. Wendt, "The Iron Mines of Putnam County," *Trans. Amer. Inst. Min. Eng.*, XIII., 478. "Iron Mines of New Jersey," *School of Mines Quarterly*, iv., III. N. L. Britton, *Ann. Rep. N. J. Survey*, 1886, p. 77. Rec. G. H. Cook and J. C. Smock, *Geol. of N. J.*, 1868. Rec. (See also subsequent annual reports, especially 1873, p. 12.) F. L. Nason, *Ann. Rep. N. J. Survey*, 1889. Rec. J. W. Pullmann, "The Production of the Hibernia Mine, New Jersey," *Trans. Amer. Inst. Min. Eng.*, XIV., 904. J. C. Smock, "The Magnetite Iron Ores of New Jersey," *Idem*, II., 314; "A Review of the Iron Mining Industry of New Jersey," *Idem*, June, 1891. Rec.

J. E. Wolff has contributed a very important and suggestive paper upon the large bed of magnetite at Hibernia. The ore extends for about one mile as developed, and forms a persistent band in a series of gneisses which under the microscope are found to contain quartz, orthoclase, plagioclase, microcline, microperthite, brown or green hornblende, a deep green or color-

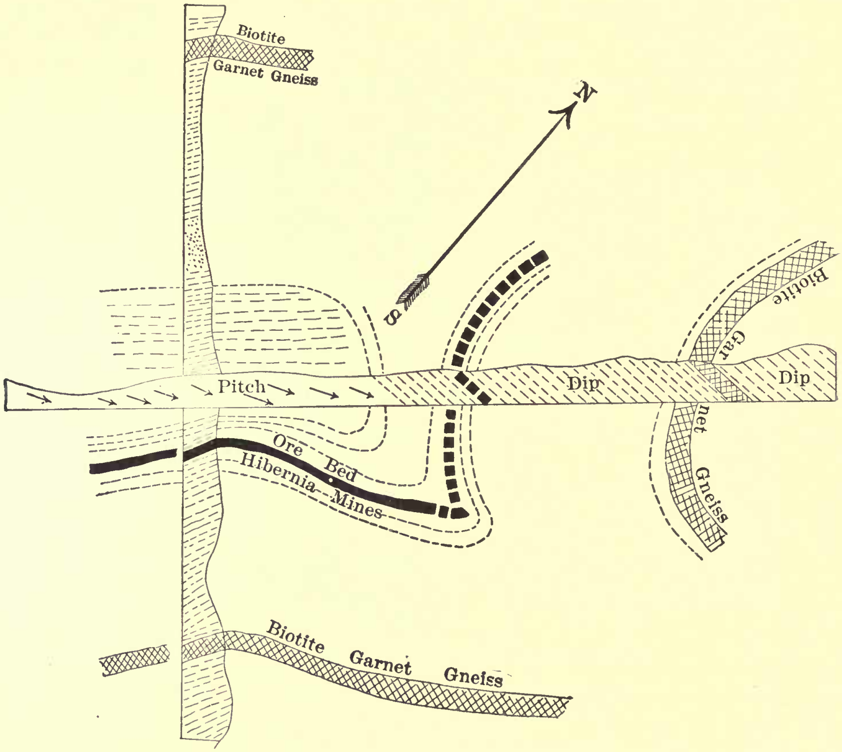

Fig. 52.—*Sketch map illustrating the geological structure of the Hibernia magnetite bed, Hibernia, N. J. The ore outcrops for one mile. After J. E. Wolff, Annual Report of the State Geologist of New Jersey for* 1893.

less augite, sometimes diallage, biotite, sometimes hypersthene, and as accessories, apatite, magnetite, and zircon. The dark silicates may form intermittent bands by their greater abundance, but are of no stratigraphic value. All the large minerals are in elongated spindles, whose long axes correspond to the pitch of the gneiss. They are thought by Wolff to have assumed this shape in crystallizing, during metamorphism. About a half mile from the ore and parallel with it is a band of biotite-garnet-graphite gneiss that is persistent, and that is folded as shown in Fig. 52. This latter rock is supposed to be a metamorphosed limestone, and the whole series is regarded as metamorphosed sediments by Wolff.[1] F. L. Nason has worked out the structural geology of the Ringwood mines, and has found that they are quite well interpreted as lying along a pitching series of folded gneisses.[2]

2.03.06. South Mountain, Pa. Small lenses of magnetite occur in Berks, Bucks, and Lehigh Counties of southeastern Pennsylvania, in the metamorphic rocks of the South Mountain belt. They are very like those to the north in New Jersey, but are lower in both iron and phosphorus. Their product has reached 100,000 tons yearly. The Cornwall magnetite is described under Example 13, for its geological structure is entirely different from the lenses.[3]

2.03.07. Example 12*c*. Western North Carolina and Virginia. Beds of magnetite, of the characters already described, in Archean gneisses and schists. The ore body at Cranberry, N. C., is the largest and best known. It occurs in Mitchell County, and has lately been connected by rail with the lines in east Tennessee. According to Kerr, the principal outcrop is 1,500 feet long and 200 to 800 feet broad; but, of course, this is not all ore. The mines can afford very large quantities of excellent Bessemer grade. Pyroxene and epidote are associated with the ore. Kerr has referred the magnetite to the Upper Laurentian. In the southern central portions of North Carolina other magnetites occur in the mica and talcose schists, which have been referred to the Huronian. (See H. B. C. Nitze, *Bull. I., N. C. Geol. Survey*, for detailed report.) (Example 10.) Magnetite has also been lately reported from Franklin and

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[1] J. E. Wolff, "Geological Structure in the Vicinity of Hibernia, N. J., and its Relation to the Ore Deposits," *N. J. Geol. Survey*, 1893, 359.

[2] F. L. Nason, "The Geological Structure of the Ringwood Iron Mines, N. J.," *Trans. Amer. Inst. Min. Eng.*, XXIV., 505, 1894.

[3] E. V. d'Invilliers, Rep. D3, *Penn. Survey*, Vol. II. (South Mountain Belt of Berks County). Rec. F. Prime, Rep. D3, Vol. I., *Penn. Survey* (Lehigh County). B. T. Putnam, *Tenth Census*, Vol. XV., p. 179.

Henry Counties, Virginia, and Stokes County, North Carolina. Some doubt, however, is cast on its amount and quality.[1]

2.03.08. Example 12*d*. Colorado Magnetites. Beds of magnetite of a lenticular character in rocks described as syenite (Chaffee County) and diorite (Fremont County). With these a number of others are mentioned which vary from the example, but of which more information is needed before they can be well classified. The last are mere prospects. The mines in Chaffee County have been the only actual producers. There are three principal claims—the Calumet, Hecla and Smithfield. They extend continuously over 4,000 feet. The wall rock is called syenite. Chauvenet describes them as having resulted from the oxidation of pyrites, and as being in rocks of Silurian age. They average 57% Fe, with only 0.009 P, but are comparatively high in S, reaching 0.1 to 2.0%. These mines and those at the Hot Springs, mentioned under Example 2, have furnished the Pueblo furnaces with most of their stock. The deposit in Fremont County is at Iron Mountain, but is too titaniferous to be valuable. It is a lenticular mass in olivine-gabbro, and is again referred to under 2.03.11. A large ore body has been reported from Costillo County, in limestone (Census Report) or syenite (Rolker). In Gunnison County, at the Iron King and Cumberland mines, excellent ore occurs in quartzites and limestones, called Silurian. At Ashcroft, near Aspen, high up in the northern side of the Elk Mountains, is a great bed or vein of magnetite in limestones of Carboniferous age with abundant eruptive rocks near. It is thought by Devereux to be altered pyrite. Still, pyrite is a common thing with magnetite elsewhere. There are other smaller deposits in Bowlder County, and elsewhere in the State.[2]

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[1] H. S. Chase, "Southern Magnetites and Magnetic Separation," *Trans. Amer. Inst. Min. Eng.*, XXV., 551–557, 1896. W. C. Kerr, *Geology of North Carolina*, 1875, 264. J. P. Kimball, "On the Magnetite Belt at Cranberry, N. C.," etc., *Amer. Geol.*, XX., 299–312, 1897. H. B. C. Nitze, "Notes on the Magnetites of Southwestern Virginia and the Contiguous Territory of North Carolina," *Trans. Amer. Inst. Min. Eng.*, XX., 174, and discussion, 185. "The Magnetic Iron Ores of Ashe Co., N. C., *Idem*, XXI., 260. "Magnetic Iron Ore in Granville Co., N. C.," *Eng. and Min. Jour.*, April 23, 1892, p. 447. B. Willis, *Tenth Census*, XV., 325; *Eng. and Min. Jour.*, Jan. 7, 1888. Kerr and Hanna, "Ores of North Carolina," 1893.

[2] R. Chauvenet, "Papers on Iron Prospects of Colorado," *Ann. Reps. Colo. State School of Mines*, 1885 and 1887; also *Trans. Amer. Inst. Min.*

2.03.09. In Wyoming an immense mass of titaniferous magnetite is known near Chugwater Creek. It is more fully described under Example 13, with which type of ore body it belongs.

2.03.10. Example 12*e*. California Magnetite. Beds of magnetite of lenticular shape in metamorphic slates and limestones on the western slope of the Sierra Nevada. Others of different character are also known. In Sierra and Placer counties lenses of excellent ore are found, accompanying an extended stratum of limestone in chlorite slate. A great ore body of magnetite described as a vein has lately been reported from San Bernardino County. It is said to be from 30 to 150 feet thick, and to lie between dolomitic limestone and syenite.[1] A great bed of a kind not specified is reported from San Diego County.[2]

2.03.11. Example 13. Masses of titaniferous magnetite in igneous rocks which are most often gabbros or related types. General comments were made upon these in 1.06.14 and 1.06.16. In many cases such ore bodies seem undoubtedly to be excessively basic segregations of fused and cooling magmas. Whether the tendency of these early crystallizations to concentrate is due to Soret's principle, to magnetic currents or attractions, or to the high specific gravity of the mineral which might cause it to sink in the magma, is perhaps not always clear. for all these explanations have been suggested. The masses are not yet of practical value in North America, and hence are not, strictly speaking, ores; but no one familiar with their size and amount can resist the conviction that they will ultimately be utilized. The commonest rocks forming the walls are gabbros, norites, diorites or peridotites, all of which are close relatives. Later metamorphism, such as mountain-making processes and the

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Eng., Denver meeting, 1889. Rec. W. B. Devereux, "Notes on Iron Prospects in Pitkin County, Colorado," *Trans. Amer. Inst. Min. Eng.*, XII., 608. B. T. Putnam, *Tenth Census*, Vol. XV., p. 472. Rec. C. M. Rolker, "Notes on Iron Ore Deposits in Colorado," *Trans. Amer. Inst. Min. Eng.*, XIV., 266. Rec.

[1] *Ann. Rep. State Mineralogist*, 1889, p. 235.

[2] *Ibid.*, 1889, p. 154. J. R. Browne, "Mineral Resources West of the Rocky Mountains," 1868. C. King and J. D. Hague, "Mineral Resources West of the Rocky Mountains," 1874, p. 44. H. G. Hanks and W. Irelan, *Ann. Reps. State Mineralogist, California.* (Very little on iron.) F. von Richthofen, private reports quoted in *Tenth Census*, Vol. XV., p. 495. J. D. Whitney, *Geol. Survey of Cal.*, Vol. I.

like, sometimes give the wall rock a gneissic structure and stretch out the ore into apparent beds. The ores have some characteristic peculiarities of chemical and mineralogical composition. As a rule, although not invariably, they are low in sulphur and phosphorus. On analysis they almost always afford small percentages of vanadium, chromium, nickel and cobalt. They may be so rich in alumina and magnesia as to indicate the presence of spinel. In fact, one variety of these ores, that is found near Peekskill, N. Y., and at Routivara, in Sweden, is an aggregate of spinel and titaniferous magnetite. Ores of this variety show genetic relations with some deposits of emery and corundum. The pig iron afforded by the titaniferous ores has certain excellencies peculiar to itself that may be due to one or more of the above ingredients.[1]

Many years ago T. S. Hunt recognized the fact that the titaniferous ores of Canada and the Adirondacks were limited to the labradorite rocks of the Norian or Upper Laurentian series. It is now known that they may occur both in anorthosites and in basic gabbros. The ore-bodies are of enormous size on the lower St. Lawrence (Bay St. Paul), on the Saguenay River, and near Lake Sandford, in the heart of the Adirondacks. Smaller, but still very large masses, are known in Quebec, north of Montreal; in Ontario, north of Kingston; in Westport and Elizabethtown, N. Y., and in several other places not far from the national boundary.[2]

[1] The chemical characters are discussed by J. F. Kemp in a paper on "The Titaniferous Iron Ores of the Adirondacks," *Nineteenth Ann. Rep. Dir. U. S. Geol. Survey*, Part III., p. 377. A detailed review of titaniferous ores the world over, by the same writer, will be found in the *School of Mines Quarterly*, July and November, 1899. All the analyses known to be published to date are compiled.

[2] On the Canadian ores see: F. D. Adams, "Ueber das Norian oder Ober-Laurentian von Canada, *Neues Jahrbuch, Beilage Band*, VIII., 419; an English translation will be found in the *Canadian Record of Science*, 1894, 169; 1895, Jan., p. 1, July, p. 1. "On the Igneous Origin of Certain Ores," *Proc. General Mining Association of the Province of Quebec*, Jan. 12, 1894. E. J. Chapman, "On Some Iron Ores of Central Ontario," *Trans. Royal Soc. of Can.*, 1885, 9. See also *Idem*, 1884, 159, R. W. Ells, *Geol. Survey of Canada*, 1888–89, 14K. B. J. Harrington, *Idem*, 1873–74, 227. T. S. Hunt, *Idem*, 1847, 59; 1867, 212. F. J. Pope, "Titaniferous Ores of Ontario," *Trans. Amer. Inst. Min. Eng.*, May, 1899. On the ores in New York see: E. Emmons' Report on the Second District, N. Y., State Survey, 244, 1842. J. F. Kemp, "The Titaniferous Iron Ores of the Adi-

The ores near Peekskill are low in titanic oxide, not ranging above four per cent., but they are extremely rich in alumina, and attention was first directed to them by J. P. Kimball, on account of this ingredient. They constitute excessively basic developments in the norites of the Cortlandt series of gabbroic rocks, that cover about twenty-five square miles on the Hudson River. They are also present as small, separate dikes. They consist of spinel, magnetite, corundum, garnet and occasional sillimanite, and are remarkably close parallels with some results of artificial experiments obtained by Josef Morozewicz. They have been utilized for emery and are near relatives in a geological way to some deposits of corundum and emery.[1]

A very curious and interesting knob, or boss, of peridotite is exposed at Iron Mine Hill, Cumberland, R. I., that is so enriched with titaniferous magnetite as to receive attention as an ore. It protrudes through mica schists and is closely akin to the Swedish one at Taberg, as was recognized many years ago by M. E. Wadsworth.[2]

A belt of titaniferous ores traverses New Jersey and affords magnetites of moderate percentages of TiO_2.[3] Several belts

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rondacks," *Nineteenth Ann. Rep. Director U. S. Geol. Survey*, 377, 1899. Also *Fifteenth Ann. Report of N. Y. State Geologist*, 608, 1898. G. W. Maynard, "The Iron Ores of Lake Champlain," *Jour. Brit. Iron and Steel Inst.*, 1874. A. J. Rossi, "Titaniferous Ores in the Blast Furnace," *Trans. Amer. Inst. Min. Eng.*, XXI., 832, 1893. "The Smelting of Titaniferous Ores," *The Iron Age*, Feb. 6 and 20, 1896.

[1] J. D. Dana, *Amer. Jour. Sci.* Further notes by G. H. Williams, *Idem*, Feb., 1887, 194. J. P. Kimball, *Amer. Chemist*, IV., 1874, 321 ; *Trans. Amer. Inst. Min. Eng.*, IX., 19, 1880. Their geological relations will be more fully described in a forthcoming paper by J. F. Kemp and M. B. Yung. On the artificial production of these ore mixtures, see Josef Morozewicz, *Tschermaks Min. u. Petr. Mitth.*, "On the Related Swedish Ores." W. Petterson, *Geol. Fören. in Stockholm Förhandl.*, XV., 45, 1893. Hj. Sjogren, *Idem*, 55 and 140.

[2] M. E. Wadsworth, "Lithological Studies," *Bull. Mus. Comp Zöol. Harvard College*, VII., 1881, 183. A later note will be found in the *Bulletin Amer. Iron and Steel Association*, Nov. 20, 1889. See also, A. L. Holley, *Trans. Amer. Inst. Min. Eng.*, VI., 224, 1877. C. T. Jackson, *Geological Survey of Rhode Island*, 53, 1840. N. S. Shaler, *Sixteenth Ann. Rep. U. S. Geol. Survey*, II., 321. *Bull. Mus. Comp. Zöol., Harvard College*, XVI., 185. B. Willis, *Tenth Census*, XV., 567.

[3] On New Jersey, see the *Annual Reports of the State Geologist* as follows: 1873, 53, 55; 1875, 35; 1876, 54; 1877, 49; 1878, 99, 100; 1879, 62, 67, 76; 1880, 125. R. W. Raymond, *Trans. Amer. Inst. Min. Eng.*, XXI.,

occur in North Carolina.[1] The wall rocks have not been as yet accurately determined in either State. In the extreme northeastern corner of Minnesota, on Mayhew Lake, and at other points within the huge area of gabbros in this State, the ores are known, and some small amount of work has been expended on them.[2] Titaniferous ore has been described by Arnold Hague as forming great dikes in granite on Chugwater Creek, Wyo. Olivine-gabbro and anorthosite are in the neighborhood, and have been determined as the wall rock of at least one mass of ore by B. F. Hill.[3] The rock was collected by W. G. Knight. The ores are also known in at least three places in Colorado. One is in Fremont County, at the so-called Iron Mountain, which is situated about fifty miles west of Pueblo, in the Wet Mountain valley, on a tributary of Grape Creek. A sample of rock believed to have come from the walls has been determined by J. F. Kemp to be an olivine-gabbro.[4] Another locality is Caribou Hill in Boulder County,[5] and a third

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1892, 275. B. F. Fackenthal, *Idem*, 279. Isidor Walz, *Amer. Chemist*, June, 1876, 453. The Church mine on Schooley's Mountain is the best known one.

[1] On North Carolina, see *North Carolina Geol. Survey*, II., 1893, 181. J. P. Lesley, "Notes on the Titaniferous Iron-ore Belt near Greensboro, N. C.," *Proc. Amer. Phil. Soc.*, XII., 1871, 139. H. B. C. Nitze, *Bulletin I., N. C. Geol. Survey.* Bailey Willis, "On the Dannemora Mine," *Tenth Census*, XV., 310.

[2] W. S. Bayley, "Peripheral Phases of the Great Gabbro Mass of Northeastern Minnesota," *Jour. Geol.*, Vol. I., p. 818. See also, for notes on their petrography, *Idem*, Vol. III., p. 1. C. R. Van Hise, *Bull. Geol. Soc. Amer.*, VII., 1895, 488. N. H. Winchell, *Tenth Ann. Rep. Minn. Geol. Survey*, 1882, 85. N. H. and H. V. Winchell, *Bulletin VI., Idem*, 136. M. E. Wadsworth, *Bulletin II., Idem*, 63, 73.

[3] Arnold Hague, *U. S. Geol. Explor. Fortieth Parallel*, II., 12, 1877. F. V. Hayden, *U. S. Geol. and Geogr. Survey, Territories*, 1870, 14. B. F. Hill, *School of Mines Quarterly*, July, 1899. W. G. Knight, *Bull. XIV. Wyo. Agric. Experiment Station*, 177, 1893. Howard Stansbury, *Exploration and Survey of the Valley of the Great Salt Lake*, 1852, 266. F. Zirkel, *U. S. Geol. Explor. Fortieth Parallel*, VI., 107.

[4] F. M. Endlich, *U. S. Geol. and Geogr. Survey of the Territories*, 1873, 333. B. T. Putnam, *Tenth Census*, XV., 472.

[5] Regis Chauvenet, "Notes on Iron Prospects in Northern Colorado," *Biennial Rept. of the Colo. State School of Mines*, 1886, 16. B. T. Putnam, *Tenth Census*, XV., 476.

is in the Cebolla district, Gunnison County,[1] where the amount is reported to be large. The ores in basic nepheline rocks in Brazil[2] are the only others in the Western Hemisphere. The Swedish and Norwegian ores are similar in their geological relations to the several American types, viz.: those at Ekersund and Soggendahl,[3] to the ores of Quebec and the Adirondacks; those at Routivara[4] to the aluminous ores of the Cortlandt series; the Taberg[5] ore is like that at Cumberland, R. I.; and the Alnö[6] occurrence resembles the Brazilian type. The titaniferous iron sands will be referred to under magnetite sands.

2.03.12. Example 14. Cornwall, Pa. Deposits of soft magnetite, resting against igneous dikes and associated with green, pyritous shales, Siluro-Cambrian limestone and Triassic sandstone. These ore bodies are to be classed among the largest ever mined. They form three hills extending in an east and west direction, and called respectively Big Hill, Middle Hill and Grassy Hill. As the accompanying contour map shows, Big Hill is the highest and narrowest, while Middle Hill contains the most ore. The hills lie just at the southeastern edge of the Great Valley, and are six miles from the flour-

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[1] Regis Chauvenet, "Iron Resources of Gunnison Co.," *Amer. Rep. Col. State School of Mines*, 1887, 18. "Iron Resources of Colorado," *Trans. Amer. Inst. Min Eng.*, XVIII., 272. Arthur Lakes, "The Gréat Cebolla River Deposits," *Colliery Engineer*, XVI., 267, 1896.

[2] O. A. Derby, "Magnetite Ore Districts of Jacupiranga and Ipanema, Sao Paulo, Brazil," *Amer. Jour. Sci.*, April, 1891, 311.

[3] T. Dahl, *Förhandl. videnskabs Natm. i. Stockholm*, 1863. D. Forbes, *Chem. News*, December 11, 1868, 275. S. Forbes, *Jour. Brit. Iron and Steel Inst.*, 1874, 131. Th. Kjerulf, *Nyt. Magazin for Natv.*, XXVII., 1883. H. Rosenbusch, *Idem.* T. C. Thomassen, *Idem*, XXIV., 287. C. F. Kolderup, *Bergen's Museum's Aarbog. in Stockholm*, 1896, 159. Rec. H. H. Reusch, *Geol. Fören in Stockholm*, 1877, 197; *Neues Jahrbuch*, 1878. J. H. L. Vogt, *Idem*, XIII., 476, 683, XIV., 211; *Geological Magazine*, IX., 82; *Neues Jahrbuch*, 1893, II., 69; *Zeitschr. für prakt. Geologiè*, January, 1893, 6; October, 1894, 384; *Archiv. für Mathem. og Naturvidenskab, Kristiania*, X. and XII., 1887. The papers of Kolderup and Vogt are of chief value for reference.

[4] W. Petterson, *Geol. Fören. i. Stockholm*, XV., 45, 1893; (*Neues Jahrbuch*, 1894, I., 88); H. Sjogren, *Idem*, XV., 55, 140, 1893; (*Neues Jahrbuch*, 1894, I., 88).

[5] A. Sjogren, *Geol. Fören. i. Stockholm*, III., 42, 1876; (*Neues Jahrbuch*, 1876, 434). A. E. Tornebohm, *Idem*, V., 610; *Neues Jahrbuch*, 1882, II., 66. J. H. L. Vogt, *Zeitschrift für prakt. Geologie*, January, 1893, 8.

[6] A. G. Hoegbom, *Geol. Fören. i. Stockholm*, XVII., 100, 214, 1895.

ishing little city of Lebanon. The geological section (Fig. 53) illustrates the position of the strata. The Siluro-Cambrian series is cut by an immense diabase dike near its southeastern limit, and on the south side of the dike which forms the northern rampart of the three hills lies the ore. The ore is a soft, rather earthy magnetite, which occasionally shows octahedra. While richer and purer on the original weathered surface, it is now interlaminated and closely involved with layers of limey shales which contain pyrite, at times in beautiful crystals. Most of the ore is merchantable raw, but large quantities are so low from this admixture of shales that they are being saved for possible future magnetic concentration. The presence of the pyrite makes it necessary to roast all the raw ore before

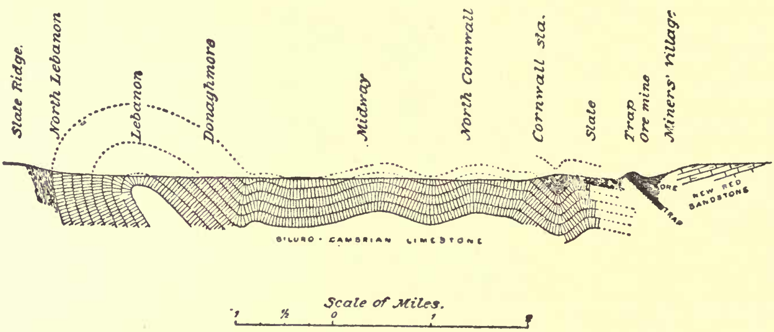

FIG. 53.—*Section along Cornwall Railroad from Lebanon to Miner's Village. After E. V. d'Invilliers. Amer. Inst. Min. Eng., XIV.*, 898, 1886

smelting, but the phosphorus is so low that Bessemer pig is the chief resulting product.

Big Hill differs from the others in structure. The northern dike with a steep southerly dip has an offsetting and very heavy branch to the southwest which forms with it a great trough or basin so far as one can see. The bottom of the ore has been reached by one rather shallow hole, but it seems quite certain that the dikes will come together at a point indicated by the several dips. The surface of the southerly branch is strongly corrugated. The ore of Middle Hill extends to a greater distance south from the dikes than that of Big Hill, and is cut by one small and unimportant offset of trap that is two or three feet across. At the western end of the workings, lime-

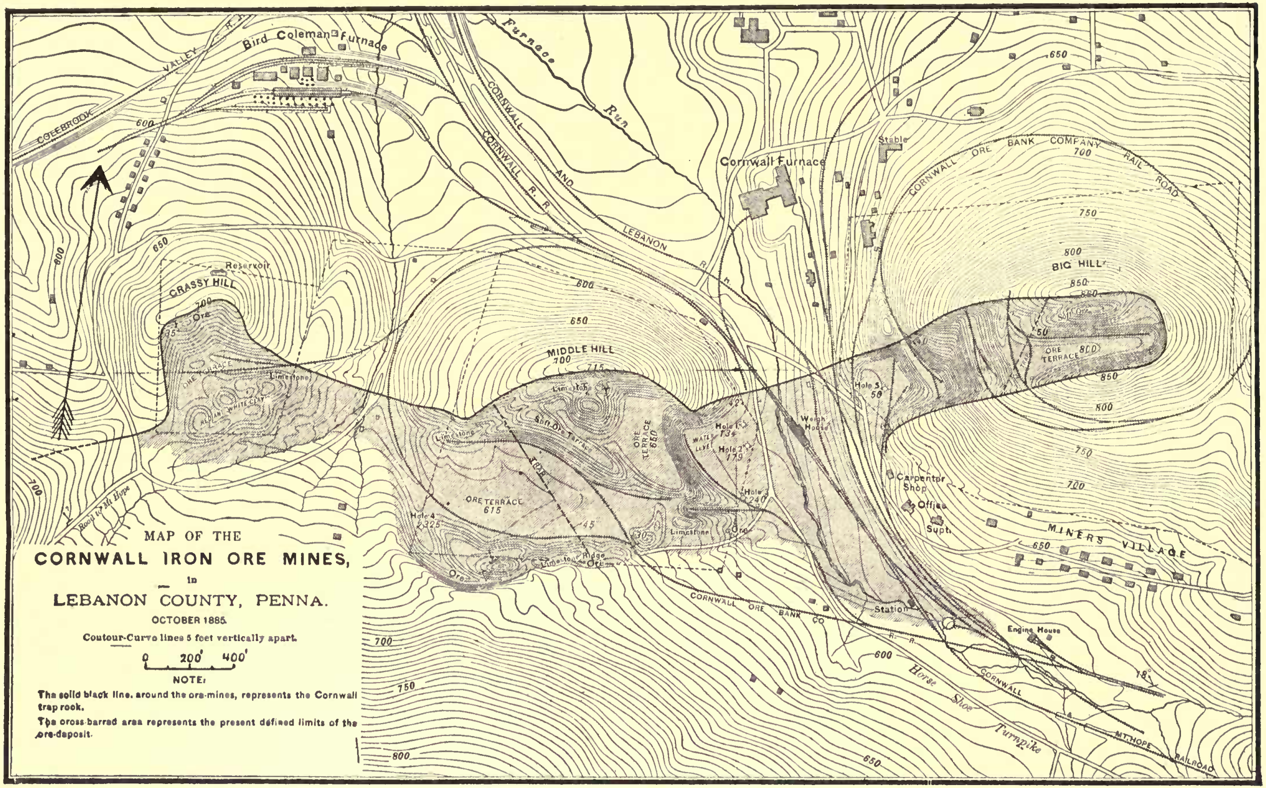

FIG. 54.—*Map of Cornwall Mines. After E. V. d'Invilliers, Trans. Amer. Inst. Min. Eng., Vol. XIV.*, 904

stone is quite thick and in good exposure. It reaches well over to Grassy Hill. Grassy Hill is smaller, and is much less developed than either of the others. E. V. d'Invilliers has emphasized the important point that the dip of the ore in Big Hill is southwest at such an angle as to bring it below the Middle Hill bed, and that this latter also dips below the limestone and the Grassy Hill beds. Such being the case, enormous reserves must lie under the two western hills. The depths of the several bore holes given on the map and all in ore indicate its presence in very great amount, but it is important to show in this connection the absence of faults, for the map of Bailey Willis notes their presence, and observations of the writer corroborated their existence.

The pyrite in the calcareous shales is occasionally replaced by chalcopyrite in irregular nodules or veinlets. The presence of copper was early noted, and some mining was done for it near the surface. Fine museum specimens of moss-copper, azurite, malachite, etc., were afforded. Even during the earlier iron-mining some copper ore was set aside as a small by-product. Copper is still present in the mine-water, for bright shovels left in it become coated, and the bones of dead animals thrown out on the ore banks, as well as chips of wood, etc., become tinted a bright green.

Much difference of opinion has prevailed about the age and geological relations of these ores. Some have thought them Mesozoic and a part of the Triassic, while others, and notably J. P. Lesley, have regarded them as belonging to the Siluro-Cambrian series and analogous to the limonites of the Great Valley, but metamorphosed. The great trap dikes afford the most reasonable explanation or cause of the change, and to these may be referred the alteration. The apparent origin of many Siluro-Cambrian limonites from the hydration and oxidation of pyritous shales and schists gives much support to this view, and the association of limestone with the ore and the general stratigraphical relations are hard to explain in any other way.[1]

[1] E. V. d'Invilliers, "Cornwall Iron Ore Mines," *Trans. Amer. Inst. Min. Eng.*, XIV., 873. Rec. Lesley and d'Invilliers, *Ann. Rep. Second Penn. Geol. Survey*, 1885, 491. Rec. J. P. Lesley, *Final Rep.*, I, 351, 1892. T. S. Hunt, "The Cornwall Mines," etc., *Trans. Amer. Inst. Min. Eng.*, IV., 319. H. D. Rogers, *First Penn. Geol. Survey*, II., 718. B. Willis, *Tenth Census*, XV., 223.

The total production to April, 1894, is stated by Mr. Boyd, the superintendent of the mines, to be upward of 12,000,000 tons, while an annual output of 800,000 can be easily maintained. The ore varies from 40 to 55% Fe. It almost never contains as much as 0.02 P, but runs up to 4% S. It is also siliceous.

2.03.13. Several other mines of somewhat related character to the Cornwall deposits are known along the edges of this Triassic belt, and associated with its trap intrusions. The mining districts lie near its north and south boundaries, and not far from its contacts with the older rocks. On the north side from east to west there are the Boyertown (Berks County), the Fritz Island and the Wheatfield, near Reading, and finally the Dillsburg in York County, west of the Susquehanna. On the south side in the same order are the French Creek, St. Mary's and the Jones, all quite near together and nearly south of Reading. Of these the Boyertown mines have been most worked.[1] The Cornwall mines are between the Wheatfield and the Dillsburg. At the Boyertown mines the ore lies both between a brecciated limestone and Mesozoic sandstone and wholly within the limestone, but trap dikes are not lacking. At Fritz Island the ore is entirely enclosed in limestone, and is penetrated by a trap dike. In the Wheatfield mines the same brecciated limestone appears, and has the ore intimately associated with it. On both occurs the Mesozoic sandstone, and the succession is five times repeated by faulting. The usual trap penetrates the ore. The French Creek and St. Mary's mines are unique in that they are contained in gneiss. They are famous sources of fine crystals of pyrite, chalcopyrite and other minerals. The Jones mine exhibits the ore between trap and limestone, the trap being over the ore in the North pit and

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[1] P. Fraser, "Study of the Specular and Hematite Ores of Iron of the New Red Sandstone in York County, Pa.," *Trans. Amer. Inst. Min. Eng.*, V., 132. Also *Penn. Geol. Survey*, Rep. CC, 205, 217. H. Hoefer, "Die Kohlen und Eisenerzlagerstätten Nord Amerika's," 241. Also *Penn. Survey*, Rev. C2. E. V. d'Invilliers, "Cornwall Iron Ore Mines," *Trans. Amer. Inst. Min. Eng.*, XIV., 873. Rec. Lesley and d'Invilliers, *Ann. Rep. Second Penn. Survey*, 1885. J. P. Lesley, *Final Report*, Vol. I., p. 351, 1892. Rec. T. S. Hunt. "The Cornwall Mines," etc., *Trans. Amer. Inst. Min. Eng.*, IV., 319. H. D. Rogers, *First Penn. Geol. Survey*, II., 718. B. Willis, *Tenth Census*, Vol. XV., p. 223. Rec.

under it in the south. A green shale is also met here, as indeed in most of the other localities, although not specially mentioned. At Dillsburg the evidence against the Triassic age of the ores is less positive, and upon this occurrence Fraser has based a strong argument for the latter view. Triassic sandstone at times forms both walls, although there are instances where limestone appears as the foot. In all these localities the presence of copper is notable. It and the magnetic or metamorphosed condition of the ore are probably referable to the trap.

2.03.14. Example 14*a*. Iron County, Utah. Beds of magnetite and hematite bearing evidence of being metamorphosed limonite, in limestones of questionable Silurian age, and associated with eruptive rocks described as trachyte. The limestones have been much upturned, metamorphosed, and pierced by dikes and eruptive masses. The ore forms great projecting ridges and prominent outcrops, locally called "blow-outs." The usual lenticular shape is not lacking. They occur over an area of fifteen by five miles, and are in the southern end of the Wasatch Mountains. The samples show rich ores, which at times exceed the Bessemer limit of phosphorus. In the Star district the ore apparently lies between the quartzite and granite. Hematite occurs in large amount, as does quartz, while some streaks have large crystals of apatite. The importance of the deposits lies in the future. They are the largest in the West, and are interesting in their bearing on the general origin of the magnetite. Coal, not proved to be good for smelting, is near, but centers of iron consumption are very far away.[1]

2.03.15. Example 15. Magnetite sands. Beds of magnetite sands concentrated on beaches or bars by waves and streams. The magnetite has been derived from the weathering of igneous and metamorphic rocks through which it is everywhere distributed. When in the sand of a sea beach, it and other heavy minerals tend to become concentrated by the sorting action of the waves. They resist the retreating undertow better than lighter materials. Such deposits are very abundant at

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[1] W. P. Blake, "Iron Ore Deposits of Southern Utah," *Trans. Amer. Inst. Min. Eng.*, XIV., 809. J. S. Newberry, "Genesis of Our Iron Ores," *School of Mines Quarterly*, March, 1880. Rec. *Engineering and Mining Journal*, April 23, 1881, p. 286; *Proc. National Academy*, 1880. B. T. Putnam, *Tenth Census*, Vol. XV., 486. Rec.

Moisie, on the St. Lawrence, below Quebec, and in the United States are known in smaller developments on Lake Champlain; at Quogue, L. I.; on Block Island; in Connecticut; along the Great Lakes, and on the Pacific coast. Grains of garnet, olivine, hornblende, etc., minerals of high specific gravity, are also in the sands. Many are too high in titanium to be of use, but there is no more difficulty in their concentration than in that of artificially crushed ore. In Brazil and New Zealand they have attracted attention.[1]

2.03.16. *On the Origin of Magnetite Deposits.* It is important to note that magnetite deposits are almost always in metamorphic rocks, which owe their character to regional metamorphism or to the neighborhood of igneous rocks (Pennsylvania and Utah). Gneisses form the commonest walls, but so-called norites, or gabbros, and crystalline limestones also contain them. Where there is lamination or foliation the magnetite conforms to it. As the history of the metamorphic rocks is so often uncertain, the magnetites share the same doubt. In igneous rocks magnetite is the most widely occurring of the rock-making minerals. In all explanations the prevailing lenticular shape, the general arrangement in linear order, and the existence of great beds must be considered. The shape is very similar to that of deposits of specular hematite, with which magnetite is often associated. (Examples 9 and 10.) The following hypotheses have been advanced for the origin of magnetites: 1. Intruded (eruptive) masses. This supposes that the lenses have been intruded like a trap dike, and have then been squeezed and pinched apart. Though formerly much advocated, it is now generally rejected. 2. Excessively basic portions of igneous rocks. This supposes that large amounts of iron oxide have separated in the cooling and crystallizing of basic magmas. There are such occurrences, although seldom, if ever, pure enough or abundant enough for mining. The titaniferous magnetite of the Minnesota gabbros has been alluded to (2.02.25), and also the Brazilian ore and the Cum-

[1] T. S. Hunt, *Geol. Survey, Canada,* 1866–69, 261, 262; quoted in *Sixteenth Ann. Rep. Dir. U. S. Geol. Survey,* III., 50, 51; *Can. Nat.,* VI., 79. A. A. Julien, "The Genesis of the Crystalline Iron Ores," *Acad. Nat. Sci., Phila.,* 1882, 335; *Engineering and Mining Journal.* February 2, 1884. On New Zealand sands, E. M. Smith, *Proc. Brit. Iron and Steel Inst.,* May, 1896; *Eng. and Min. Jour.,* June 13, 1896, p. 566.

berland Hill (R. I.) peridotite. Should such igneous rocks be subjected to regional metamorphism and the stretching action characteristic of it, the ore masses might be drawn out into lenses. 3. Metamorphosed limonite beds. This idea has been most widely accepted in the past. It presupposes limonite beds formed as in Examples 1 and 2, which become buried and subjected to metamorphism, changing the ore to magnetite, and the walls to schists and gneisses. Igneous rocks have apparently changed limonites to magnetite at Cornwall, Pa., and in Utah, but such changes by regional metamorphism are less easy to demonstrate. The limonite may have resulted from the oxidation of lenses of pyrite. 4. Replaced limestone beds, or siderite beds subsequently metamorphosed. Such deposits may pass through a limonite stage. The general process is outlined under Example 9*c*, as developed by Irving and Van Hise in the Gogebic district. The lenticular deposits of siderite at the Burden mines (Example 4) are very suggestive, and some such original mass might in instances be metamorphosed to magnetite. 5. Submarine chemical precipitates. This is outlined under Example 9*d*, as applied by the Winchells in Minnesota. 6. Beach sands. The lenses are regarded as having been formed as outlined under Example 15. The same heavy minerals sometimes occur with magnetite lenses as are found on beaches.[2] 7. River bars. This regards the lenses as due to the concentration of magnetite sands in rivers or flowing currents. Hence the overlapping lenses, the arrangement in ranges or on lines of drainage, and the occasional swirling curves found on the feathering edges of lenses, as in the Dickerson mine, Ferromont, N. J.[3] It is also reasonable to suppose that lakes or still bodies of water may have occurred along such rivers, and have occasioned the accumulation. 8. Segregated veins. By this method the iron oxide is conceived to concentrate from a state of dissemination in the walls by slow segregation in solution to form the ore bodies along favorable beds. The action is analogous to the formation of concretions, and is illustrated on a small scale by the well-

[1] See also Dakyns and Teall, *Quar. Jour. Geol. Soc.*, LXVIII., p. 118.

[2] See B. J. Harrington, *Can. Geol. Survey*, 1873, 193; A. A. Julien, *Phila. Acad. Sci.*, 1882, 335.

[3] See H. S. Munroe, *School of Mines Quarterly*, Vol. III., p. 43—an important paper.

known disks of pyrite, or of siderite, that form in clays and shales. It is a curious fact, however, that some magnetites are in wall rock that hardly shows a trace of a dark silicate. The lenses at Hammondville, in the Lake Champlain district, are in a white, or light-colored gneissoid rock, consisting of quartz, acidic plagioclase, and a few scattered garnets. In such surroundings segregation could not be applied, but where the walls are supplied with hornblende and other ferruginous minerals, and are reasonably basic, it might be advocated.

Several other hypotheses with small claims to credibility could be cited. They are outlined at length in *Bull. VI., Minn. Geol. Survey*, p. 224, but in this place there has been no desire to take up any but those deserving serious attention. It may be said that while one or the other of the above seven hypotheses may in instances be applied with reason, yet most candid observers with widened experience have grown less positive in asserting them as axiomatic.

ANALYSES OF MAGNETITES.

(Caution in interpreting analyses is again emphasized as under 2.01.26.)

	Fe.	P.	S.	TiO_2.	SiO_2.	Al_2O_3.
Canada (Rideau Canal)	50.23	......	......	9.80	......	......
Chateaugay mines, N. Y., lump	49.24	0.029	0.052	......	18.447	......
" " concentrated	66.00	0.003	......	......	......	......
Mineville, N. Y. (Mine 21)	62.10	1.198	......	......	......	......
Orange County, N. Y. (Forest of Dean)	63.00	0.621	0.148	......	......	......
Putnam County, N. Y.	48.82	0.021	0.080	......	11.75	3.500
New Jersey (Hibernia)	53.75	0.364	......	......	......	......
Cornwall, Pa.	42.70	0.135	0.620	......	......	3.411
Cranberry, N. C.	64.64	0.004	0.115	......	......	......
Colorado (Calumet)	49.23	0.026	......	......	3.85	......
" (Iron King)	58.75	0.044	0.123	......	......	......
Utah (Iron County)	62.60	......	0.120	......	4.80	......
California (Gold Valley)	60.68	......	......	......	10.87	......

2.03.16. Of importance in connection with iron ore deposits are the recent studies of the distribution of phosphorus along certain lines in the beds, by a knowledge of which it is possible to keep more valuable Bessemer ore distinct from less valuable. Such lines have been found in Michigan, and have been called by D. H. Browne "isochemic lines." Though less marked at the Burden mines (Example 3), the phosphorus was characteristic of certain varieties of the ore. Much work has also been done on the same question at Iron Mountain, Mo.[1]

PYRITE.

2.03.17. Example 16. *Pyrite Beds.* Beds (veins) of pyrite, often of lenticular shape and of character frequently analogous to magnetite deposits, in slates and schists of the Cambro-Silurian or Huronian systems, and less often in gneiss of the Archean. Slates are most common, and gneiss least so. They extend from Canada down the Appalachians to Alabama, being found at Capelton, Quebec; Milan, N. H.; Vershire, Vt.; Charlemont, Mass.; Louisa County, Virginia; Ducktown, Tenn., and at many points less well-known in Alabama. Anthony's Nose, N. Y., the Gap mine, Pennsylvania, and Sudbury, Ontario, being different geological relations, will be mentioned under "Nickel" with other similar occurrences.

2.03.18. The ore bodies lie interfoliated in the slates or schists, and the different lenses often overlap and succeed each other in the footwall, and exhibit all the phenomena cited under magnetites. Chalcopyrite is usually present in small amount, and where the copper reaches 3 to 5% they are valuable as copper ores. (See under "Copper.") At present they are of increasing importance as a source of sulphuric acid fumes for the manufacture of vitriol. Small amounts of lead and zinc sulphide are often present, and rarely a little silver. Nickel and cobalt occur, especially in the pyrrhotitic varieties. They are worthless as a source of iron. The smaller deposits of auriferous pyrites in the Southern States will be mentioned under "Gold."

2.03.19. Some pyrites lenses may have accumulated in a way analogous to the bog ore hypothesis, cited under "Magnetite"; but instead of the iron being precipitated as oxide, it has probably come down as sulphide from the influence of decaying organic matter, and has subsequently shared in the metamorphism and solidification of the wall rock. At the same time it must be

[1] D. H. Browne, "On the Distribution of Phosphorus at the Luddington Mines," etc., *Trans. Amer. Inst. Min. Eng.*, XVII., p. 616. I. Olmsted, "The Distribution of Phosphorus in the Hudson River Carbonates," *Trans. Amer. Inst. Min. Eng.*, XVIII., p. 252. W. B. Potter, "Analysis of Missouri Ore." published in *Mineral Resources*, 1890, p. 47.

admitted to be an obscure point. By many they are thought, with more reason, to have originated like a bedded fissure vein whose overlapping lenticular cavities have been formed by the buckling of folded schists.[1] (Cf. "Gold Quartz," as later described.) The Ducktown veins are on lines of dislocation beyond question. Replacements of pinched beds of limestone are always to be considered, and the presence of intruded dikes, though disguised by metamorphism, is always to be kept in mind.

2.03.20. The excavations in some of the mines in the pyrite beds of Canada, just north of the Vermont line, have shown dikes of granite in close association with the ore. Thin sections of the granite indicate that it has suffered extremely severe dynamic metamorphism, for crushed and strained crystals make up nearly all of its substance. It is quite probable that the disturbance which causes the schistosity or slaty cleavage of the country rock likewise developed the strains in the granite which must thus have been intruded previous to its operation. Before the shattering the dikes may have exerted a genetic influence in connection with the ore body, but now the ore is usually lean near them. The ore bodies are also cut by fine examples of the trap (camptonite) dikes which are abundant in the Lake Champlain Valley. Prof. J. H. L. Vogt, of Christiania, Norway, has written of late regarding the origin of similar great bodies of sulphides in Europe, and when they occur in connection with rocks,

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[1] W. H. Adams, "The Pyrites Deposits of Louisa County, Virginia," *Trans. Amer. Inst. Min. Eng.*, XII., p. 527. C. R. Boyd, "The Utilization of the Iron and Copper Sulphides of Virginia, North Carolina, and Tennessee," *Trans. Amer. Inst. Min. Eng.*, XIV., p. 81; *Resources of S. W. Virginia.* H. Credner, "At St. Anthony's Nose, Hudson River," *B. und H. Zeit.*, 1866, p. 17; "Pyrite in Virginia, Tennessee, and Georgia," *B. und H. Zeit.*, 1871, p. 370. H. T. Davis, *Mineral Resources of the U. S.*, 1885, p. 501. William Martyn, *Mineral Resources,* 1883–84, p. 877. E. C. Moxham, "The Great Gossan Lead of Virginia" (altered pyrite in Carroll County), *Trans. Amer. Inst. Min. Eng.*, XXI., p. 133. A. F. Wendt, "The Pyrites Deposits of the Alleghanies," *School of Mines Quarterly,* Vol., VII., and separate reprint; also *Engineering and Mining Journal,* June 5, 1886, p. 22, and elsewhere. Rec. H. A. Wheeler, "Copper Deposits of Vermont," *School of Mines Quarterly,* IV., 210. Arthur Winslow, "Pyrites Deposits of North Carolina," *Ann. Rept. N. C Experiment Station*, 1886.

which though now gneissoid, have been originally igneous, he regards them as basic segregations of an igneous magma. (See further 1.06.16.) Where they occur in schists he attributes their formation to ore-bearing solutions, penetrating along planes of weakness, and stimulated by neighboring igneous intrusions. In some of the instances cited the known igneous intrusions (as at Rammelsberg) are at some distance, and thus are not directly associated, so far as one can see, with the ore. The genetic connection is therefore somewhat hypothetical.

2.03.21. The relative importance of the different kinds of ore is shown by the following tables for 1880 and 1896. The increase in red hematite is due to the Lake Superior region, and to Alabama. In the immediate future the soft ores of the Mesabi district will help to greatly swell the total, but during 1893-94 there was great depression in the mining of iron ore throughout the country:

	1880.	*Per cent. of Total.*	1896.	*Per cent. of Total.*
Red hematite	2,512,712	31.51	12,576,288	78.58
Magnetite	2,390,389	29.98	1,211,526	7.57
Brown hematite	2,149,417	26.95	2,126,212	13.28
Carbonate	922,288	11.56	91,423	0.57
	7,974,806	100.00	16,005,449	100.00

As indicating the relative importance of the different mining regions, the following figures are of interest. No individual State producing less than 100,000 tons is given.

States.	*Total in* 1896.	*States.*	*Total in* 1896.
Michigan	5,706,736	Tennessee	535,484
Minnesota	4,283,880	New York	385,477
Alabama	2,041,793	New Jersey	264,999
Virginia	859,466	Colorado	215,819
Pennsylvania	747,784	Georgia and N. Carolina	175,331
Wisconsin	607,405	All the others	181,275
Grand total			16,005,449

2.03.22. NOTE. Large quantities of excellent Bessemer hematite are shipped to Baltimore and other Atlantic ports from the mines on the southeastern coast of Cuba, in the Juragua Hills. Santiago de Cuba is the largest town in this region, and is some twenty miles west of the mines. The coast range of hills consists mainly of syenite, according to J. P. Kimball, and the syenite is penetrated by many dikes and is mantled by sheets of diorite with which the ores are associated. Kimball refers the precipitation of much of the iron oxide which came from the diorite to coraline limestone, which had been accumulated as coral reefs on the syenite before the diorite was intruded, but he also mentions other deposits in the diorite not associated with limestone. From observations of another group of ores sixteen miles east of those studied by Kimball, F. F. Chisholm reached a different conclusion regarding their origin. Chisholm refers them to a source below and apparently regarded them as veins or replacements of dikes. The amount of ore along this coast, both in place and as float is very great,[1] and will be an important feeder to American furnaces. Between three and four hundred thousand tons are now annually imported. Chisholm gives the following analyses:

	Fe.	S.	P.
Juragua (Kimball)	64.65	0.146	0.037
Sigua (Graham)	64.00	0.040	0.016
Berraco (Chisholm)	60.00	0.027	0.027

Although not a source of supply for American furnaces, it is interesting to note in this connection that in Mexico vast deposits of hematite and martite occur in Cretaceous limestone associated with intrusions of diorite. The paper of R. T. Hill cited below gives a review and full bibliography of the various localities. The notable deposits so far as yet opened up are at the Cerro de Mercado, in Durango,[2] the Sierra de Mercado,

[1] J. P. Kimball, "Geological Relations and Genesis of the Specular Iron Ores of Santiago de Cuba," *Amer. Jour. Sci.*, December, 1884, p. 416; also "The Iron Ore Range of the Santiago District of Cuba," *Trans. Amer. Inst. Min. Eng.*, XIII., 613; *Eng. and Min. Jour.*, December 20, 1884, p. 409. F. F. Chisholm, "Iron Ore Beds in the Province of Santiago, Cuba," *Proc. Colo. Sci. Soc.*, III., 259, 1890. H. Wedding, "Die Eisenerze der Insel Cuba," *Stahl und Eisen.* 1892, No. 12. Prof. J. W. Spencer has been recently working on the geology of Cuba and presented some of his results at the meeting of the American Association in Brooklyn, August, 1894.

[2] J. Birkinbine, "The Cerro de Mercado or Iron Mountain of Durango," *Trans. Amer. Inst. Min. Eng.*, XIII., 189, 1884. J. P. Carson, "Iron Manufacture in Mexico." *Idem,* VI., 399. R. T. Hill, "The Occurrence of

near Monclova in Coahuila,[1] and others of minor importance in the States of Jalisco,[2] Guerrero[3] and elsewhere. Several of these are now the basis of a small local smelting industry.

Hematite and Martite Iron Ores in Mexico," *Amer. Jour. Sci.*, February, 1893, 111. B. Silliman, "Martite of the Cerro de Mercado, or Iron Mountain of Durango, and Certain Iron Ores of Sinaloa," *Amer. Jour. Sci.*, November, 1882, 375. See also on the Durango Iron Mountain, *Annales del Ministerio de Fomento de la Rep. Mexicana Tomo,* III., 1877; *Eng. and Min. Jour.* on "Iron in Mexico," November 10, 1888, p. 391.

[1] P. Frazer, "Certain Silver and Iron Mines in the States of Nueva Leon and Coahuila, Mex.," *Trans. Amer. Inst. Min. Eng.*, XII., 537. R. T. Hill, as cited in previous footnote.

[2] J. P. Carson, as cited in second footnote.

[3] N. S. Manross, "Notes on Coal and Iron Ores in State of Guerrero, Mex., *Amer. Jour. Sci.*, May, 1865, p. 309; Remarks by J. D. Dana, p. 358

CHAPTER IV.

COPPER.

2.04.01. *Copper Ores.*

TABLE OF ANALYSES.

	Cu.	*S.*	*Fe.*
Native copper (generally with some silver)	100.00	....	....
Chalcocite, Cu_2S	79.80	20.2	....
Chalcopyrite, $CuFeS_2$	34.60	34.9	30.50
Bornite, Cu_3FeS_3	61.79	25.8	11.70
Tetrahedrite, $4CuS_2$, Sb_2S_3 (variable) 26.50 Sb.	36.40	26.7	1.39
Enargite, Cu_3AsS_4 (As, 19.1)	48.40	32.5	.....
Cuprite, Cu_2O	88.8C	....	.....
Melaconite (tenorite), CuO	79.86	....	.....
Malachite, $2CuOCO_2$, H_2O	40.28	....	.....
Azurite, $3CuOCO_2$, H_2O	46.31	....	.....
Chrysocolla, $CuOSiO_2$, $2H_2O$	22.06	....	.....

2.04.02. Example 16, Continued. Pyrite or pyrrhotite beds (veins), with intermingled chalcopyrite. Whether the deposits are true beds or veins parallel with the foliation, is as yet a matter of dispute. The resemblance to magnetite suggests a bed, and this view is generally taken by German writers. The California mines occur closely associated with the auriferous (pyritous) quartz bodies, which are always esteemed veins. But as detailed knowledge increases, it is more and more appreciated that the ore bodies are mostly if not entirely veins and have been deposited along lines of dislocation.[1]

Pyrites and pyrrhotite (called mundic by the miners) are the principal constituents of such bodies, but often the copper reaches 2.5 to 5%, and then they are valuable for copper. There

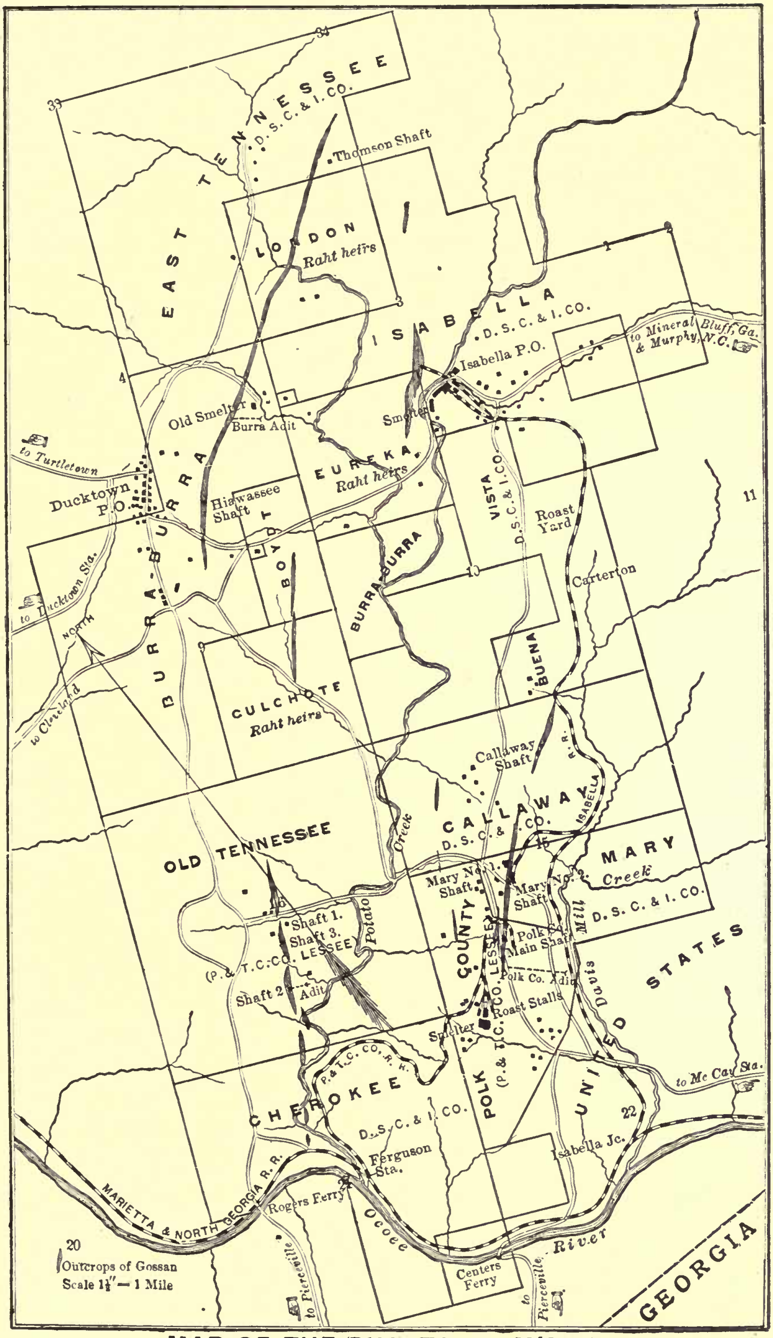
[1] Compare in this connection J. H. L. Vogt, "Ueber die Kieslagerstätten von Typus Rorös Vigsnäs, Sulitelma in Norwegen und Rammelsberg in Deutschland," *Zeitschr. für prakt. Geologie*, February, April and May, 1894.

is quite a characteristic group of minerals that is associated with the ores. Zinc blende is almost always present in small quantities, and is a great drawback to the ore when employed for acid. Galena is met in traces. Quartz, calcite, some form of amphibole, and often very beautiful garnets are associated. Ducktown is noted for its zoisite. All the secondary minerals of the oxidized zones of sulphides are met. The ores are often roasted for sulphurous fumes in acid works, and afterward the residues are shipped to the copper smelters. The mines have been or are being worked for copper near Sherbrooke, and at a great number of other points in Quebec, just north of Vermont. There are also not a few localities in Maine, New Brunswick, Nova Scotia and Newfoundland, where operations of a more or less serious nature have been undertaken. Citations to the literature regarding these will be found at the close of the description of Ducktown. At Milan, N. H., there are several deposits in argillitic schists, and in the same region there are numerous other locations. At Vershire, Vt., there is a belt some twenty miles long, with three principal mining points. Of these the middle one, containing the Ely mine, is the largest. Two beds of ore occur, separated by from 10 to 20 feet of schists. The lower averages about four feet, but fluctuates; the upper is still more variable, and may reach 25 feet. They are both formed by a succession of thin lenses. The ore is chalcopyrite, mingled with pyrrhotite and quartz

2.04.03. More complete observations are available upon the Ducktown, Tenn., deposits, than upon any others of the type in America. The excellent paper by Carl Henrich is here specially drawn upon and has been supplemented by some few further notes by the writer. Ducktown is situated in the southeastern township of Tennessee, and occupies a small plateau between bounding ranges of higher mountains. The plateau has been much dissected by the present drainage, but its stumps remain, and serve to indicate the peneplain of Tertiary date.[1] The country rock is mica schist, with occasional heavier beds that tend toward quartzite or even gneiss. Some hornblendic rocks are present with the ores, but whether they represent intruded dikes as suggested by Henrich, or streaks of siliceous

[1] C. W. Hayes. "Geomorphology of the Southern Appalachians," *National Geographic Magazine*, VI., 68, 1894.

Fig. 2.



MAP OF THE DUCKTOWN MINES.

FIG. 55.—*Map of the mines and of the outcrop of gossan, showing the relations and extent of the veins at Ducktown, Tenn. After Carl Henrich, Trans. Amer. Inst. Min. Eng., XXV., 178, 1895.*

limestone, it is not possible to determine. The schists are metamorphosed shales, and the schistosity appears to be generally parallel to the original bedding. The geological age is still in dispute, but is probably Pre-Cambrian.

The schists strike N. 20-25 E., and have a prevailing dip of about 50 to 55 S. E. There are variations of the latter which are due to rolls and faults. The schists have been broken by dislocations along which the ores have been deposited. The strike of the ore is parallel to the strike of the schists, and the dip is, as a rule, the same as that of the schists, but cases have been observed where the ores cut the dip of the country rock, although with such soft and easily mashed materials it is difficult to identify the unconformity. There are two principal belts of fracture as shown by the map, Fig. 55, and probably several minor ones, between. The Old Tennessee, Burra Burra, London and East Tennessee lie along the northwest belt; the Polk County, Mary, and Calloway form the southeast belt; and the Culchote and Isabella lie in the interval. The ore bodies are huge lenticular masses of sulphides, which probably owe this shape, as far as it is at all discernible, to diagonal faulting since the veins were filled. The common ore is an aggregate of pyrrhotite, chalcopyrite, calcite, quartz, zoisite, and in some mines much actinolite. Zinc blende and galena are present, but are insignificant. Garnets are occasionally met in quantity. On some of the claims pyrites is abundant, as in the Burra Burra, and, as is reported to be the case at the Isabella, it taking the place of the pyrrhotite to a greater or less degree. The content of copper varies up to 3.5%, with occasional bunches that run higher. The old black copper ores that accumulated at the water-level are now exhausted. (See Fig. 56.) From observations on the succession and character of the minerals in the vein, J. F. Kemp has drawn the following conclusions regarding the geological history of the veins. By a process of regional metamorphism, a sedimentary series of shales and sandstones was altered to mica schists and quartz schists. Where the ore is now found, zoisite, tremolite, and garnet were also produced, but it is not known whether they are met outside of the mines or not. They indicate the former presence of magnesian and calcareous rocks, although, generally speaking, lime is practically unknown in the metamorphic rocks of the district and the local waters are remarkably pure and soft. Whether a calcareous shale or an intruded dike yielded the lime silicates, or whether they are metamorphosed, calcareous, vein material from an older vein filling cannot be stated. After the general metamorphism, a series of dislocations was developed along the lines of the present veins, and

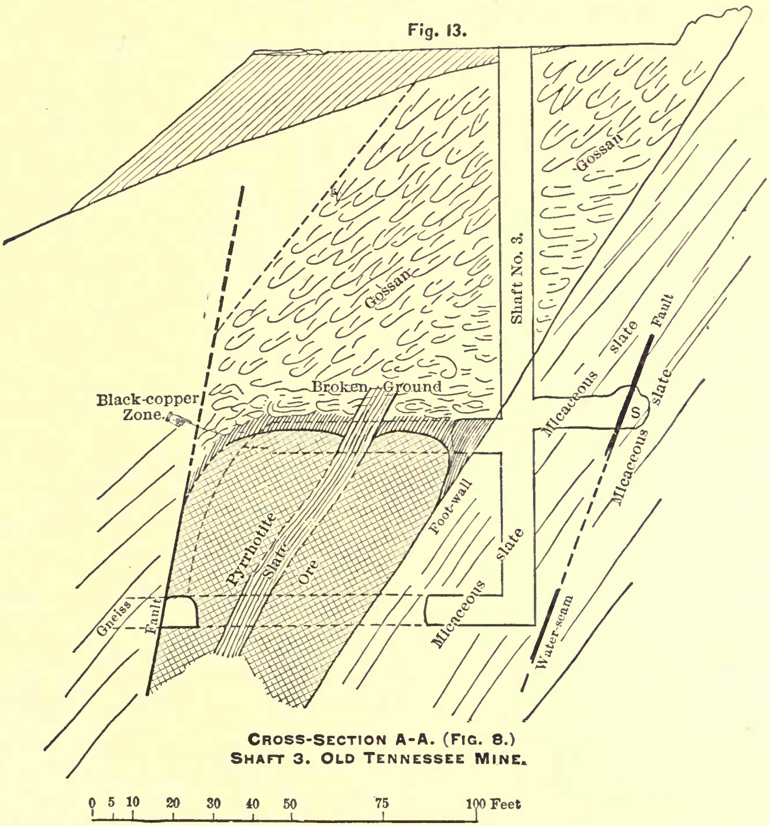


Fig. 56.—*Cross-section, Shaft 3, Old Tennessee Mine, Ducktown, Tenn., showing the gossan, the black ore, the pyrrhotite and a fault. After Carl Henrich, Trans. Amer. Inst. Min. Eng., XXV.*, 198, 1895.

pyrrhotite and sometimes pyrite were introduced. After the deposition of the pyrrhotite there was further movement which shattered the pyrrhotite and allowed the introduction of chalcopyrite in streaks and fine veinlets all through it. Still later, and apparently after another movement calcite came in and penetrated the shattered sulphides and older silicates. After the introduction of the calcite, by some movement fissures notably horizontal were produced, which became filled with glassy quartz, and which have yielded the so-called "floors." More or less contemporaneously with the quartz, coarsely crystalline pyrrhotite, chalcopyrite and blende were produced, which are in marked contrast with the earlier sulphides. The oxidation of the veins above the ground water, the formation of the brown hematite outcrops and the development of the zone of enrichment (the black ores) bring the process down to the present.[1]

2.04.03. Throughout the mountainous region of western North Carolina, eastern Tennessee and northern Alabama are many other copper deposits of more or less serious importance. One of the best known is the one formerly operated at Ore Knob.

This is described by Kerr as a true fissure vein, extending 2,000 feet on the strike, which is parallel to that of the gneiss, but cutting the dip in descent. The width averaged about 10 feet. The gossan extended to a depth of 50 feet, and furnished the usual body of rich ore at the contact with the sulphides. The mine has not been operated for some years.[2]

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[1] *Trans. Amer. Inst. Min. Eng.*, 1899.

[2] For a general account of the sulphides in the East, see A. Wendt, "The Pyrites Deposits of the Alleghanies," *School of Mines Quarterly*, VII., 1886.

CANADA, *Geol. Survey of Canada*, 1863, 709. James Richardson, *Idem,*, 1896, 34–44. R. W. Ells, "Copper in Quebec," *Idem*, 1890, Vol. IV., 29K. Rec. "The Mining Industries of Eastern Quebec," *Trans. Amer. Inst. Min. Eng.*, XVIII., 316, 1889. John Blue, "Copper Pyrites Mining in Quebec in 1894," *Journal Gen'l Mining Assoc. Prov. Quebec*, II., 147, 1894. S. L. Spofford, "Albert Mines and Capelton Chemical Works," *Idem*, 214. C. T. Jackson, "The Great Copper-bearing Belt of Canada," *Proc. Bost. Soc. Nat. Hist.*, IX., 202, 1862. Copper prospects have received attention in southwestern New Brunswick, on Adams, Campobello, and other islands. See Bailey and Matthew, *Geol. of Canada*, 1870–71, p. 13. "On Notre Dame Bay, Newfoundland," M. E Wadsworth, *Amer. Jour. Sci.*, iii., XXVIII., 28, 102.

MAINE.—"Blue Hill District", *Eng. and Min. Jour.*, August 28, 1880, p. 140. F. L. Bartlett, "Mines of Maine," in *Mines, Miners and Mining Interests of the United States*, Philadelphia, 1882, 133. J. D. Whitney, *Metallic Wealth of the United States*, 312.

NEW HAMPSHIRE.—C. H. Hitchcock, *Geol. of N. H.*, III., Part III,, p. 47.

VERMONT.—"Elizabeth Copper Mines," *Eng. and Min. Jour.*, November

FIG. 57.—*View of the Mary Mine, Ducktown, Tenn., from the west. The deeply dissected character of the country is well shown. From a photograph by J. F. Kemp, June, 1898.*

2.04.04. Example 16*b*. Spenceville, Cal. Copper ores are known and have been more or less worked in a number of places along the western Sierras, of which Spenceville, Nevada

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6, 1886, p. 327; "The Pyrrhotite of the Ely Mine," *Idem*, April, 10, 1886, 263. F. M. F. Cazin, *Trans. Amer. Inst. Min. Eng.*, XXIII., 604, 1894. H. Kochnike, "Die Vermont Kupfer-Grube," *Berg- u. Hütten. Zeit.*, 1892, 297. Richardson, "Copper Ore of Stafford, Vt.," *Amer. Jour. Sci.*, i., XXI., 383. H. S. Wheeler, "Copper Deposits of Vermont," *School of Mines Quarterly*, IV., 219. Rec.

PENNSYLVANIA.—MARYLAND, AND VIRGINIA.—J. F. Bailey, "Copper Deposits of Adams County, Pa.," *Eng. and Min. Jour.*, February 17, 1883, 88. J. F. Blandy, "Lake Superior Copper Rocks in Pennsylvania," *Trans. Amer. Inst. Min. Eng.*, VII., 331. P. Frazer, "Some Copper Deposits of Carroll County, Md.," *Trans. Amer. Inst. Min. Eng.*, IX., 23. 1881. "Hypothesis of the Structure of the Copper Belt of the South Mountain, *Idem*, XII., 82, 1884. "Geology and Copper Deposits of Adams County, Pa.," *Eng. and Min. Jour.*, XXXV., 112, 1883. C. H. Henderson, "Copper Deposits of the South Mountain, Pa.," *Trans. Amer. Inst. Min. Eng.*, XII., 85, 1884. C. T. Jackson, "Copper Mine, Elk Run, Fauquier County, Va.," *Proc. Bost. Soc. Nat. Hist.*, VI., 183, 1857. Arthur Keith, Harper's Ferry Folio, *U. S. Geological Survey.*

NORTH CAROLINA, TENNESSEE, AND ALABAMA.—"The Stone Hill Copper Mine and Works, Cleburne, Ala.," *Eng. and Min. Jour.*, August 4, 11, 18, 1877, pp. 86 and following. W. P. Blake, "Notes and Recollections Concerning the Mineral Resources of Northern Georgia and Western North Carolina," *Trans. Amer. Inst. Min. Eng.*, XXV., 796. W. B. Brewer, "Ducktown Copper Mining District," *Eng. and Min. Jour.*, March 23, 1895, 271. "Copper Mining in Alabama," *Proc. Ala. Ind. and Sci. Soc.*, VII., 13, 1897. Carl Henrich, "The Ducktown Deposits and the Treatment of the Ducktown Copper Ores," *Trans. Amer. Inst. Min. Eng.*, XXV., 173, 1895. Rec. J. F. Kemp, "The Order of Formation of the Minerals in the Ducktown Veins," *Idem*, 1899. T. S. Hunt, "Ore Knob and Some Related Deposits," *Trans. Amer. Inst. Min. Eng.*, II., 125. Kleinschmidt (on Virginia, Tennessee, and North Carolina), *Gangstudien*, Vol. III., p. 256. (A good, short, but old account.) E. E. Olcott, "Ore Knob Copper Mine and Reduction Works," *Trans. Amer. Inst. Min. Eng.*, III., 391. Rec. W. B. Phillips, "Copper Deposits of North Carolina," *Eng. and Min. Jour.*, April 1, 1899, 382. Tripple and Credner, "Report on the Ducktown Region to the American Bureau of Mines," 1866. M. Tuomey, "A Brief Note of Some Facts Connected with the Ducktown (Tenn.) Copper Mines," *Amer. Jour. Sci.*., II., 19, 181. A. F. Wendt, "The Pyrites Deposits of the Alleghanies," *School of Mines Quarterly*, Vol. VII., 1886; *Eng. and Min. Jour.*, July 10 and following, 1886. J. D. Whitney, "Remarks on the Changes that Take Place in the Structure and Composition of Mineral Veins," etc., with especial reference to Ducktown, Tenn., *Amer. Jour. Sci.*, ii., XX., 53.

County, Copperopolis and Campo Seco, Calaveras County, and Newton, Amador County, are the most important. There are some differences in the geological relations of these several deposits, but they are alike in being associated with igneous rocks. At Spenceville the ores occur in veins along the contact of diabase and grano-diorite.[1] In Amador County two belts of ore have been developed in amphibole schists. There are mines at Ione and Caledonia, and other openings extend in a southeasterly line to Copperopolis in Calaveras County. The amphibolite schist is a metamorphosed diabase or porphyrite. In some of the mines quartz porphyrite is associated with the veins.[2] Other copper deposits have been discovered in the areas covered by the Sonora and Placerville folios.[3] They occur in porphyrites, amphibole-schists, serpentine, and in contact zones next the intrusions of grano-diorite.

Far to the north of all the deposits cited above a very extensive body of sulphides has been opened at Iron Mountain, and bids fair to afford high-grade ore for this type. The wall rock is described as a highly siliceous porphyry.[4]

The California copper ores have been treated by wet methods to a large extent, and have contributed considerable amounts to the total output of the country.

NOTE. For Example 16*c*, see under Nickel. Some of the California mines appear to be closely related to 16*c*.

2.04.05. Example 17. Butte, Mont. Veins in fissures in granite, which have involved but slight dislocation, and which have been enlarged by replacement of the walls with ore. The vein filling is siliceous, and the metallic ores in the deposits

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[1] Lindgren and Turner, Smartsville Folio, *U. S. Geological Survey.* See also J. E. Ellis, "On the Spenceville Mines." *Mineral Resources of the U. S.; U. S. Geol. Survey*, 1884, 340. H. G. Hanks, *Rept. of California State Mineralogist*, 1884, 151. J. B. Hobson, *Idem*, for 1890, 392.

[2] H. W. Turner, Jackson Folio, *U. S. Geol. Survey.* H. G. Hanks, "On Calaveras County Mines," *Fourth Ann. Rep. Cal. State Mineralogist*, 48, 1890. Wm. Irelan, *Idem*, 1888, 150–153; "On the Newton Mines, Amador Co.," *Idem.*, p. 106.

[3] Turner and Ransome, Sonora Folio; Lindgren and Turner, Placerville Folio, *U. S. Geol. Survey.*

[4] H. Lang, "Iron Mountain Mine, Shasta Co.," *Eng. and Min. Jour.*, April 15, 22, and May 13, 1899. The paper also mentions other copper mines in this region.

productive of copper are chalcopyrite, pyrite, bornite, chalcocite, enargite, and rarely covellite and tennantite. The copper ores contain much silver and some gold, but there is a fairly distinct series of silver-bearing veins, which contain practically no copper, and which have manganese minerals that fail in the copper veins. And yet along the borders of the two areas there are veins which are somewhat transitional between the two varieties.

The geological formations at Butte are illustrated on the accompanying map, Figs. 58 and 59, which are based upon the map of the areal geology in the Butte Special Folio of the *U. S. Geological Survey.* The colors of the original are reproduced in lines, and some small details have necessarily been omitted on account of the reduction in size, and the confusion of signs without colors. The only omissions, however, are a few small areas of the Bluebird granite, and of the rhyolite. In the orginal map the areal geology is by W. H. Weed, and the veins and mining geology have been mapped by S. F. Emmons and G. W. Tower. The work was difficult and complicated, but it has been admirably done.

The Butte mining district lies on the southern and eastern slopes of a hillside or upland that rises from the valley of Silver Bow Creek. The hillside is cut by several minor north and south gulches, and is bounded on the south and east by the valley of the creek, which makes a crescentic sweep around it. Just to the west of the town rises a sharp cone of rhyolite, which is shown in Fig. 60, and which gave the camp its name in the early days. In the distance, on all sides, high mountainous ridges rise like walls as is shown in Figs. 61 and 62. The oldest rock of the district, and the one which covers the greatest area, is a basic granite. Chemical analyses prepared by the U. S. Geological Survey have proved it to be exceptionally low in silica for a granite, and to be quite uniform. SiO_2 63.88-64.34, Al_2O_3, 15.38-15.84, FeO, Fe_2O_3, 4.5-4.7, CaO, 3.97-4.3, MgO, 2.08-2.23, K_2O, 4.0-4.23, Na_2O, 2.74-2.81. This rock is called the Butte granite. It is the wall-rock of all the copper veins and of most of the silver ores. It lies east, north and south of the Big Butte. The intrusion of the Butte granite was followed, presumably after a short interval, by a white, acidic granite known as the Bluebird. An interesting contact of the two is

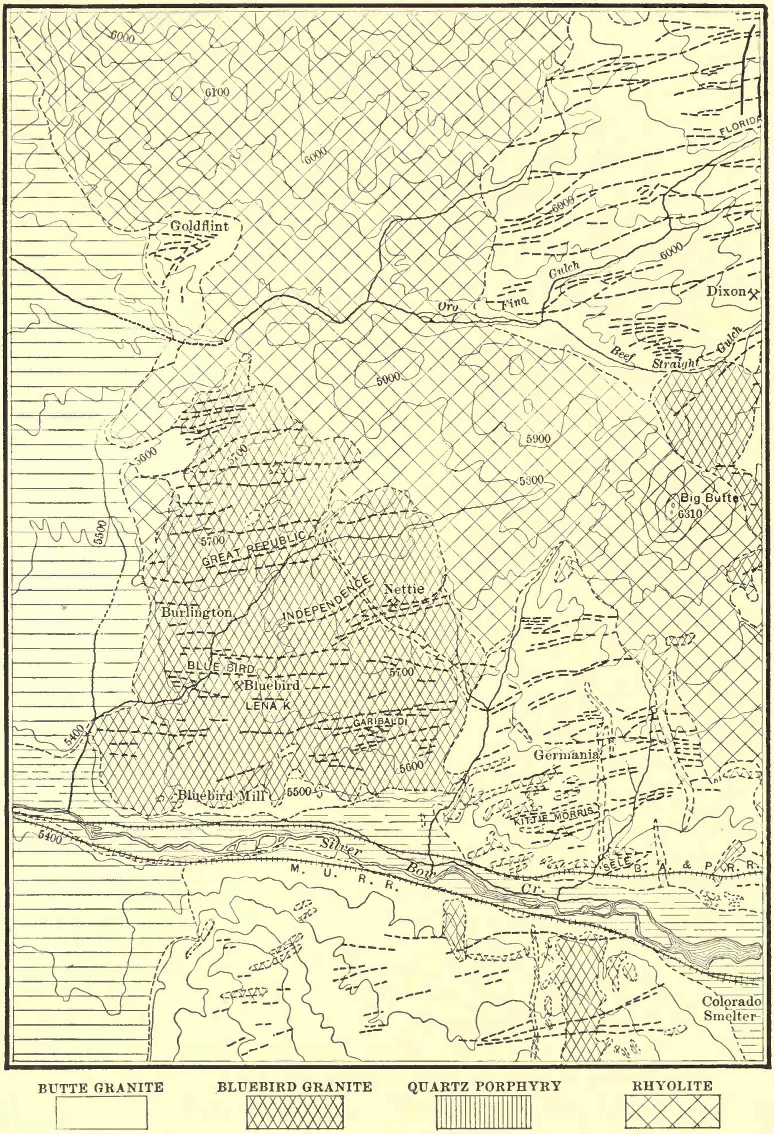

FIG. 58.—*Geological map of the Western half of Butte District, Montana, reproduced in line-work from the colored map of the Butte Special Folio, U. S. Geological Survey.*

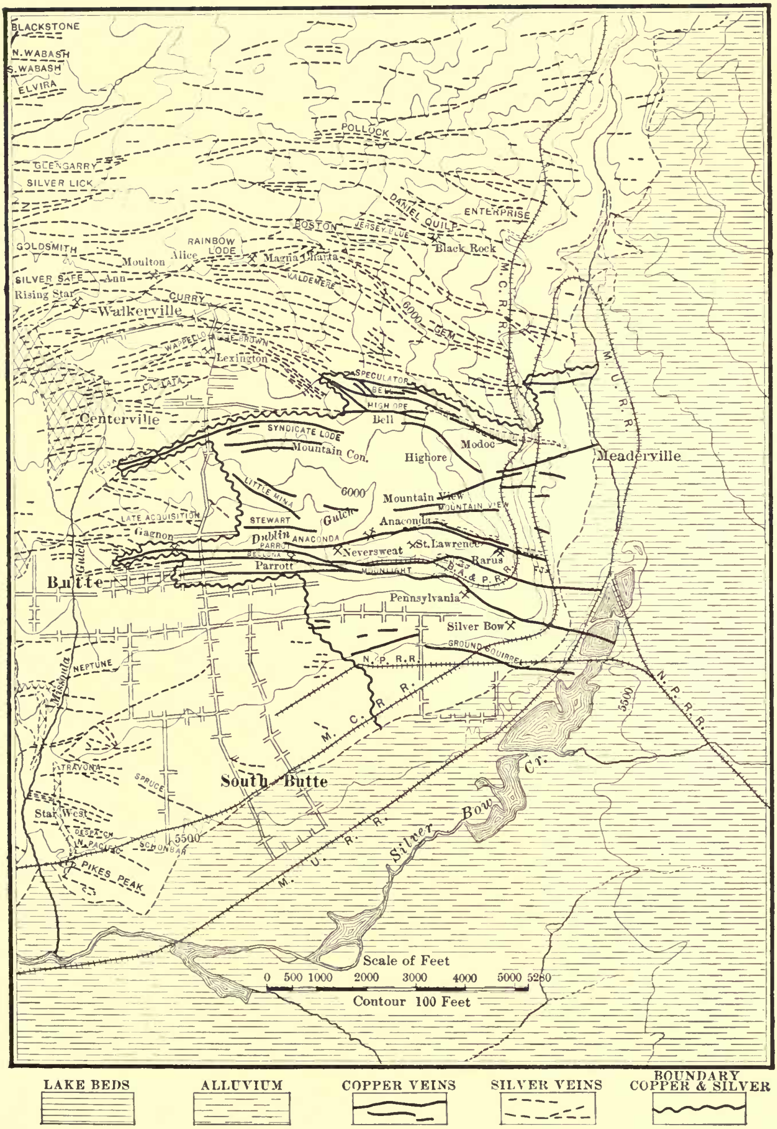

FIG. 59.—*Geological map, Eastern half, Butte District, Montana.* See FIG. 58.

shown in Fig. 63. It is supposed to have separated from the same magma that afforded the Butte granite and to have penetrated fissures in the latter while it was probably still hot, as it is now found in all manner of small veins and masses, which do not show any effects of quick chilling along the contacts. The Bluebird granite is most extensively developed in the western part of the district, but it appears on all sides of the Big Butte in small patches. The next rock in time is quartz-porphyry, which is found on the slopes west of Butte City, and between it and Meaderville. After the intrusion of the quartz-porphyry the fracturing occurred, which gave rise to the veins, for the latter cut the quartz-porphyry in a number of instances. After the deposition of the ore, the great intrusion and eruption of the rhyolite took place, which now appears as many dikes cutting the veins, as a great sheet, and as some masses of fragmental ejectments. While the rhyolite was in eruption a lake existed in the western part of the district, and in it were deposited great quantities of rhyolitic volcanic dust, which now chiefly constitutes the Lake Beds of the map. These beds have been traced to the south and west beyond the limits of the map, and have been found to contain Miocene fossils.

Outside the area of the map the Butte granite is known to penetrate Carboniferous strata, and it is not certain that it may not have followed Laramie beds. It is, certainly post-Carboniferous, and it may be post-Laramie. The veins must, therefore, have been filled in the interval between the close of the Carboniferous and the Miocene, and perhaps are post-Cretaceous. The recent gravels constitute the formation called alluvium. They are extensive in the valleys of the creeks and at times quite deep.

Butte was first developed as a placer camp as early as 1864, when, according to Emmons and Tower, the gravels of Missoula Gulch were washed. As the quartz ledges constituting the veins still project in many instances, like great walls, it is not surprising that they were early noted and located. Figures illustrative of them and of the excessive weathering of the Butte granite will be found under silver in Montana, Chapter X. Small success attended the first efforts of the deep miners until rich silver ore was found in the Travona in 1876. The copper discoveries came three or four years later, because the copper had

FIG. 60.—*View of the Big Butte, Butte City, Mont., looking northwest across Missoula Gulch. From a photograph by J. F. Kemp, June,* 1896.

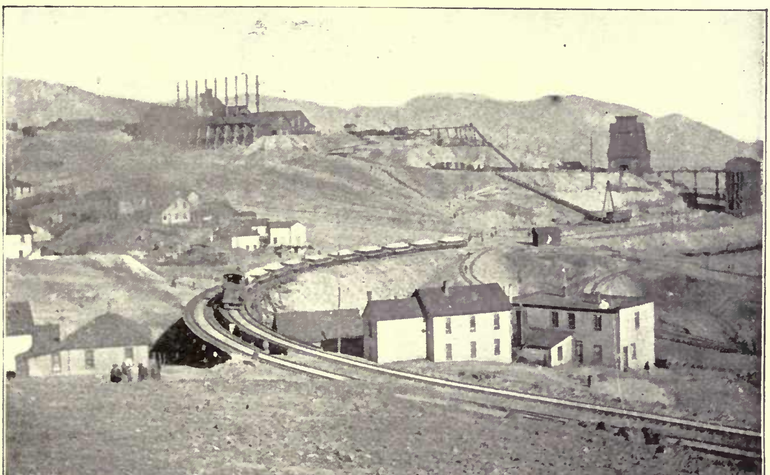

FIG. 61.—*View of the Anaconda Mine (with the nine stacks), Butte, Mont From a photograph by Alexander Brown, E. M.,* 1896.

FIG. 62.—*View of the larger Copper mines, Butte, Mont., looking nearly due east from the roof of the Hotel Butte. The mines in the center are in order the Parrot, the Never-Sweat and the Anaconda. From a photograph by J. F. Kemp, June,* 1896

been leached out of the portion of the vein above the ground-water, leaving the silver behind. When, however, the huge masses of chalcocite and bornite were met in the zone of enrichment, the copper production became established.

Study of the map will show that, although so numerous, the veins all run in an east and west direction, that they are closely parallel, and that at the most they vary not more than 45 degrees north or south of this line. They dip at high angles, being almost always over 60 degrees. The dip is to the south, except in the northern edge of the district, where the inclination is prevailingly to the north.

Small offsetting veins often connect the larger ones and even run into the wall rock as blind veins. Veinlets of all sizes can be observed on the dumps. The ore varies from five or six feet to as much as 100 feet across in the extreme cases. The original fissures do not appear to have involved much empty space, however, and the deposition has been in the nature of a replacement of the walls, and the process may, indeed, have extended from fissure to fissure, removing the intervening, rarely brecciated country rock. The ore habitually fades out into the country rock at least on one side, and as a rule all the companies have to concentrate the run of the mines. Since the completion of ore deposition, there has been extensive later dislocation, which is shown by brecciated faults, which may follow along the veins, or may cross and fault them. They are now filled with material more or less fully kaolinized and are practically barren, except where they have dragged vein matter into their substance during faulting, or have been impregnated during the alteration of the older veins.

2.04.06. The ground distinctively productive of copper is quite sharply marked off from that yielding silver alone (all the copper ores have silver) and a wavy line has been run around the former on the map. The copper area seems to have been the center of the mineralization, and in it the largest ore-bodies are found. Copper and silver solutions especially favored this portion, and on its edges the copper gradually failed, while with the silver came more or less zinc and lead, and increasing manganese. The Gagnon mine that is on the border is transitional, as the ore yields copper, but is also very rich in silver, and contains considerable blende and galena.

The mineralogy of the silver series is more fully described under Silver, Chapter X. The copper ores contain a small but constant value in gold, and there is some reason for thinking that the gold occurs as a telluride. While tellurium is present in very small amounts, it can be saved by the refiners and supplied in quantities that are, for this rare element, enormous.

The oxidization or alteration of the veins above the groundwater presents points of interest. As the wall-rock is granite, carbonates and oxides of copper are poorly developed and the oxidized ores are in contrast with those in limestones and schists. Chalcocite, bornite and covellite are the principal secondary copper minerals that have resulted, and the last named lies chiefly along fractures. The chalcocite and bornite are not, however, limited to the present water-level, but have penetrated far below it, and have enriched the veins, and a reasonable query may be raised as to whether they may not be in part original depositions. The gangue is quartz, in decomposed country rock. Barite in honey-yellow tabular crystals is occasionally met, but is only a curiosity. The outcrop of the silver veins is stained black by manganese oxide.

To the east of the area of the map and on the slopes of the bounding range of granite mountains, the veins outcrop as ledges of quartz, and considerable prospecting has been done. Some copper ores have indeed been found, but the developments do not yet (1899) assure profitable mining.

2.04.07. The total production of Butte to the close of 1896 is estimated by Emmons and Tower to have been $300,000,000, divided somewhat as follows: Gold, 500,000 ounces; silver, 100,000,000 ounces; copper, 1,000,000,000 pounds. In 1897, according to *The Mineral Industry*, the copper produced was 237,158,540 pounds, of which the Anaconda Company contributed 131,471,127. On the whole, the Butte copper district is the most productive of those as yet opened in the United States.[1]

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[1] The best account of Butte will be found in the Butte Special Folio, of the *U. S. Geol. Survey*, in which the areal geology is by W. H. Weed, and the mining geology by S. F. Emmons and G. W. Tower. This reference has been especially drawn upon in the above description. "Butte Copper Mines," *Eng. and. Min. Jour.*, April 24, 1886, 299; June 19, 1886, 445. R. G. Brown, "The Ore Deposits of Butte City," *Trans. Amer. Inst. Min. Eng.*, XXIV., 543. Rec. S. F. Emmons, "Notes on the Geology of Butte, Mont.," *Trans. Amer. Inst. Min. Eng.*, XVI., 49. Ch. W. Goodale,

FIG. 63.—*Contact of the older Butte granite (on the left) and the later intruded Bluebird granite (on the right) as exposed in a cut on the Butte, Anaconda and Pacific Railroad, west of Butte. Photographed by J. F. Kemp, 1896.*

There are copper prospects in northwestern Montana within the limits of the Lewis and Clarke Timber Reserve, and amid the high peaks of the Rockies near the international boundary. The general geology of the country involves Cambrian and Precambrian quartzites, in which are intrusions of igneous rocks, of the nature of andesites or diorites. Copper ores are found in association with the latter.[1]

2.04.08. Example 17*a*. Gilpin County, Colorado. Veins of pyrite and chalcopyrite, replacing gneiss (the rock may be granite), and dikes of quartz-porphyry, and felsite along the planes of joints, which cross the gneiss (or granite) perpendicularly to the laminations. The veins are highly auriferous, and are worked primarily for gold, the copper being produced as a by-product. The concentrates from the stamps are afterward treated for copper. The veins occupy an area of only about a mile and a half in diameter, centering about Central City. They show little indication of having filled a fissure, as usually understood, but follow the cleavage joints of the gneiss, and replace the country rock on each side of them. The joints also cross the porphyry dikes, and the veins are often in the latter rock. They are closely related in structure and origin to the galena veins of the neighboring Clear Creek County, which are referred to under "Silver," but the contrast in mineral contents between the two is very marked. They were the

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"The Concentration of Ores in the Butte District, Mont., *Idem.*, XXVI., 599, 1108. Richard Pearce, "The Association of Minerals in the Gagnon Vein, Butte City, Mont., *Trans. Amer. Inst. Min. Eng.*, XVI., 62; "On the Occurrence of Goslarite in the Gagnon Mine, Butte City," *Proc. Colo. Sci. Soc.*, Vol. II., Part I., p. 12. E. D. Peters, *Mineral Resources of the U. S.*, 1883–84, p. 374. A. Williams and E. D. Peters, "On Butte, Mont.," *Eng. and Min. Jour.*, March 23, 1885, p. 208. G. vom Rath, "Ueber das Gangrevier von Butte, Mont.," *Neues Jahrbuch*, 1885, I., 158.

Important annual reviews are also published in the *Ann. Reps. of the Director of the U. S. Geol. Survey* and in *The Mineral Industry*. The latter is especially valuable in connection with the technology and mining. General papers on copper production likewise touch on Butte, such as James Douglass, "The Copper Resources of the United States," *Trans. Amer. Inst. Min. Eng.*, XIX., 678. Some additional literature is given under "Silver," 2.10.09.

[1] R. C. Chapman, "The Geological Structure of the Rocky Mountains, within the Lewis and Clarke Timber Reserve," *Trans. Amer. Inst. Min. Eng.*, February, 1899.

basis of the first extensive deep mining in Colorado, and were located through the placer deposits in the neighboring gulches.[1]

2.04.09. Example 17*b*. Llano County, Texas. Impregnations in granite, and veins with quartz gangue in granite, carrying carbonates above, but sulphurets and tetrahedrite with some gold and silver below. Contact deposits between slates and granite are also known. It is not demonstrated as yet whether the ores are to be actually productive.[2]

2.04.10. Example 18. Keweenaw Point, Michigan. Native copper, with some silver, in both sedimentary and interstrati-

FIG. 64.—*Cross section of the Bob-tail mines, Central City, Colo. After F. M. Endlich, Hayden's Survey*, 1873, *p*. 286.

fied igneous rocks of the Keweenawan system. The metal occurs as a cement binding together and replacing the pebbles of a conglomerate; or filling the amygdules in the upper portions of the interbedded sheets of massive rocks; or as irregular masses, sometimes of enormous size, in veins, with a gangue of calcite, epidote, and various zeolites; or in irregular masses along the contacts between the sedimentary and igneous rocks. (For the general geography see Fig. 24, p. 126.)

2.04.11. The rocks of the Keweenawan system are most

[1] S. F. Emmons, *Tenth Census*, Vol. XIII., p. 68. The veins are described as cited above. J. D. Hague, *Fortieth Parallel Survey*, III., p. 493. The veins are called fissure veins by Mr. Hague. A. Lakes, *Ann. Rep. Colo. State School of Mines*, 1887, p. 102. A. W. Rogers, "The Mines and Mills of Gilpin County, Colorado," *Trans. Amer. Inst. Min. Eng.*, II., 29. Further references will be found under "Silver and Gold in Colorado."

[2] T. B. Comstock, *First Ann. Rep. Texas Geol. Survey*, 1889, p. 334. W. F. Cummins, *Idem*, 196. W. H. Streeruwitz, in *Mineral Resources of the U. S.*, 1884, p. 342.

strongly developed on the south shore of Lake Superior, especially in Keweenaw Point, which juts out northeasterly, cutting the lake into two nearly equal portions. They extend some distance east and west, and are also known on the north shore. They consist of sandstone and thin beds of conglomerate, interstratified with sheets of diabase, both compact and amygdaloidal, and of melaphyre. They are succeeded on the east by the Eastern Sandstone, which on the south shore is thought by Irving, Chamberlin and others in some places to abut unconformably against them, and in others to pass under them from an overthrust fault. Wadsworth, however, considers that the Eastern Sandstone passes conformably beneath the Keweenawan, and that it is older.

The Eastern Sandstone forms a comparatively low, flat bench some miles across, between the lake and the ridge of the Keweenawan, whose rocks rise quite abruptly in a marked escarpment. The several streams that fall over this scarp in cascades have served by their erosion to expose the contacts. The best known are the Hungarian and Douglas Houghton Rivers. On the west or northwest side the escarpment is much less pronounced and the contact is less well shown and has not been so sharply located. The sandstone is called the Western Sandstone. It is now pretty well shown that the Eastern Sandstone is a close equivalent to the Potsdam, for though itself lacking in fossils, it is known to pass conformably beneath fossiliferous Lower Silurian limestone near L'Anse.

On Keweenaw Point the beds dip northwesterly and pass under Lake Superior to reappear with a southeasterly dip on Isle Royale and the Canadian shore. Western Lake Superior occupies this synclinal trough. In Keweenaw Point the dip is greatest on the southwest, being about 60° at Hancock. To the northeast it gradually flattens to 30° or less on the lake shore. (For the general geology of the neighboring region see under Example 9.)

It is interesting to note that the early investigators of the geology of this country drew a parallel between the sandstones and traps of Lake Superior and the similar Triassic deposits of the Atlantic coast (see Example 21), even going so far as to regard the former as the western equivalent of the latter.[1]

[1] C. T. Jackson, *Amer. Jour. Sci.*, i., XLIX., 1845, pp. 81–93.

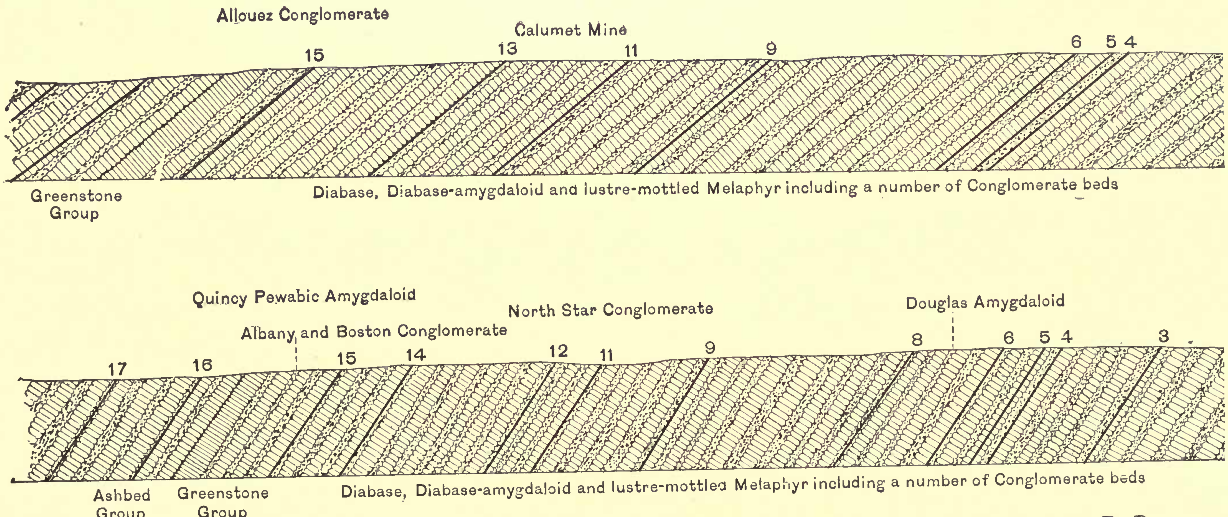

FIG. 65.—*Geological section of Keweenaw Point, Mich., near Portage Lake and through Calumet. After R. D. Irving, Monograph V., U. S. Geol. Survey, Pl. 18. The section runs northwest.*

There are three principal mining districts—the Keweenaw Point, on the end of the Point; the Portage Lake, in the middle; and the Ontonagon, at the western base. Mines have also been worked on Isle Royale, and copper is found in small amounts on

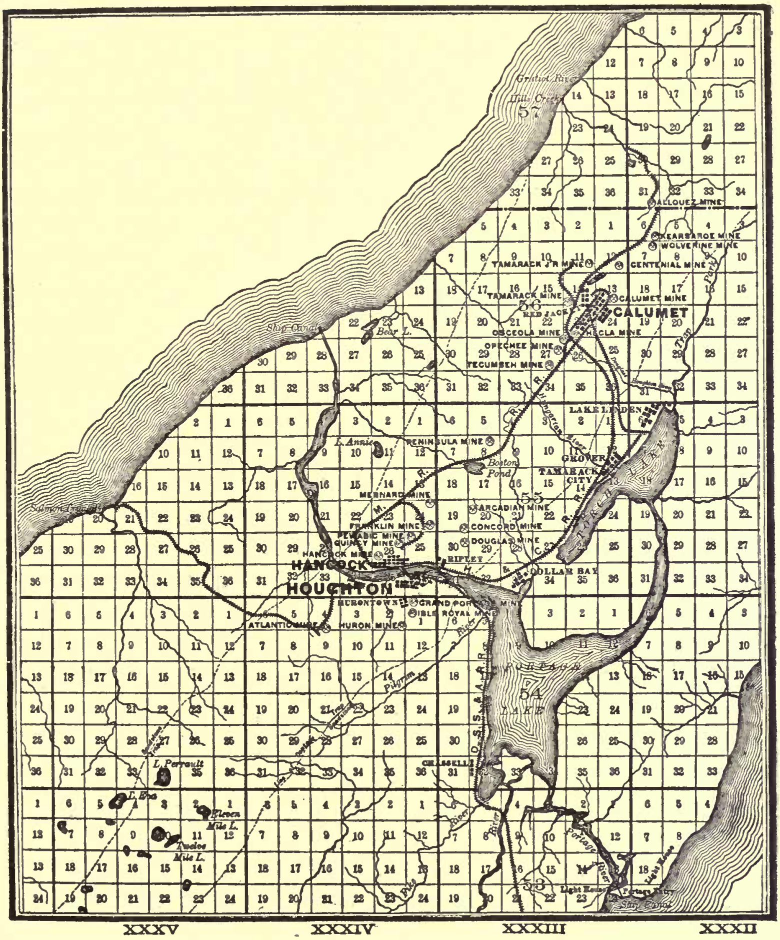

FIG. 66.—*Map of the Portage Lake District, Keweenaw Point, Mich. Adapted from a map in the catalogue of the Michigan College of Mines.*

the north shore. The Portage Lake district is now the principal and almost the only producer. In the first-named district most of the mines are on original fissures, which have later become much enlarged by the alteration of the walls. They are usually from one to three feet broad, but may reach 10, 20, and 30 feet, this last in the more loosely textured rocks. These expansions are also richer in copper. The veins stand nearly vertical, and cross the beds at right angles. They were the earliest discovered, and the first to be extensively worked. The metallic masses, both large and small, occur distributed through the gangue. The best-known mines of the district are the Central, Cliff, Phœnix and Copper Falls. All have been recently closed except the Central, which, after temporary suspension in 1894, resumed operations in 1896. A conglomerate appeared to cut off the vein, although probably a fault and movement parallel with the dip occasioned the displacement. With favorable markets several other vein mines may be intermittently worked. The vein mines have been the great source of fine minerals in the past, the Phœnix being well known for its zeolites.

2.04.12. In the Portage Lake district the mines are either in conglomerate (Calumet and Hecla, Tamarack, Peninsula, etc.) or in amygdaloidal, strongly altered diabase, certain very scoriaceous sheets of which are known as ash-beds (Quincy, Franklin, Atlantic, etc.). In the conglomerates the copper has replaced the finer fragments, so as to appear like a cement, and often the boulders themselves, or particular minerals in them, are permeated with copper. The rich portions are of limited extent along the strike as they give way to barren rock, after a stretch it may be of several thousands of feet, and they go down as great chutes somewhat diagonally on the dip to very great depths. The Tamarack workings, below the Calumet and Hecla, have been pushed on the bed nearly a mile below the outcrop, and show no diminution or essential change in the copper rock. Three copper-bearing conglomerates have been identified, the Calumet and Hecla, the Albany and Boston (also called the Peninsula) and the Allouez. The first is much the richest, but has not been found productive at any other point on the strike than in the great mine which gives it its name. The amygdaloids have copper in their small cavities, but in the open or shattered rock it fills all manner of irregular spaces, often in fragments of great size. It is associated with calcite, zeolites, datolite, epidote, and a chloritic mineral, or "green earth" containing Fe_2O_3. The distribution of the copper in the amygdaloidal sheets is much the same as in the conglomerates. It is limited along the strike, and goes down at a slight diagonal in great chutes whose ends have never yet been reached. This arrangement must have an important bearing on the method of origin.

2.04.13. In the Ontonagon district the copper follows planes approximately parallel to the bedding of the sandstones and igneous rocks, and in one case at least (the National mine) along the contact between the two. The copper is quite irregular in its distribution, but has the same associates that are mentioned above.

On the Origin of the Copper.—The original source of the copper was thought by the earlier investigators to be in the eruptive rocks themselves, and that with them it had come in some form to the surface, and had been subsequently concentrated in the cavities. Pumpelly has referred it to copper sulphides distributed through the sedimentary, as well as the massive rocks from which the circulating waters have leached it out as carbonate, silicate, and sulphate. Although the traps are said by Irving to be devoid of copper, except as a secondary introduction, it would be interesting to test their basic minerals for the metal in a large way, as has been so successfully done by Sandberger on other rocks. It is probable that these may be its source.

Irving states that the coarse basic gabbros of the system contain chalcopyrite, but they do not occur near the productive mines. The electro-chemical hypothesis of deposition was earliest advocated (Foster and Whitney), and on account of the electrolytic properties of the two metals copper and silver, at first thought, it seems to be a reasonable explanation. Still, the unsatisfactory character of all experiments made in other regions to detect such action militates against it. Pumpelly, however, has worked out an explanation much more likely to be the true one. He found, on studying the mineralogical changes which have taken place in the rocks, that the alteration had been very thorough, and that it had involved a most interesting series of minerals, which are now chiefly manifested in the cavity fillings. It is to be appreciated, as has been especially well shown by the recent detailed geological sections of L. L. Hubbard,[1] that, in the productive region, the Keweenawan rocks consist of a vast series of basic lava flows, with a few of more acidic types, and with occasional intercalated conglomerates. H. L. Smyth[2] has also emphasized the fact that these successive lava sheets must have remained for protracted periods after their outpourings, exposed to the atmospheric agents, and to weathering, before they sank beneath the sea, and were buried under the conglomerates. As a matter of observation the upper portions of the sheets are notably more cellular and decomposed than are the lower. Two kinds of amygdaloids were indeed recognized by Pumpelly,[3] brown ones, or true amygdaloids, in which the alteration was excessive, and which were probably derived from cellular lava sheets; and green ones, or pseudo-amygdaloids, which are hard and dense, and probably owe their apparent amygdules to the decomposition of pyroxene, olivine or feldspar crystals. Pumpelly traces out the following series of minerals. The first to develop was chlorite. Either contemporaneously with the chlorite or next after it, laumontite, a hydrated basic silicate of calcium and aluminum, resulted. Laumontite, prehnite and epidote, all non-alkaline silicates, next segregated in the cavities, and were followed by quartz. They are thought to correspond to the decay of the pyroxenic minerals in the lavas. The copper manifestly came in after this, and its deposition seems to have proceeded along with the formation of a green chloritic mineral, or green-earth, which has displaced the prehnite, quartz and calcite of the earlier stages. Calcite, it should be added, marks almost every stage of the paragenesis. Presumably the reducing action produced by the oxidation of FeO to Fe_2O_3 in the production of the chloritic "green-earth," caused the reduction and precipitation of the copper from some aqueous solution of sulphate, carbonate or silicate. After all this had occurred a quite different series of minerals (except that calcite continued to form) was introduced, which are characteristically alkaline silicates. Anal-

[1] *Geological Survey of Michigan*, V., opp. p. 166.

[2] *Science*, February 14, 1896, p. 251.

[3] *Geological Survey of Michigan*, I., Part II., 14. *Amer. Jour. Sci.*, September, 1871. *Proc. Amer. Acad. Arts and Sciences*, XIII., p. 268, 1878. *Geol. Wisconsin*, III., 31.

cite, apophyllite, datolite, and last of all orthoclase, are the chief members. Pumpelly regards them as produced by the alteration of the feldspars of the basalts, and in a continuous succession of changes following those just cited, but H. L. Smyth advances the view that they and the copper came in after the tilting and faulting of the strata, and probably in uprising solutions along the fissures, which are illustrated in the vein mines. He remarks that apophyllite contains fluorine and datolite, boron, and that the mineralization of the fissure veins is often extended in lateral enrichments, where the fissures cut porous beds. Pumpelly specially favored the overlying sandstones and descending solutions as sources of the copper. Wadsworth gives a resumé of all the views advanced up to 1880[1] and himself favors a derivation by leaching of the neighboring and overlying trap.

As stated in mentioning the great ore-chutes above, the circulations must have followed the general lines indicated by them, so that it is evident that the rich currents were of limited extent. The anomalous condition presents itself of native copper, a mineral that is usually characteristic of the oxidized zone of deposits of sulphides, extending to great depths below the ground-water level.

It is natural to raise the query as to the possible passage of the native copper into sulphides in depth, but there is as yet no evidence of this change. Any minerals in the nature of sulphides are extraordinarily rare. A little whitneyite and domeykite (copper arsenides) and chalcocite occur in the amygdaloid, formerly worked at the Huron mine; chalcocite has been found in the Bohemian Mountains and in the Copper Falls mine. Native copper changes to chalcocite 90 feet down in the Mamaisne mine, near the Sault (L. L. Hubbard). A pocket of melaconite, the black oxide, was opened in the early days at Copper Harbor.

2.04.15. The discovery of copper dates back to the explorations of the French, who, in the seventeenth century, left the

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[1] M. E. Wadsworth, "Notes on the Geology of the Iron and Copper Districts," *Bull. Mus. of Comp. Zöol.*, VII., 76, 123. *Report of the State Geologist of Michigan*, 1892, 167–170, and especially 169. Rec. Also in a pamphlet of the Duluth, South Shore & Atlantic R. R., 1890. "Origin and Mode of Occurrence of the Lake Superior Copper Deposits," *Trans. Amer. Inst. Min. Eng.*, XXVII., 669.

settlements on the lower St. Lawrence and penetrated the Great Lakes. The country was the scene of a great mining excitement in the forties. After many vicissitudes and exploded schemes the district settled down to the largest production of any American region. Within the last few years, however, Butte, Mont., has exceeded it. Many interesting traces of prehistoric mining were found by the early explorers, for the copper was a much-prized commodity among the aborigines.

2.04.16. Some important mining for copper has been done on Isle Royale, along the Canadian shore, and in Minnesota, but although Keweenawan rocks are in great force, no large amount of the metal has been found.[1]

[1] It would be impossible and undesirable to give in this place complete references to the literature. Such a bibliography will be found in Irving's monograph, and in Wadsworth's. The more important papers are given below, with some additions to the lists mentioned above.

Bauerman, H., "On the Copper Mines of Michigan," *Quar. Jour. Geol. Soc.*, XXII., 448, 1866. Good account of the minerals.

Credner, H., On the geology, etc., *Neues Jahrbuch*, 1869, p. 1.

Foster and Whitney, Report on the Lake Superior Copper Lands, 1850.

Hall, C. W., "A Brief History of Copper Mining in Minnesota," *Bull. Minn. Acad. Nat. Sci.*, Vol. III., No. 1, p. 105.

"History of Copper Mining in the Lake Superior District," *Engineering and Mining Journal*, March 18, 1882, p. 141.

Hubbard, L. L., "Two New Geological Sections of Keweenaw Point," *Proc. Lake Sup. Min. Inst.*, II. Rec.

Irving, R. D., "The Copper-bearing Rocks of Lake Superior," *Monograph V., U. S. Geol. Survey*, especially p. 419. Rec. Bibliography, p. 14.

"Keweenaw Point with Particular Reference to the Felsites and their Associated Rocks," *Geol. Survey of Mich.*, VI., Part II., 1899.

Lane, A. C., Geological Report on Isle Royale, *Mich. Geol. Survey*, VI., Pt. I.

Lawson, A. C., "Notes on the Occurrence of Native Copper in the Animikie Rocks of Thunder Bay," *Amer. Geol.*, V., 174.

Palache, Ch., "The Crystallization of Calcite from the Copper Mines of Lake Superior," *Geol. Survey, Mich.*, VI., Part II., Appendix.

Poole, H., "Michipicoten Island and its Copper Mines," *Eng. and Min. Jour.*, August 6, 1892, p. 125; September 3, p. 220.

Pumpelly, R., *Geol. Survey of Mich.*, 1873, Vol. I.

"On the Origin of the Copper." *Amer. Jour. Sci.*, ii., III., 183–195, 243–253, 347–353. Rec. A later and fuller paper is in *Proc. Amer. Acad.*, 1878, Vol. XIII., p. 233.

Rominger, C., "Copper Regions of Michigan," *Geol. Survey of Mich.*, V. 85, 1895.

Wadsworth, M. E., *Notes on the Geology of the Iron and Copper Districts of Lake Superior.* Cambridge, 1880. Bibliography, p. 133. See also footnote to page 211 above.

2.04.17. Example 19. St. Genevieve, Missouri. Beds of chalcopyrite associated with chert in magnesian limestone of the Cambrian system. St. Genevieve is situated on the Missis-

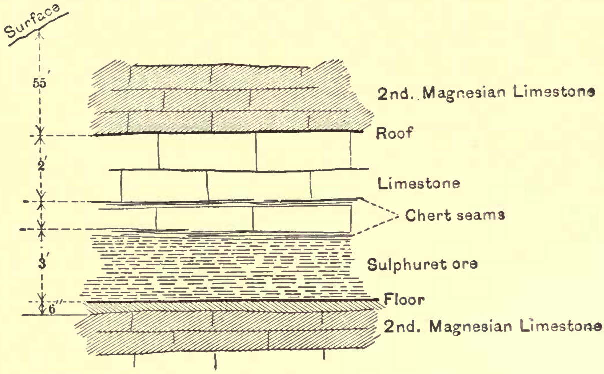

FIG. 67.—*Cross section in the St. Genevieve copper mine, illustrating the relations of the ore. After F. Nicholson, Trans. Amer. Inst. Min. Eng., X.,* 450.

sippi, about forty miles south of St. Louis. The Second Magnesian Limestone of the Cambrian outcrops, with the Carboniferous on the north, and more or less Quaternary in the vicin-

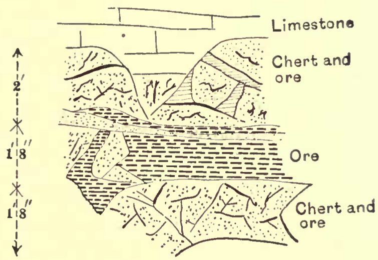

FIG. 68.—*Section at the St. Genevieve mine, illustrating the intimate relations of ore and chert. After F. Nicholson, Trans. Amer. Inst. Min. Eng , X.,* 451.

ity. There are two nearly horizontal beds of ore, of widths varying between three inches and several feet. They lie be-

Whitney, J. D., "On the Black Oxide of Copper of Lake Superior," *Proc. Boston Soc. Nat. Hist.*, January, 1849, p. 102; *Amer. Jour. Sci.* ii., VIII., 273.

Metallic Wealth of the United States, p. 245. Rec.

Whittlesley, C., "On Electrical Deposition," *Amer. Assoc. Adv. Sci.* XXIV., 60.

Wright, C. E., and Lawson, C. D., *Mineral Statistics of Michigan.* Annual formerly issued.

tween chert seams, and are associated with clay and sand. The ore is thought by Nicholson to have been deposited in cavities formed by dolomitization, much as is advocated by Schmidt for the lead and zinc deposits of southwest Missouri, and as is described under Example 25. For ten years the mines have not been operated.[1]

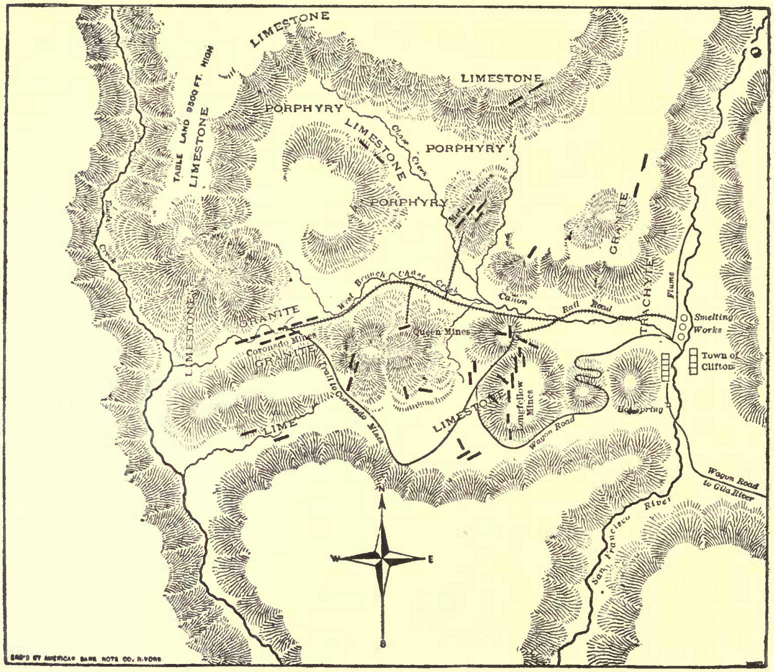

FIG. 69.—*Geological map of the Morenci or Clifton copper district of Arizona. After A. F. Wendt, Trans. Amer. Inst. Min. Eng., XV 23.*

2.04.18. Example 20. Arizona Copper. Bodies of oxidized copper ores in Carboniferous limestones, associated with eruptive rocks. In addition to these, which are the most important, there are veins in eruptive rocks, or in sandstones, or ore bodies of still different character as set forth under the several sub-examples. The copper districts are nearly all in

[1] F. Nicholson, "Review of the St. Genevieve Copper District," *Trans. Amer. Inst. Min. Eng.*, X., 444. B. F. Shumard, "Observations on the Geology of the County of St. Genevieve, Missouri," *Trans. St. Louis Acad. Sci.*, I., 40; abstract in *Amer. Jour. Sci.*, ii., XXVIII., 126.

the southeastern part of the territory, but the Black range is near the center.

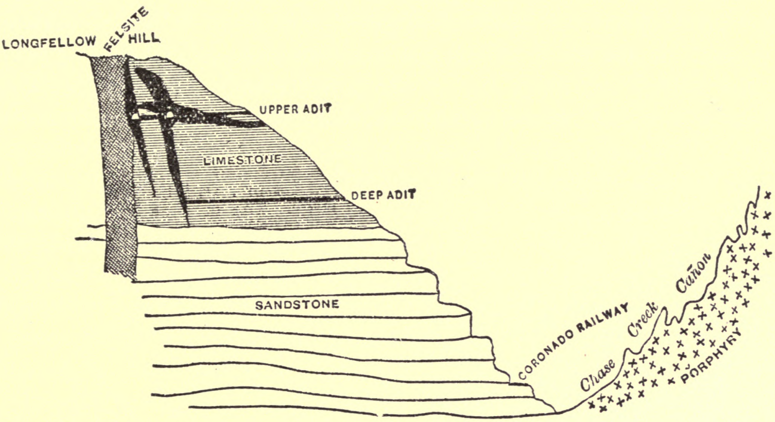

FIG. 70.—*Vertical section of Longfellow Hill, Clifton district, Arizona. After A. F. Wendt, Trans. Amer. Inst. Min. Eng., XV.*, 52.

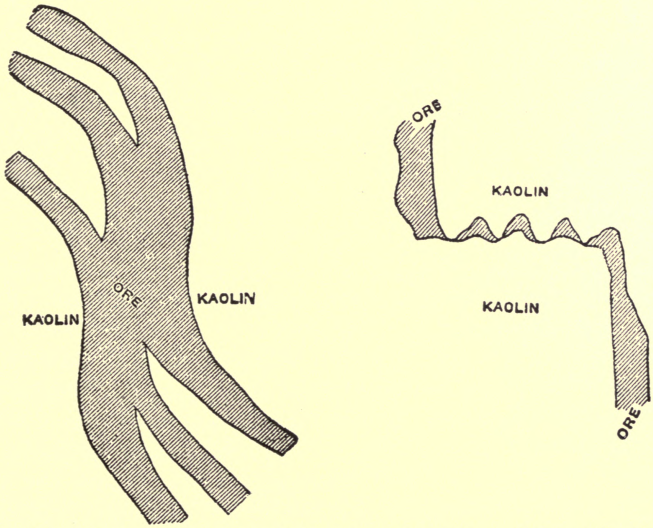

FIG. 71.—*Horizontal sections of Longfellow ore body. After A. F. Wendt, Trans. Amer. Inst. Min. Eng., XV.*, 52.

2.04.19. Example 20*a*. Morenci. The Morenci district, known also as the Clifton or Copper Mountain, lies in a basin, six to ten miles across, whose high surrounding hills consist of limestone, probably Lower Carboniferous, which rests on sandstone, and this on granite. The principal mines are grouped about the town of Morenci. Clifton is seven miles distant at the point where the smelter of the Arizona Copper Company is located. In the basin is a mass of porphyry, containing frequent great inclusions of limestone. Felsite or porphyry dikes are also abundant in the surrounding sedimentary and granite rocks. Several miles to the east there is an outflow of late trachyte and evidence of recent volcanic action. From this it appears that eruptive phenomena are abundant and widespread.

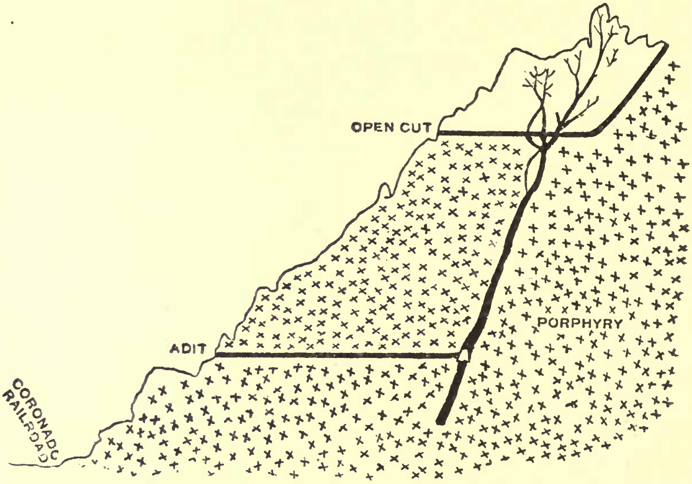

FIG. 72.—*Geological section of the Metcalf mine, Clifton district, Arizona. After A. F. Wendt, Trans. Amer. Inst. Min. Eng., XV.*, 36.

2.04.20. The ores are classified by Henrich as follows:

1. Contact deposits. These occur in a zone of decomposed and kaolinized porphyry, between a bluish, fine-grained limestone, and solid porphyry. Many ore bodies, and probably the largest, are directly on the limestone, while others are surrounded by the decomposed porphyry. As included masses of limestone, with associated ore, are found in the decomposed porphyry, it is probable that these ore bodies may have originally replaced such. The ores are malachite, azurite, cuprite, with some metallic copper and melaconite, in a gangue princi-

pally of limonite. Wad is also frequent. Much clay of a residual character occurs with the ores.

2. Deposits in limestone. These are closely associated with the first class, and have apparently formed as outlying bodies in the limestone, as they are connected by ore channels with the principal lines of circulation along the contact. They appear to contain more wad and lime than the typical contact deposits.

3. Deposits in porphyry. These form sheets and pockets in porphyry, or impregnate the solid rock itself. They are oxidized at the surface, but pass in depth into chalcocite. The principal gangue is kaolinized porphyry. The impregnated porphyries are to-day the chief ore supply.

According to Wendt the Coronado vein fills a longitudinal fissure in a quartz porphyry dike. It afforded chalcocite above, but passed into chalcopyrite below. Wendt also mentions a group of veins in granite that likewise afforded chalcocite.[1]

2.04.21. Example 20*b*. The Bisbee district, called also the Warren district, is situated in the Mule Pass Mountains in southern Arizona, near the Mexican line. The range runs east and west, and consists of beds of Lower Carboniferous limestone, dipping away from a central mass of porphyritic rock. The ores are found in the cañons on the south side, which have been formed by erosion, along the contact of the limestone and porphyry. They are of the same oxidized character as at Morenci, and in the important mines occur in limestone. James Douglass describes them as being situated at a distance from the porphyry of perhaps a thousand feet or more, and as forming in their unaltered state huge masses of pyrites with copper often as low as two per cent. They have been produced, as nearly as one can judge by replacement of the limestone, through the agency of solutions, which brought much siliceous and aluminous matter as well. It is natural to look to the porphyry as the source of the latter material. The sul-

[1] J. Douglass, "Copper Resources of the United States," *Trans. Amer. Inst. Min. Eng.*, XIX. 678, 1890. Rec. "Arizona Copper and Copper Mines," *Eng. and Min. Jour.*, August 13, 1881, p. 103. "Clifton Copper Mines of Arizona," *Ibid.*, February 21, 1880, p. 133. C. Henrich, "The Copper Ore Deposits near Morenci, Ariz.," *Ibid.*, March 26, 1887, pp. 202, 219. Rec. A. Wendt, "Copper Ores of the Southwest," *Trans. Amer Inst. Min. Eng.*, XV., p. 23. Rec.

phides pass in alteration into bodies of oxidized ore, which remain in the midst of ferruginous clay, called "ledge matter" by Dr. Douglass. Thoroughly oxidized masses, as well as others whose outer shell is alone changed, are known. One mass in the Czar shaft of the latter character is estimated at 1,000,000 tons of ore. The degree of alteration does not appear to be dependent on the vertical position, as bodies of sulphides are known to be higher up than thoroughly oxidized masses, but in this arid region the ground-water stands at a very considerable depth, and appears not to have been yet actually reached, although much trouble is caused by floods during periods of rain. Above the bodies of ore empty caves are usually found, and so frequent is this association that when the prospecting drifts strike a cave the miners immediately sink in the expectation of striking an ore body in depth. Sink-holes on the surface have been successfully used as guides in the same way. In the accompanying picture of the mine, Fig. 73, the limestones dip into the hill, away from the shaft, and the ores are found in them, and beneath the valley below.

The rock referred to as porphyry above has been microscopically determined by A. A. Julien for Arthur Wendt to be a quartz-porphyry with a felsitic ground mass (felsite-porphyry of Julien). Its contact with the limestones is marked by a zone of kaolinization, or alteration, and is not sharp. Positive evidence of contact metamorphism has not yet been recorded, but the effects of circulating waters are pronounced. The results of detailed geological study of the region will be awaited with interest.[1]

2.04.22. Example 20*c*. Globe District. As in the other districts the most productive mines are in limestone near the contact with eruptive rocks.

1. Contact deposits in limestone. At the Globe mines the Carboniferous limestone abuts against a great dike of diorite, while trachyte and granite are near. Along the contact there is abundant evidence of thermal action in the kaolinized rock.

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[1] J. Douglass, "Copper Resources of the United States." *Trans. Amer. Inst. Min. Eng.*, XIX., 678, 1890. Rec. "The Copper Queen Mine," New York meeting of the *Amer. Inst. Min. Eng.*, February, 1899. See *Eng. and Min. Jour.*, February 25, 1899, p. 230. A. Wendt, "Copper Ores of the Southwest," *Trans. Amer. Inst. Min. Eng.*, XV., p. 52. Rec.

FIG 73.—*View of the Copper Queen mine, Bisbee district, Arizona. From a photograph by James Douglass.*

The great bodies of oxidized ores are found on this contact and extend out into the limestone. The one on the Globe claim is described by Wendt as resembling a great chimney.

2. A fissure vein in sandstone, containing arsenical and antimonial copper ores, and known as the Old Dominion, was formerly worked.

3. Fissure veins in talcose slate and gneiss, and filled by a quartz gangue with bunches of malachite and azurite (New York and Chicago mines), and now no longer worked.

4. Numerous small veinlets forming a stockwork, in gneiss near a dike of diorite, which is crossed by a dike of trachyte. These are known as the Black Copper Group. The ores are too low grade for profitable exploitation. Of greater interest are the bodies of chrysocolla, found in the wash down the hill from the outcrop of the veins, and evidently due to the superficial drainage of the stockworks. Similar bodies of ore, though not chrysocolla, were found at Rio Tinto, in Spain.[1]

2.04.23. Example *20d*. Santa Rita District. Although in New Mexico, this district has much in common with those already mentioned. A great dike of felsite cuts limestones, and along the contact, as well as in the felsite itself, copper ores are found.

1. Contact deposits in limestone. These afforded the usual oxidized ores, but were not found to extend to any great depth, and while for a time productive, they were soon exhausted.

2. Deposits in felsite. These consisted of pellets and sheets of native copper in the dike itself, which were oxidized to cuprite near the surface. (Cf. Lake Superior amygdaloids, Example 18.) They were worked by the Mexicans in the early part of the present century.[2]

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[1] J. Douglass, "Copper Resources of the United States," *Trans. Amer. Inst. Min. Eng.*, XIX. 678, 1890. Rec. "The Globe District," *Eng. and Min. Jour.*, April 9, 1881, p. 243. W. E. Newberry, "Notes on the Production of Copper in Arizona," *School of Mines Quarterly*, VI., 370. A. Trippel, "Occurrence of Gold and Silver in Oxidized Copper Ores in Arizona," *Eng. and Min. Jour.*, June 16, 1883, p. 435. A. Wendt, "Copper Ores of the Southwest," *Trans. Amer. Inst. Min. Eng.*, XV., p. 60.

[2] A. F. Wendt, "Copper Ores of the Southwest," *Trans. Amer. Inst. Min. Eng.*, XV., 27. Wislizenus, "On the Santa Rita Mines: Memoir of a Tour in Northern Mexico, 1846–47," p. 47; *Amer. Jour. Sci.*, ii., VI., 385, 1848

2.04.24. Example 20*e*. Black Range District. This is now the leading copper producer of Arizona, and has come into great prominence within a few years. In its geological relations it appears to be more like the California deposits than any others, but there are as yet but few recorded details. It appears that there is a great dike of more or less porphyritic, dark green rock that has been extensively fractured along a broad line of dislocation for several miles. The fractured zone strikes north 10° west, and outcrops about 5,800 feet above tide. The writer has examined thin sections of the dike-rock, which is locally called diorite, but the specimens at hand were too thoroughly decomposed to admit of close identification. No dark silicates were visible, and chloritic products alone indicated their former presence. Broadly rectangular feldspars were the chief minerals, but they were too badly altered, even to indicate their character, although no positive, polysynthetic twinning could be detected. Quartz was common. In depth sheared dike rock is met that resembles slate. The ore, which embraces both bornite and chalcopyrite, fills the cracks and larger fissures and impregnates the slaty rock. There is some galena present, and earthy lead sulphate has resulted from it in the gossan. The ore carries both gold and silver. The inaccessible situation of the mines long hindered their development, but now, with a mountain railway to give them an outlet, they are very productive. They are operated by the United Verde Company, and are about 20 miles west of Prescott.[1]

2.04.25. Example 20*f*. Copper Basin. Beds of closely textured conglomerate and sandstone, resting on granite and gneiss, and having a cement of copper carbonates. Copper Basin lies about twenty miles southwest of Prescott, and is formed by a depression in greatly decomposed granite, which is traversed by numerous small veinlets of copper ores. The granite is pierced by porphyry dikes, and covered by the sedi-

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[1] J. F. Blandy, "The Mining Region Around Prescott, Ariz.," *Trans. Amer. Inst. Min. Eng.*, XI., 286. G. K. Gilbert, "On the General Geology of the Black Mountain District," *Wheeler's Survey*, III., p. 35. A. R. Marvine, "Brief Details of the Verde Valley," *Wheeler's Survey*, III., p. 209. A. F. Wendt, "Copper Ores of the Southwest," *Trans. Amer. Inst. Min. Eng.*, XV., 63. Rec.

mentary conglomerates and sandstones into which its copper is thought by Blake to have partially leached and precipitated as a cement. Reference, by way of comparison, may be made to the Lake Superior conglomerates, in which, in part, the native copper serves as a cement.[1]

2.04.26. There are numerous other copper districts in Arizona of minor importance, or entirely undeveloped, but the examples above cited probably illustrate the occurrences quite fully. Those not referred to are of sporadic development. Copper prospects are known in the Grand Cañon of the Colorado, and have received some attention.[2] Mention should also be made of the mines in Lower California, opposite Guaymas, a brief description of which will be found in Wendt's paper.[3] The copper ores impregnate beds of submarine volcanic tuff, and are unique in their geological relations.

Much copper is now met in depth at Leadville, Colo. The geology of the mines is set forth under Lead-Silver.

2.04.27. Example *20g*. Crismon-Mammoth, Utah. In the Tintic district, Juab County, are three great ore belts, in vertically dipping dolomitic limestone, as more fully set forth under "Silver" (Example *35a*). One of these, the Crismon-Mammoth, contains ores that bear silver, gold, and copper in proportions of about equal value. They have been a very difficult mixture to treat successfully. Of late considerable copper has been produced, placing the ore deposits among those deserving mention. The Crismon-Mammoth vein or belt covers a maximum width of 70 feet, and runs 500 feet on the strike, dipping 75° west. The ores seems to have been deposited along the bedding planes, though often cutting across them. The productive portions are found in richer chutes or chimneys, amid much low-grade material and gangue, and are of all shapes and sizes, from 25 feet in diameter, down. The Copperopolis

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[1] W. P. Blake, "The Copper Deposits of Copper Basin, Arizona, and their Origin," *Trans. Amer. Inst. Min. Eng.*, XVII., 479.

[2] J. F. Blandy, "On Arizona Copper Deposits," *Eng. and Min. Jour.*, 1897, Vol. LXIV., p. 97.

[3] See also M. E. Saladin, "Note sur les Mines de Cuivre du Boleo (Basse Californie)," *Bull. de la Société de l'Industrie Minérale*, 3 Serie, VI., 5, 283.

is thought to be on the same belt, and is a neighboring location of similar geological structure and ores.[1]

A very important body of chalcocite was discovered in 1898 in Bingham Cañon, whose geological relations are similar to those described for the lead-silver ores under 2.08.23. Its location was on the Highland Boy claim.

2.04.28. Wyoming, Idaho, Washington. Oxidized ores have been exploited to some extent at the Sunrise mines, in the Laramie Range, Wyoming. Iron ores are in the same region (see under Hematite). Other copper prospects have been opened in the Wood River region in northern Wyoming, and at other points, but the geological relations have not yet been described.

2.04.29. In the extreme western border of Idaho, near the Oregon line, the Seven Devils district has been located and developed to a considerable degree. Intrusions of diorite have pierced a white marble and upon the contacts and upon inclusions have developed extensive aggregates of garnet, epidote and specular hematite, together with very considerable amounts of bornite. Green prophyritic dikes are also present. Lindgren regards the ore as formed by pneumatolytic processes set up by the diorite. As also remarked by Lindgren the type of ore body is known in Mexico, and indeed a number of cases have come to the notice of the writer.[2]

Not a few copper prospects have been located in Washington, but they are as yet of somewhat undemonstrated value. North of Lake Chelan in the Stehekin district copper sulphides, pyrites and mispickel impregnate brecciated, andesitic dikes in marble.[3] A vein in King County[4] is described as occurring in syenite.

2.04.30. Example 21. Copper ores in Triassic or Permian sandstone. They occur as oxidized ores, with native silver,

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[1] O. J. Hollister, "Gold and Silver Mining in Utah," *Trans. Amer. Inst Min. Eng.*, XVI., p. 10. D. B. Huntley, *Tenth Census*, Vol. XIII., p. 456. A report on the Tintic District is in press with the *U. S. Geol. Survey*, but is not available at this writing.

[2] R. L. Packard, "On an Occurrence of Copper in Western Idaho," *Amer. Jour. Sci.*, October, 1895, 298. W. Lindgren, "Copper Deposits of the Seven Devils," *Mining and Scientific Press*, Feb. 4. 1899, 125. Rec.

[3] As learned from the writer's friend, Charles Of, from whom material has been obtained and examined.

[4] R. H. Norton, "A Washington Copper Deposit," *Eng. and Min. Jour.*, February 11, 1899, 173.

and chalcocite in contact deposits in Triassic and Permian sandstones at their junction with diabase or gneiss, or as disseminated masses replacing organic remains. Copper ores are very common throughout the estuary Triassic rocks of the Atlantic coast, and although formerly much mined, they are now proved valueless, and of scientific interest only.

2.04.31. Example 21*a*. Contact deposits in sandstone at its junction with diabase. These include the New Jersey ores, vigorously worked before the Revolution. They consist of the carbonates, of cuprite and of native copper, disseminated through sandstone near the trap. The Schuyler mines, near Arlington, N. J., and several other openings near New Brunswick, N. J., are best known. These Triassic diabases often show chalcopy-

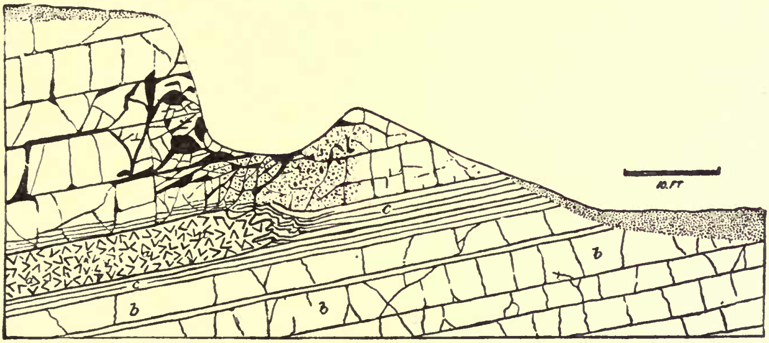

FIG. 74.—*Cross section of the Schuyler Copper mine, New Jersey.* a, *trap;* b, *sandstone;* c, *shales; the black shading, copper ores. After N. H. Darton, U. S. Geol. Survey, Bull.* 67, *p.* 57.

rite, and it is probable that the copper came from this or from copper in the augite of the rock, in accordance with Sandberger's investigations. The deposits are unreliable, and except at a very early period have never been an important source of ore.

2.04.32. Example 21*b*. Contact deposits in sandstones at the junction with gneiss. A number of deposits were formerly worked of this character, especially at Bristol, Conn., and at the Perkiomen mine, Pennsylvania. The mine at Bristol, Conn.. is a well-marked contact deposit, on the line between the Triassic sandstone and the schistose rocks. The contact runs northeast and southwest. has suffered great decomposition from mineral solutions, and has been largely kaolinized. A broad band of this decomposed material, 30 to 120 feet wide, lies next the sandstone, and contains disseminated ore. Then follow micaceous and hornblende slates, often with horses of gneiss. The slates are much broken by movements that have formed cavities for the ores. It is reasonable to connect the stimulation of the ore currents with the neighboring trap outbreaks. Unusually fine crystals of chalcocite and barite have made the mine famous the world over. While at one time a source of copper, for many years it has been unproductive.[1]

2.04.33. Example 21*c*. Chalcocite and copper carbonates replacing vegetable remains, etc., in the Permian or Triassic sandstones of Texas, New Mexico, and Utah. In the Permian of northern central Texas are three separate copper-bearing zones, forming three lines of outcrop that extend in a general northeasterly direction over a range of about three counties. The ore is largely chalcocite in beds of shale, and often replaces fragments of wood. It may be available in time.[2]

At various places in Utah and New Mexico (Abiquiu, N. M., Silver Reef, Utah), the sandstones, as reported by Newberry and others, have copper ores disseminated through them and deposited on fossils, at times with associated silver (Utah). The copper, whether coming from the waters along the shore line or from subterranean currents, was precipitated by the organic matter. (See also under "Silver," in Utah.) These deposits are not yet sources of copper.[3]

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[1] L. C. Beck, "Notice of the Native Copper Ores, Copper, etc., near New Brunswick, N. J.," *Amer. Jour. Sci.*, i., XXXVI., 107. G. H. Cook, *Geol. of N. J.*, 1868, p. 675; also L. C. Beck, *Ibid.*, 218-224. J. G. Percival, *Rep. on Geol. of Conn.*, p. 77. C. A. Shaeffer, "Native Silver in New Jersey Copper Ore," *Eng. and Min. Jour.*, February, 1882, p. 90. C. U. Shepard, *Geol. of Conn.*, 1837, p. 47. B. Silliman and J. D. Whitney, "Notice of the Geological Position and Character of the Copper Mine at Bristol, Conn.," *Amer. Jour. Sci.*, ii., XX., 361. J. D. Whitney, *Metallic Wealth.* Rec.

[2] W. F. Cummins, "Report on the Permian of Texas and its Overlying Beds," *First Ann. Rep. Texas Geol. Survey,* p. 196. J. F. Furman, "Geology of the Copper Region of Northern Texas and Indian Territory," *Trans. N. Y. Acad. Sci.*, 1881–83, p. 15.

[3] F. M. F. Cazin, "The Origin of the Copper and Silver Ores in Triassic Sand Rock," *Eng. and Min. Jour.*, April 30, 1880; December 11, 1880, 331. "The Nacemiento Copper Deposits," *Ibid.*, August 22, 1885, p. 124. A.

2.04.34. Copper production in 1882, 1890 and 1897, in tons of 2,000 pounds each:

	1882.	1890.	1897.
Lake Superior	28,578	50,372	72,920
Montana	4,529	56,490	118,579
Arizona	8,992	17,398	40,510
Colorado	747	441	4,719
New Mexico	434	425	......
California	413	11	7,065
Utah	303	503	1,927
Elsewhere	1,412	3,906	2,874
Copper sulphate	.....	.....	6,501
	45,408	129,546	255,095

The figures indicate in general a vast increase in production, and, above all, the advance of Montana. For detailed statistics *The Mineral Industry*, issued annually by the Scientific Publishing Company, New York, and the Annual Reports of the Director of the U. S. Geological Survey are the chief books of reference.

W. Jackson, *Rep. Director of the Mint*, 1880, p. 334. J. S. Newberry, "Copper in Utah, Triassic Sandstones," *Eng. and Min. Jour.*, Vol. XXXI., p. 5. Also October 23, 1880, p. 269; January 1, 1881, p. 4. See also *Tenth Census*, Vol. XIII., Precious Metals, pp. 40, 478. C. M. Rolker, "The Silver Sandstone District of Utah," *Trans. Amer. Inst. Min. Eng.*, IX., 21. R. P. Rothwell, quoted in *Tenth Census*, Vol. XIII., p. 478. B. Silliman, "The Mineral Regions of Southern New Mexico," *Trans. Amer. Inst. Min. Eng.*, XVI., 427.

CHAPTER V.

LEAD ALONE.

2.05.01. The deposits of lead are treated in three different classes, according as they produce or have produced lead alone, lead and zinc, or lead and silver. Of late years the lead-silver ores have been the great source of the metal. Only the southeast Missouri region is of much importance among the others, although considerable lead is also obtained in association with zinc.

LEAD SERIES.

	Pb.	*S.*
Galena, PbS........................	86.6	13.4
Cerussite, $PbCO_3$..................	77.5	....
Anglesite, $PbSO_4$..................	68.3	....
Pyromorphite, $Pb_3P_2O_8+1/3PbCl_2$.	76.36	....
Earthy mixtures of these last three and limonite.		

2.05.02. Example 22. Atlantic border. Veins of galena in the Archean rocks of the States along the Atlantic border; also others in Paleozoic strata, as described in the sub-examples.

2.05.03. Example 22*a*. Veins in gneiss and crystalline limestone, sometimes with a barite or calcite gangue. These deposits were vigorously exploited forty years ago or more, but have since been of small importance other than scientific. They may be described best by districts, as they hardly deserve a greater prominence.

2.05.04. (1) St. Lawrence County, New York. Veins with galena in a gangue of calcite in Archean gneiss. Those near Rossie are perhaps best known, especially for their unusually interesting calcite crystals. There are numbers of veins in the district which are notable in that the galena is without zinc or iron associates. The lead carries a very small amount of silver, not enough to separate. Hornblende and mica schists occur in the same region, and the Potsdam sandstone is not far removed. A few minor veins cut the Trenton limestone near Lowville, Lewis County, sometimes with fluorite for a gangue.[1]

2.05.05. (2) Massachusetts, Connecticut and eastern New York. Veins of galena with more or less chalcopyrite and pyrite in a quartz gangue in gneiss, slates, limestones or mica schists. The mines near Northampton, Mass., were formerly well known, although never productive of a great deal of metal; but as there is a large, prominent vein, it attracted attention. There are numerous others in the same region. Veins also occur at Middletown, Conn., where much silver is said to be found in the galena. More recently (*circa* 1873) at Newburyport, Mass., argentiferous galena attracted attention, but was not of any importance. Other veins are known at Lubeck, Me., and in various parts of New Hampshire and Vermont. For a time small lodes in the slates of Columbia County, New York, were unsuccessfully exploited, of which the Ancram mine is of historic interest. Although these galena veins are numerous, they are not to be taken too seriously.[2]

2.05.06. (3) Southeastern Pennsylvania. Veins on the contact of Archean gneiss and Triassic sandstone and diabase. These were referred to under Example 21*b*. As noted by Whitney, the copper is especially strong in the sandstone, and the lead in the gneiss. Trap dikes are abundant, and the eruptive phenomena in connection with them may have occasioned the activity of the circulations which filled the veins. The Wheatley mine is best known. It has afforded a great variety of lead

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[1] J. C. Beck, *Mineralogy of New York*, p. 45. E. Emmons, "Geology of the Second District," *N. Y. Geol. Survey*, 1842. G. Hadley, "Crystallized Carbonate of Lead at Rossie," *Amer. Jour. Sci.*, ii., II., 117. F. L. Nason, "Calcite from Rossie," *Bull. 4, N. Y. State Museum*, 1888. J. D. Whitney, *Metallic Wealth*. Rec.

[2] B. K. Emerson, Geology of old Hampshire Co., Mass., comprising Franklin, Hampshire and Hampden counties. *Monograph XXIX, U. S. Geol. Survey*. See also *Bulletin 126.—Idem*. C. A. Lee, "Notice of the Ancram Lead Mine," *Amer. Jour. Sci.*, i., VIII., 247. A. Nash, "Notice of the Lead Mines and Veins in Hampshire County, Massachusetts," *Amer. Jour. Sci.*, i., XII., 238. R. H. Richards, "The Newburyport Silver Mines," *Trans. Amer. Inst. Min. Eng.*, III., 442. B. Silliman, at Southampton, Mass *Bruce's Journal of Mineralogy*, I., 65. J. D. Whitney, *Metallic Wealth*.

minerals, especially pyromorphite. The mines have not been worked in years.[1]

2.05.07. (4) Davison County, North Carolina. Veins in talcose slate were formerly exploited, but are now little known, except as having furnished beautiful crystals of oxidized lead minerals.[2]

2.05.08. Example 22*b*. Sullivan and Ulster Counties, New York. Veins along a line of displacement on the contact between the Hudson River slates and the sandstones of the Medina stage (Shawangunk grit), carrying galena and chalcopyrite in a quartz gangue; or else gash veins filled with the same in the grit. These mines formerly produced considerable lead and copper, but are now best known for the excellent quartz crystals which they have furnished to all the mineralogical collections of this and other lands.[3]

2.05.09. Example 23. The Disseminated Lead Ores of Southeast Missouri. Galena, accompanied by varying amounts of nickeliferous pyrite, disseminated through dolomitic limestone of Lower Silurian or Cambrian age, its determination being in dispute. The dolomitic limestone is called the St. Joseph limestone by Arthur Winslow,[4] who considers it Lower Silurian. C. R. Keyes[5] has designated it the Fredericktown, and classifies it with the Cambrian. As shown in the accompanying map, which is based on one by Winslow, the mining districts are distributed along a line running west of north. At the north is Bonne Terre, the most productive of all up to the present. A few miles south is the Flat River district, including Desloge. The next is Doe Run, and then after a considerable interval Mine la Motte. Recently prospects have been opened near Fredericktown. Much drilling has been done between these centers, but without notable results. The geological relations are simple. On the south and southwest are

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[1] H. D. Rogers, *Geol. of Penn.*, II., 701; also *Amer. Jour. Sci.*, ii., XVI., 422. J. D. Whitney, *Metallic Wealth*, p. 396.

[2] J. C. Booth, "Analyses of Various Ores of Lead, etc., from King's Mine, Davison County, North Carolina," *Amer. Jour. Sci.*, i., XLI., 348. W. C. Kerr, *Geol. of North Carolina*, p. 289.

[3] J. D. Whitney, *Metallic Wealth.* W. W. Mather, *N. Y. State Survey, Report on First District*, 358.

[4] *Bull. 132, U. S. Geol. Survey*, p. 11.

[5] "Mine la Motte Sheet," in *Mo. Geol. Survey*, Vol. IX., Report 4, p. 48

the Archean granites, porphyries and diabase dikes, earlier mentioned in connection with the specular hematites of Iron Mountain and Pilot Knob. Scattered knobs of them are also

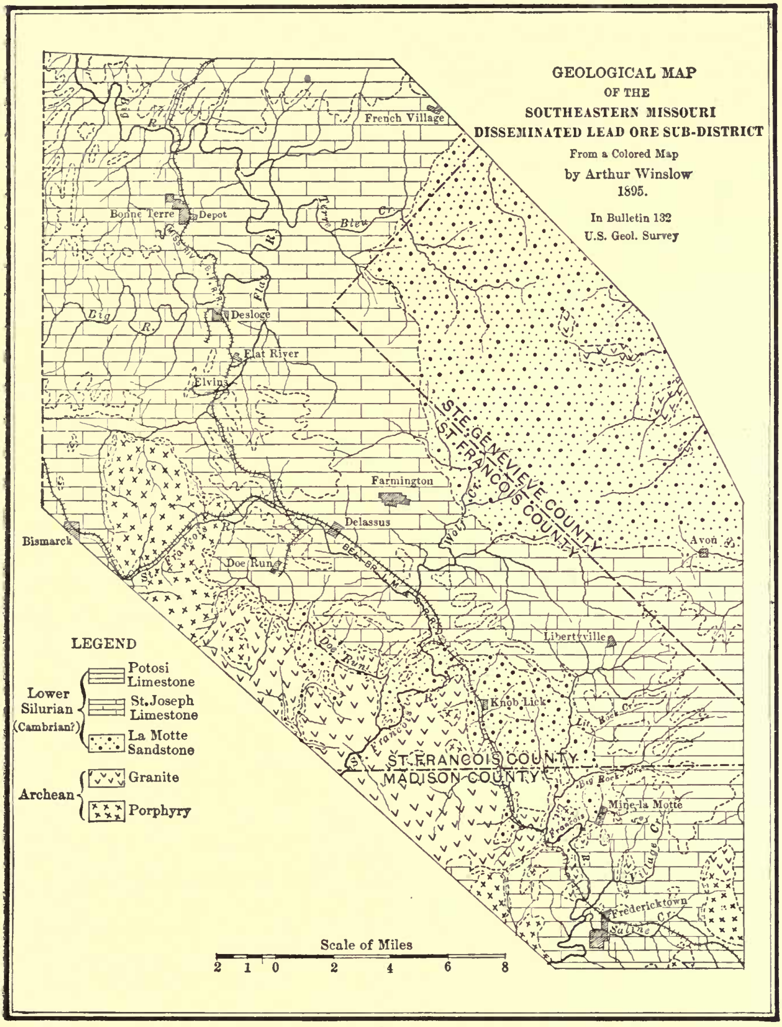

FIG. 75.

met to the eastward. On the granites and porphyries rests the La Motte sandstone, of variable thickness, but possibly reaching 400 feet, according to Winslow. Conformably on the sandstone lies the St. Joseph dolomitic limestone, the ore-bearing formation. It varies from 200 feet at Mine la Motte to 600 feet at Bonne Terre. It varies from shaly to massive structures, and is often coarsely granular in texture. In rock of the latter character, and, in the southern districts, usually not far above the sandstone, is found the ore. At Bonne Terre, however, the ore is a long distance above the base. The ore is galena, often mingled with more or less pyrites, and as a rule it is disseminated through the limestone so as to form an integral part of the rock. It also forms sheets sometimes along joints and stratification planes, and seems to favor the darker or more bituminous varieties of the dolomite. At Mine la Motte certain "diggings" or mines seem to have some connection with a local fault, but others do not indicate such relations, and elsewhere small fissures, or joints, often so tight as only to be revealed by the dropping of water, are the only cracks of any kind apparent. The St. Joseph formation lies very flat, and is practically devoid of fossils. Above it comes a cherty limestone, called the Potosi by Winslow (Leseur by Keyes). It is widespread, but has no immediate connection with the ore.

The ore bodies are in the nature of impregnations of the wall rock which extend fairly parallel with the stratification and are of varying thickness. They fade out gradually into low grade or barren rock. They may be cut at several horizons by the shafts or drill holes. One at Bonne Terre has been mined, according to Winslow, over an area nearly three-quarters by one half of a mile, and ore is known through almost 250 feet vertical thickness. The yield to date has been about a quarter of a million tons of lead. Throughout the districts the shafts are not deep, seldom reaching 400 feet. The ore as mined contains from 7 to 10 per cent. galena, although blocks of over a ton of the pure sulphide have been taken out.

The formation of these ore bodies is a very obscure question. The writer in 1887 applied to them the views that had been early advanced by Whitney for the gash veins of the Upper Mississippi, namely, that decaying marine vegetation had precipitated the sulphides from sea water. This is very doubtful, as traces of algæ, or any other fossils, are extremely rare. W. P. Jenney in 1893 referred them to solutions uprising along faults, which were thought to cut the ore bodies, and from which the mineralizing waters had spread laterally through the porous beds. The fault at Mine la Motte along which the ore occurs has been earlier cited as giving some support to this view, although right at the fault the ore bodies tend to grow lean. Elsewhere faults are insignificant so far as known. Winslow favors the descent of solutions from above, and thinks that the sulphides have been supplied by the weathering of overlying strata, now in large part removed. These regions have been land since the early Carboniferous times, and the superficial decay has been enormous. Lead-bearing solutions, it is thought, have filtered downward through the joints, faults and small cracks, and have deposited their dissolved materials by replacement of the limestone. The conduits seem, however, insignificant when compared with the ore bodies, and it is evident that all the explanations thus far suggested involve difficulties.

In the Mississippi Valley in this portion of the country the Lower Carboniferous and earlier rocks contain lead over an area of more than 3,000 square miles. Aside from these disseminated ores, zinc is always associated with the lead; but in southeastern Missouri it is practically unknown in the deposits of the disseminated type. There are, however, in the neighboring districts several mines, such as the Vallé, which are closely analogous to the gash veins later described, and which do contain zincblende. The history of Mine la Motte dates back to the early part of the eighteenth century, when this region figured largely in John Law's Mississippi bubble. The mine is said to have furnished lead for bullets during the war of the Revolution.[1]

[1] A bibliography of the lead and zinc regions of Missouri, by Arthur Winslow, will be found in the *Reports of the Missouri Geol. Survey*, VII., Part II., p. 743. It comes down to 1894. A bibliography of Missouri geology in general was prepared by F. A. Sampson and issued as *Bulletin 2 of the Mo. Geol. Survey*, in 1890. A revised edition by C. R. Keyes appears in Vol. X., of the *Survey*, p. 221, and comes down to 1896. The more important or the more recent papers are given below: G. C. Broadhead, "The Southeastern Missouri Lead District," *Trans. Amer. Inst. Min. Eng.*, V., 100. Rec. J. R. Gage, "Occurrence of Lead Ores in Missouri," *Idem*, III., 116; also *Geol. Survey of Missouri*, 1873–74, pp. 30, 603. W. P. Jenney, "The Lead and Zinc Deposits of the Mississippi Valley," *Trans. Amer. Inst. Min. Eng.*, XXII., 171, 621, 1893. J. F. Kemp, "Notes on the

2.05.10. The great increase in lead production in the United States came about 1880, with the opening of the Leadville ore bodies. From 1877 until 1881 Eureka, Nev., was an important source, but since then it has greatly declined. Utah has preserved a fairly uniform production since the early seventies. Lead from all sources is here mentioned, although lead-silver ores are subsequently treated. The amounts are in tons of 2,000 pounds. For detailed statistics see the annual volume on *The Mineral Industry* (New York: Scientific Publishing Company) and the Annual Reports of the Director of the U. S. Geological Survey. The figures for 1896 are taken from the Eighteenth Annual Report, Part V., p. 240.

	1880.	1890.	1896.
Missouri, Kansas, Wisconsin, Illinois	27,690	55,000	51,887
Colorado	35,674	60,000	44,803
Nevada	16,659	2,500	1,173
Utah	15,000	24,000	35,578
Idaho, Montana		24,000	57,732
Elsewhere	2,802	15,994	6,323
	97,825	181,494	197,496

From 80 to 85% of the total product is from lead-silver ores.

Ore Deposits, etc., of Southeastern Missouri," *School of Mines Quarterly*, October, 1887, 74; April, 1888, 212. C. R. Keyes, "The Mine la Motte Sheet," *Geol. Survey of Missouri*, IX., Report 4, 1896. A. Litton, *Second Ann. Rep. of the First Geol. Survey of Mo.*, 12–64, 1854. James E. Mills, *Report on the Mine la Motte Estate*, New York, 1877. H. S. Munroe, "The New Dressing Works of the St. Joseph Lead Co., at Bonne Terre, Mo.," *Trans. Amer. Inst. Min. Eng.*, XVII., 659, 1888. J. W. Neill, "Notes on the Treatment of Nickel-Cobalt Mattes at Mine la Motte," *Idem*, XIII., 634. F. Posepny, "On Mine la Motte," *Genesis of Ore Deposits*, p. 107; *Trans. Amer. Inst. Min. Eng.*, XXIII., 303, 1893. H. A. Wheeler, "On Southeast Missouri Lead Mines, *The Colliery Engineer*, 1892. C. P. Williams, "Industrial Report on Lead, Zinc and Iron in Missouri," Jefferson City, 1877. Arthur Winslow, "Lead and Zinc Deposits of Missouri," 2 vols., *Missouri Geol. Survey*, VII., Parts I. and II., 1894. A very complete book on lead and zinc in general. Fairly complete bibliography, Part II., p. 743. A fuller one by F. A. Sampson will be found in *Bulletin 2 of the Mo. Geol. Survey*, 1890. Arthur Winslow, "Lead and Zinc Deposits of Missouri," *Trans. Amer. Inst. Min. Eng.*, XXIV., 634, 931, 1894. "Notes on the Lead and Zinc Deposits of the Mississippi Valley and the Origin of the Ores," *Jour. Geol.*, I., 612, 1893. "Report on the Iron Mountain Sheet," *Mo. Geol. Survey*, IX., Report 3, p. 32, relates to Doe Run. "The Disseminated Lead Ores of Southeastern Missouri," *Bulletin 132, U. S. Geol. Survey*, 1896. Rec. The best brief account, "Historical Sketch of Lead and Zinc," *Eng. and Min. Jour.*, November 17, 24, 1894; January 19, 1895.

CHAPTER VI.

LEAD AND ZINC.

2.06.01. Example 24. The Upper Mississippi Valley. Gash veins and horizontal cavities (flats), principally in the Galena and Trenton limestones of the Upper Mississippi Valley, and containing galena, zincblende, and pyrite (or marcasite), with calcite, barite, and residual clay. The deposits are found in southwest Wisconsin, eastern Iowa, and northwestern Illinois. The greater portion of the productive territory lies in Wisconsin, and covers an area which would be included in a circle of sixty miles radius, whose limits would pass a few miles into Illinois and Iowa. A low north and south geanticline runs through central Wisconsin, dating back to Archean times and called by Chamberlin "Wisconsin Island." On its western slope the Cambrian and Lower Silurian rocks are laid down, and these in the western limit of the lead district pass in the adjoining States under the Upper Silurian. They are folded also in low east and west folds, but in the aggregate the whole series dips very gradually westward. The chief east and west fold forms the south bank of the Wisconsin River, and may have been the cause that deflected it from a southerly course. The easterly part of the lead region is 350 feet higher than the western, and the northern is 500 feet above the southern. The general slope is thus southwesterly.

2.06.02. The Galena limestone is a dolomite reaching 250 feet in thickness. On the hilltops left by erosion Maquekota (Hudson River) shales are seen. The Galena has shaly streaks, which have largely furnished the residual clay of the cavities. There are also cherty layers and sandy spots. Under the Galena lies the Trenton, from 40 to 100 feet thick, and made up of an upper blue portion, which is a pure carbonate of lime, and a lower buff portion that is magnesian. The upper portion of the blue has a band of shale locally called the "Upper Pipe Clay," and the pure, cryptocrystalline limestone under this is called "Glass Rock." The blue contains much bituminous matter. The buff is locally called "Quarry Rock," and is prolific in fossils. Under the Trenton lies the St. Peter's sandstone, 150 feet below which is the Lower Magnesian (Oneota), 100 to 250 feet, and still lower the Potsdam, averaging 700 to 800 feet. The Potsdam rests on the quartzites and schists of the Archean. The ore bodies especially favor the shallow, syn-

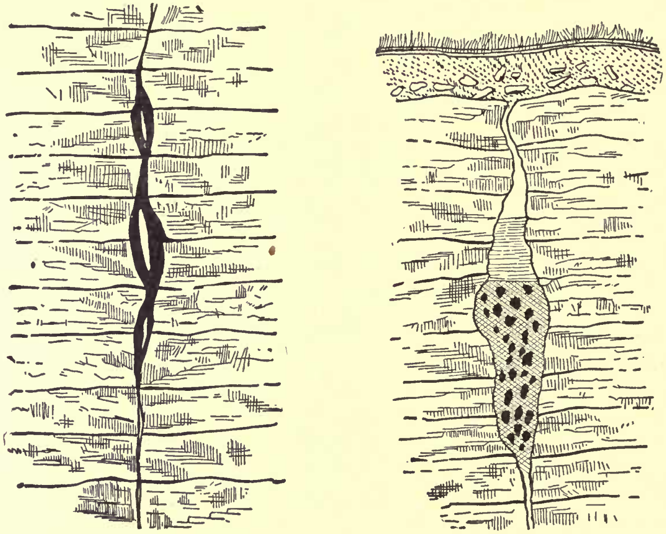

FIG. 76.—*Gash veins, fresh and disintegrated. The heavy black shading indicates galena. After T. C. Chamberlin, Geol. Wis., Vol. IV.*, 454.

clinal depressions of the east and west folds. They occur in crevices, the great majority of which run east and west. The productive ground comes in spots, which are separated by stretches of barren ground. The lead ores are chiefly produced by the crevices in the Upper Galena. In the Lower Galena the zinc ores become relatively more abundant, and they are also in the Trenton. The ores do not extend in any appreciable amounts either above or below these horizons. The upper deposits favor the vertical gash vein form; the lower tend rather to horizontal openings, called flats, which at the ends dip down (pitches) and often connect with a second sheet (flat) lying lower. There are several minor varieties of those two main types of cavity, which mainly depend for their differences on the grade of decomposition, which the walls have undergone, and whether there was an original opening, or only a brecciated and crushed strip. Chamberlin cites twelve varieties in all, some of which are based on rather fine distinctions. A. G. Leonard has described a sheet of galena, at the Lansing mine, in Iowa, that was three to four inches thick, 25 to 35 feet high, and over 1,000 feet long. Some of the Iowa crevices have proved remarkably persistent on the strike. H. F. Bain has called the writer's attention to the Lansing mine in Allamakee, Iowa, which has yielded lead ore without any zinc whatever,

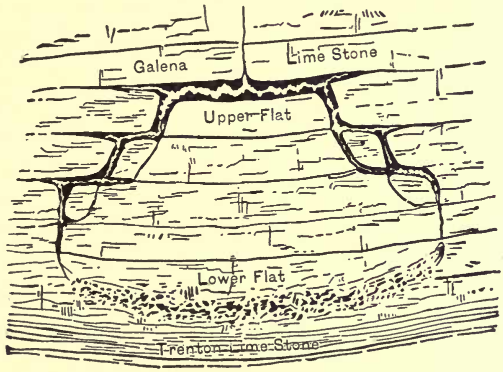

FIG. 77.—*Idealized section of "flats and pitches," forms of ore bodies in Wisconsin. After T. C. Chamberlin, Geol. Wis., Vol. IV.*, 458.

and which is peculiar in that it occurs in the Oneota or Lower Magnesian limestone, and is therefore below the main productive horizon of the gash veins. The crevice also trends north and south as against the usual east and west strike of the gash veins.

2.06.03. The cavities were referred by J. D. Whitney to joints, formed either by the drying and consolidating of the rock, or by gentle oscillations of the inclosing beds. The later work has largely corroborated this, and they are generally thought to be chiefly caused by the cracks and partings formed by the gentle synclinal foldings. Such cavities have usually been enlarged by subsequent alteration of the walls. Whitney also essentially outlined the explanation of origin, which has been more fully elaborated by Chamberlin. Both these writers have urged that the ores could not have come from below, for the lower rocks are substantially barren of them. The conclusion therefore follows that they were deposited in the limestones at the time of their formation. The source of the ores is placed in the early Silurian sea, from which it is thought they were precipitated by sulphuretted hydrogen, exhaled by decaying seaweeds, or similar dead organisms on the bottom. In carrying the idea further, Chamberlin has endeavored to reproduce the topography of the region in the Lower Silurian times and to indicate the probable oceanic currents. These are conceived to have made an eddy in the lead district, and to have collected there masses of seaweed, etc., resembling the Sargasso Sea. While interesting, this must be considered very hypothetical. When the sulphides became precipitated they were doubtless finely disseminated in the rock, and were gradually segregated in the crevices. The sulphurous exhalations from the bituminous limestones may have aided in their second precipitation. W. P. Jenney in 1893 referred the east and west fissures, mentioned above as crevices, to faults, which are as a rule not far from the vertical, but may dip 35° to 40°. The smaller north and south series are considered to be likewise due to faulting, but to be earlier, as they are thrown by the east and west set. The displacement from the latter is horizontal rather than vertical. The intersections of the two sets are said to be especially favorable to ore bodies. The name "run" is applied to the ore body, it having been adopted from southwest Missouri. The ore is thought to have been deposited along the fault fissures by uprising solutions, which have spread laterally into those beds, that, from their chemical composition (being dolomitic) or their open structure, were favorable to them.

In the same year (1893), W. P. Blake discussed these ore bodies, paying a tribute to Percival's early views on faulting as a cause of the veins, and describing its obscurity and the difficulty of demonstrating its presence. Blake, however, cited the Helena mine near Shullsburg as an instance in which the mineralization did occur near a pair of faults. Blake also lays stress upon the presence of thin seams of rich bituminous shale, in layers usually about as thick as cardboard, which occur in a richly fossiliferous limestone at the top of the Trenton, just beneath the ore-bearing "Galena" dolomite, and which are regarded as very probable factors in the precipitation of the ore.

The mining region, it should be emphasized, lies within the peculiar, unglaciated area, which is one of the notable geological features of this portion of the country. It has, therefore, long been exposed to the atmospheric agents, and has not been denuded of the residual products of decay as have the glaciated districts.

The papers of Jenney and Blake led to a notable discussion of these ore bodies, and to wide divergence of views regarding them. Arthur Winslow, in connection with his more extended treatment of those in Missouri, has urged that the sulphides have been supplied from the overlying strata, during the extensive, subaerial decay to which these have been subjected. Passing into solution they are thought to have percolated into the crevices and to have been precipitated. A. G. Leonard, in his study of the Iowa veins, reaches a similar conclusion, but on account of the impermeability of the Maquekota shales, restricts the source of the ore to the Galena dolomite. The frequent occurrence of the ores in stalactites projecting downward from the roof of a chamber gives support to these views. Leonard favors Chamberlin's view of the precipitation from a supposed Sargasso Sea of the Ordovican times.

The paragenesis of the minerals shows the following succession: (1) Pyrite, (2) Galena, (3) Pyrite; or (1) Pyrite, (2) Blende, (3) Galena, (4) Pyrite; or (4) Calcite. The ores, especially of zinc, are often oxidized, and afford considerable calamine and smithsonite. Some oxidized copper ores are produced at Mineral Point, formed by the alteration of chalcopyrite. In the early mines lead alone was sought, but of late years the zinc has been produced in greater quantities, and is more valuable than the lead.[1] Smithsonite is found in commercial quantities as well as blende.

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[1] WISCONSIN.—J. A. Allen, "Description of Fossil Bones of Wolf and Deer from Lead Veins.", *Amer. Jour. Sci.*, iii., II., 47. W. P. Blake, "The Mineral Deposits of Southwest Wisconsin," *Trans. Amer. Inst. Min. Eng.*, XXII., 558. 1893. Rec. *Amer. Geol.*, XII., 237, 1893. "The Ex-

2.06.04. Example 24*a*. Washington County, Missouri. Gash veins in the Potosi cherty limestone of eastern Missouri in the same region as the disseminated ores of Example 23, and containing galena, barite (locally called "tiff"), calcite, and residual clay. The cavities are described by Whitney as resembling in all respects the gash veins further north, which, however, lie in rocks higher in the geological series. These mines were the earliest worked, but have been given up since the

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istence of Faults and Dislocations in the Lead and Zinc Regions of the Mississippi Valley, with Observations upon the Genesis of the Ores," *Idem*, 621. Rec. This last paper was written in discussion of one by W. P. Jenney, cited below. "Wisconsin Lead and Zinc Deposits," *Bull. Geol. Soc. Amer.*, V., 25, 1893. "Progress of Geological Surveys in the State of Wisconsin—a Review and a Bibliography," *Trans. Wis. Acad. Sci.*, IX., 225. T. C. Chamberlin, *Wis. Geol. Survey*, IV., 1882, p. 367. Rec. E. Daniels, "Geology of the Lead Mines of Wisconsin," *Amer. Asso. Adv. Sci.*, VII., 290; *Wis. Geol. Survey*, 1854; *Eng. and Min. Jour.*, July 6, 13, 20, 27, August 3, 10, 24, October 5, 1878, December 14, 1889, 522. James Hall, "Notes on the Geology of the Western States," *Amer. Jour. Sci.*, i., XLII., 51. W. H. Hobbs, "A Contribution to the Mineralogy of Wisconsin," *Bull. Univ. of Wis.*, Science Series I., 114; see also *Zeitsch. für Kryst.*, XXV., 257, 1895. J. T. Hodge, "On the Wisconsin and Missouri Lead Region," *Amer. Jour. Sci.*, i., XLIII., 35. R. D. Irving, "Mineral Resources of Wisconsin," *Trans. Amer. Inst. Min. Eng.*, VIII., 478. E. James, "Remarks on the Limestones of the Mississippi Valley Lead Mines," *Phila. Acad. Sci.*, V., Part I., p. 51. W. P. Jenney, "The Lead and Zinc Deposits of the Mississippi Valley," *Trans. Amer. Inst. Min. Eng.*, XXII., 171, 621, 1893. Rec. J. Murrish, Report on the Lead Regions, 1871, as commissioner for their survey. D. D. Owen, "Report on the Lead Region," *U. S. Senate Documents*, 1844. J. G Percival, *Wis. Geol. Survey*, 1856. Squier and Davis, "Historical Account," *Smithsonian Contributions*, Vol. I., p. 208. M. Strong, *Wis. Geol. Survey*, 1877, I., 637; II., 645, 689. J. D. Whitney, *Wis. Geol. Survey*, 1861–62, I., 221. Rec. *Metallic Wealth*, p. 403, 1856. "On the Occurrence of Bones and Teeth in the Lead-bearing Crevices," *Amer. Assoc. Adv. Sci.*, 1859. Arthur Winslow, "Lead and Zinc Deposits of Missouri," *Trans. Amer. Inst. Min. Eng.*, XXIV., especially 677–690, 1894. See also Vol. VI. of *Geol. Survey of Mo.*, 135–150, 1894.

ILLINOIS.—J. Shaw, *Geol. Survey of Illinois*, 1873, II., 340. J. D. Whitney, *Idem*, 1866, I., 153.

IOWA.—A. G. Leonard, "Lead and Zinc Deposits of Iowa," *Iowa Geol. Survey*, VI., 1896. Rec. "Origin of the Iowa Lead and Zinc Deposits," *Amer. Geol.*, XVI., 288, 1895; *Eng. and Min. Jour.*, June 27, 1896, 614; *Colliery Engineer*, XVII., 121, 1896. C. A. White, *Iowa Geol. Survey*, 1870, II., p 339. J. D. Whitney, *Idem*, 1858, I., p. 422.

price of lead has been at present figures (1875 and subsequently). The ore was obtained from pockets, caves, irregular cavities, and from the overlying residual clays. This whole region has been exposed and above water since the close of Carboniferous times, and has suffered enormous surface decay (see R. Pumpelly, *Tenth Census*, Vol. XV., p. 12, and *Geol. Soc. Amer.*, Vol. II., p. 20), which has left a mantle of residual clay spread widely over its extent. In this, more or less float mineral occurred. The mines were located in Washington, Franklin, Jefferson and St. Francois counties.[1] Very similar deposits in rocks of about the same geological horizon also occur in the central part of the State, in the counties near the Osage River. The district has been called the Central by Winslow.

2.06.05. Example 24*b*. Livingston County, Kentucky. Veins in limestone of the St. Louis stage of the Lower Carboniferous, containing galena in a gangue of fluorite, calcite and clay. The ore bodies have never been well described, and no very accurate account can be given. They are found in Livingston, Crittenden, and Caldwell counties, Kentucky, in that portion of the State lying south of the Ohio River and east of the Cumberland. While limestone always forms one wall, a sandstone of geological relations not well determined forms the other. The veins run from two to seven feet wide and in instances are richer in their upper portions than in the lower. As yet they are of greater scientific than practical importance. Some galena occurs also in irregular cracks in the limestone. As a possible indication of a stimulating cause for the formation of the veins, the interesting dike of mica-peridotite may be cited, which has been described by J. S. Diller.[2] The dike occurs in the same fissure with a vein of fluorspar.[3]

[1] Compare the older references under Example 23, and the following: A. Litton, *Second Ann. Rep. Missouri Geol. Survey*, 1854. J. D. Whitney, *Metallic Wealth*, p. 419. Arthur Winslow, "Lead and Zinc Deposits of Missouri," Vols. VI. and VII. of *Mo. Geol. Survey; Trans. Amer. Inst. Min. Eng.*, XXIV., 634.

[2] "Mica-Peridotite from Kentucky," *Amer. Jour. Sci.*, October, 1892.

[3] S. F. Emmons, "Fluorspar Deposits of Southern Illinois," *Trans. Amer. Inst. Min. Eng.*, February, 1892. C. J. Norwood, "Report on the Lead Region of Livingston, Crittenden and Caldwell Counties," *Kentucky Geol. Survey*, 1875, New Series, Vol. I., p. 449.

2.06.06. Example 25. Southwest Missouri. Zincblende and very subordinate galena with their oxidized products, associated with chert, residual clay, calcite, a little pyrite and bitumen, in cavities of irregular shape and in shattered portions of Subcarboniferous limestone. Across Missouri, from a point south of St. Louis, and including the country as far to the northwest as Sedalia and Glasgow, a broad belt, called the Ozark uplift, extends southwesterly into Arkansas. It has formed a great plateau in central and southern Missouri, and consists largely of Silurian rocks. These have a fringe of Devonian on the edges and dip under the Lower Carboniferous. The plateau reaches 1,500 feet above the sea in Wright County, but on the limit is succeeded by lower country. To the southwest it drops somewhat, with Lower Carboniferous strata outcropping, which in Kansas are overlain by the coal measures. The surface then rises again in the prairies. At the edge of the plateau is a trough, in whose bottom the Lower Carboniferous strata are cut by the Spring River, which flows southwesterly from Missouri across the western State line into Kansas, and has a general direction parallel to the western limits of the uplift. It receives tributary streams on each bank, which cut the strata in strongly marked valleys, and afford good exposures. Those on the east bank, from south to north, are Shoal Creek, Short Creek, Turkey Creek and Center Creek, while from the west come the Brush, Shawnee, and Cow creeks, all in Kansas. Along the first mentioned creeks the principal mining towns are situated, but others are found on the minor streams. They extend through an area fifteen miles broad from east to west, and twenty-five miles from north to south. Newton and Jasper are the most productive counties in Missouri, while Cherokee County, in Kansas, also contains notable mines. Undeveloped districts are recorded in Arkansas, but apparently at a lower geological horizon. The ore occurs in the Keokuk or Archimedes limestone of the Lower Carboniferous. A generalized section of the rocks, according to F. L. Clerc, is as follows: On the higher prairie, some 15 feet of clay or gravel; 10 feet of flint or chert beds; 40 feet of limestone with thin beds of chert; 60 feet of alternating layers of limestone and chert; 100 feet and more of chert, sometimes chalky with occasional beds of limestone; 225 feet in total. In basins and extensive pockets in these rocks, deposits of slates with small coal seams are found, of undetermined geological relations. The large bed of limestone of the section affords a datum of reference in relation to which the ores may be de-

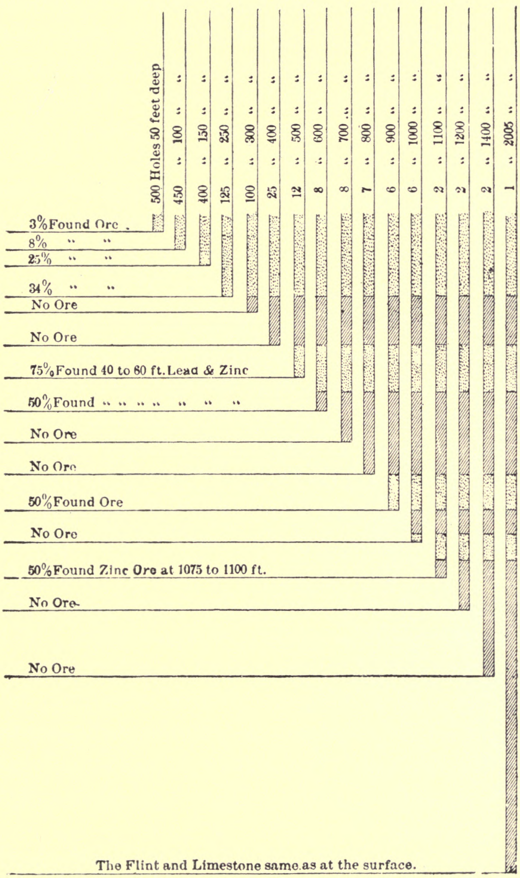

FIG. 78.—*Chart showing the results of deep borings in the Joplin district, Mo From the Engineering and Mining Journal, March* 18, 1899, *p.* 321.

scribed. A few minor, shallow deposits occur in the flints over it. In the limestone the ores are associated with a gangue of dolomitic clay and residual flint. They occupy irregular cavities or openings, locally known as circles, spar openings, and runs. (Clerc.) Below the limestone the ore is found in "sheets, bands, seams, and pockets," and filling in the interstices of a breccia of chert, which has been formed by the breaking down of the chert layers on the solutions and removal of the interbedded limestones. There are districts where the overlying bed of limestone has also disappeared, and they then lack it for a capping. The deposits extend to considerable depths below the position of the limestone. The present mines have not demonstrated as yet their limit of depth. At times the ore is associated with a later-formed quartz rock that has coated and filled the cavities of the breccia.

Although the mining is, as yet, comparatively shallow, the results of a large number of deep bore-holes are now available, and are shown in the accompanying Fig. 78. From the chart it is evident that there are four ore-bearing horizons distributed down to a depth of about 1,100 feet. Below this, and down to 2,005 feet, no ore was met. The holes were all drilled in Jasper County, and near Joplin and Webb City.

2.06.07. The removal of the interbedded layers of limestone and the caving in of the associated cherts have been the principal causes of the formation of cavities. Adolph Schmidt referred the shrinkage to the dolomitization of pure lime carbonate, an idea that has had extended adoption. Dolomitization has also an important part in causing the general porosity. Schmidt traced five periods in the geological history of the ore bodies: 1. Period of deposition of the rocks. 2. Period of dolomitization of certain strata and of principal ore deposition. 3. Period of dissolution of part of the limestone, of breaking down of chert, and of continued but diminishing ore deposition. 4. Period of regeneration, secondary deposition of carbonate of lime and quartz, and continued ore deposition. 5. Period of oxidation.

Schmidt's work was done in 1871-72. Since then the increased development of the mines has afforded greater opportunities for observation. Haworth, in 1884, referred, with much reason, the shattering of the chert in certain areas to oscillations of the strata, and Clerc, in 1887, emphasized particularly the dissolving action of water. It is a hard problem to discover the original source of the metals. The earlier writers said nothing of this subject, or else, as in Haworth's paper, discussed a possible precipitation from the ocean, or, as in Clerc's, referred them to the pockets of slate and coal. In 1893, at the Chicago meeting of the American Institute of Mining Engineers, W. P. Jenney presented an abstract of the results of his work while detailed by the U. S. Geological Survey to study these ore deposits. As will appear in the abstract of the paper given below, the ores are supposed to have come up through fissures of displacement, and hence from below. These con-

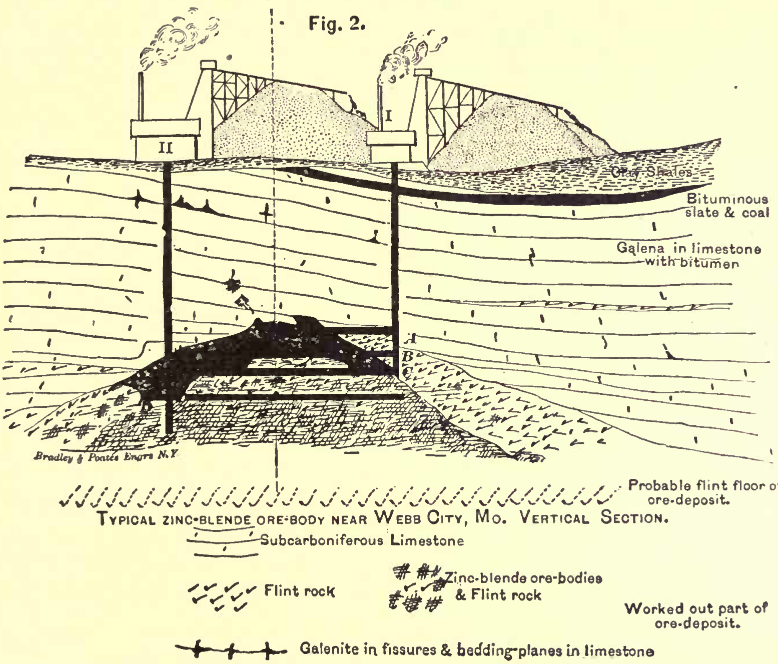

FIG. 79.—*Vertical section of a typical zincblende ore body, near Webb City, Mo. After C. Henrich, Trans. Amer. Inst. Min. Eng., XX., p.* 14.

clusions have been controverted by others, on account of the difficulty in proving the existence of faults when evidence of displacement is so obscure. In Jenney's paper all the lead or lead and zinc regions of the Mississippi Valley are considered together. They are described as occurring along three lines of upheaval. The region of Wisconsin and Iowa is on the flanks of the Archean "Wisconsin Island" of Chamberlin, referred to above under 2.06.01. The southeast and southwest

Missouri regions are on the Ozark uplift, while a minor argentiferous galena district is on the line of the Ouachita uplift of Arkansas and Indian Territory. The formation of the ore bodies in the first three of these is regarded as having been in general the same. They are thought to have originated from uprising solutions, which came through certain principal fissures, and spread laterally into strata favorable to precipitation. In southwest Missouri this was the Cherokee limestone of the Lower Carboniferous. In its unaltered state it is an extremely pure carbonate of lime. It has a maximum thickness, where not eroded, of 165 to 200 feet, and contains many interbedded layers of chert. Much organic matter, and more or less bitumen, are also at times present. The limestone seems to have been raised above the ocean level at the close of the Lower Carboniferous, and to have remained for a long period exposed to the atmospheric agents. Much caving in of unsupported layers of chert and much attendant brecciation resulted. The general stratum became quite open and cellular in certain portions. At a later period, supposed from several indications to be at the close of the Cretaceous, dynamic disturbance occurred, which along certain lines produced fissures, sometimes parallel, sometimes intersecting. Solutions arose through these which dolomitized much of the remaining limestone and caused additional porosity. Zinc and lead ores were afforded, and where the conditions were favorable they spread laterally from the fissures and deposited the sulphides in the cellular rock or replaced the limestone itself. The intersection of crossing fissures is a frequent point of deposition, and at times parallel master fissures have given a wide area of impregnation. This form of ore deposit is called a run. The runs are from 5 to 50 feet in height, 100 to 300 feet long, and 10 to 50 feet across. At Webb City they are even larger. As a general thing the ore is in the interstices of the brecciated chert, but it is also in limestone and dolomite, and associated with a silicified form of the insoluble residue left by the solution of the limestone, which Jenney calls "cherokite." All the ores require concentration. Galena usually occurs near the surface, while blende is more abundant in depth. Cadmium is at times present in the blende in notable amount.

In 1894, the very thorough report of Arthur Winslow on lead and zinc in Missouri, and incidentally elsewhere in the world, appeared, and likewise a briefer account before the American Institute of Mining Engineers. Winslow gives in the large volumes the most detailed work of reference yet issued, and reaches a quite different view regarding the derivation and formation of the ores. He emphasizes the fact that the region has long been a land area, in fact, ever since the close of the Lower Carboniferous times. The subaerial decay has therefore been excessive and a considerable thickness of overlying rock has gone. This has favored the formation of caves, sinks and underground waterways, which have often collapsed. Extremely careful analyses of fresh and large samples of the various limestones associated with or overlying the lead and zinc deposits of the State were made, as well as of a series of the Archean rocks, from which, in the course of long erosion, the others are supposed to have been derived. The Archean rocks yielded 0.00197 to 0.0068 per cent. lead (.04 to .136 pounds per ton), and 0.00139 to 0.0176 per cent. zinc (.028 to .352 pounds per ton); the Silurian Magnesian limestones, a trace to 0.00156 per cent. lead (up to .03 pounds per ton); and a trace to 0.01538 per cent. zinc (up to .307 pounds per ton); the Lower Carboniferous limestones, a trace to 0.00346 per cent. lead (up to .07 pounds per ton), and a trace to 0.00256 per cent. zinc (up to .05 pounds per ton). Winslow concludes from the above data and observations and from the difficulty, if not impossibility, of discovering actual evidence of fault fissures, that the ores have become concentrated in the shattered rock by the downward percolations of lead and zinc-bearing solutions, which have derived the metals from the overlying and largely decomposed strata.

2.06.08. Some interesting alterations of the minerals have occurred, which have changed the blende to smithsonite and calamine. In one case a secondary precipitation of zinc sulphide has yielded a white, amorphous powder, which is of very recent date. With the original precipitation of the blende, the asphaltic material may have had something to do. In the matter of production, W. P. Jenney fixes the ratios of the blende, galena, and pyrite at about 1,000 : 80 : 0.5.[1]

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[1] MISSOURI.—G. C. Broadhead, "Geological History of the Ozark Uplift," *Amer. Geol.*, III., 6. H. M. Chance, "The Rush Creek (Arkansas)

2.06.09. Other zinc and lead deposits are known in central Missouri generally resembling the above quite strongly, but of less economic importance. Some, however, are described by Schmidt as conical stockworks. They sometimes are found in Lower Silurian strata.

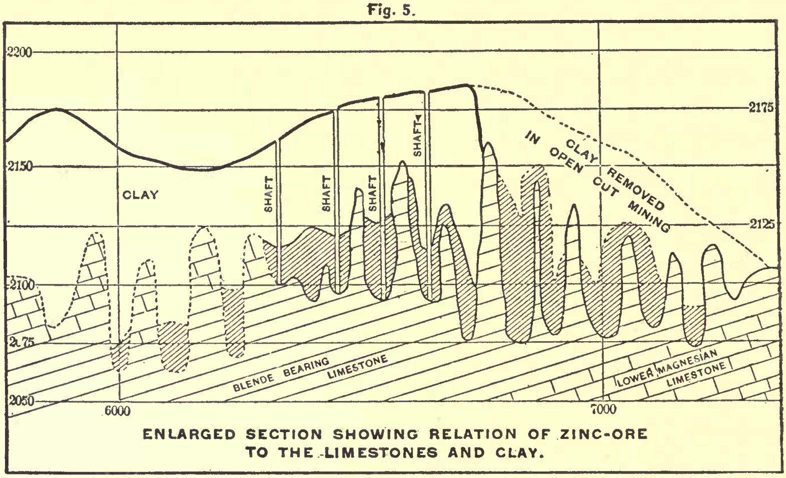

FIG. 80.—*Geological section of the Bertha zinc mines, Wythe County, Va. After W. H. Case, Trans. Amer. Inst. Min. Eng., XXII., p.* 520.

2.06.10. Both the mines of Example 25 and those of Example 24 were originally worked for lead, and the zinc minerals

Zinc District," *Trans. Amer. Inst. Min. Eng.*, Vol. XVIII., p. 505, 1890. F. L. Clerc, Geological description of the mines in a statistical pamphlet on the *Lead and Zinc Ores of Southwest Missouri Mines*, p. 4, published by J. M. Wilson, Carthage, Mo., 1887. Rec. See also *Eng. and Min. Jour.*, June 4, 1887, p. 397; "Zinc in the United States," *Mineral Resources*, 1882, p. 368. G. T. Cooley, "Dressing Lead and Zinc Ores in Kansas," *Eng. and Min. Jour.*, July 7, 1895, p. 9. *Eng. and Min. Jour.*, November 3, 1888, p. 389; March 8, 1890, p. 286. "Distribution of Lead and Zinc near Joplin, Mo.," *Idem*, March 18, 1891, 321. Rec. E. Haworth, "A Contribution to the Geology of the Lead and Zinc Mining District of Cherokee County, Kansas, Oskaloosa, Iowa," 1884. C. Henrich, "Zincblende Mines and Mining near Webb City, Mo.," *Trans. Amer. Inst. Min. Eng.*, XXI., p. 3, 1892; *Eng. and Min. Jour.*, June 4, 1892. J. R. Holibaugh, "The Lead and Zinc Mining Industry of Southwest Missouri and Southeast Kansas," *Eng. and Min. Jour.*, LVIII., 1894, 199, 394, 413, 437, 460, 485, 508 and 535. Also issued as a separate book by the Scientific Publishing Co., 50 cents. W. P. Jenney, "Lead and Zinc Deposits of the Mississippi Valley," *Trans. Amer. Inst. Min. Eng.*, XXII., 171, 1893. Rec. C. Luedeking and were regarded as a nuisance; of late years the zinc has been much more of an object than the lead. The deposits in southwest Virginia (Example 26) also produce lead, but are best known for zinc.

2.06.11. Example 26. Wythe County, Va. Residual deposits or crusts of calamine and smithsonite, resting upon Lower Silurian (Ordovician) limestone or dolomite, and probably derived from disseminated blende, during the weathering of the country rock. Deposits of blende are also known in the limestone. The ore-bearing terrane is exposed over a considerable extent of country, running from near Roanoke, one hundred miles westward. The largest mines are in Wythe County, and of these the Bertha is best known. The Bertha ores are cala-

H. A. Wheeler, "Notes on Missouri Barite," *Amer. Jour. Sci.*, December, 1891, p. 495. R. W. Raymond, "Note on the Zinc Deposits of Southern Missouri," *Trans Amer. Inst. Min. Eng.*, VIII., 165; *Eng. and Min. Jour.*, October 4, 1879. J. D. Robertson, "A New Variety of Zinc Sulphide from Cherokee County, Kansas," *Amer. Jour. Sci.*, iii., XL., p. 160. "Missouri Lead and Zinc Deposits," *Amer. Geol.*, April, 1895, 235. A. Schmidt and A. Leonhard, *Missouri Geol. Survey*, 1874. A. Schmidt, "Forms and Origin of the Lead and Zinc Deposits of Southwest Missouri," *Trans. St. Louis Acad. Sci.*, III., 246; *Amer. Jour. Sci.*, iii., X., p. 300. *Die Blei und Zink Erzlagerstätten von Südwest Missouri*, Heidelberg, Germany, 1876. E. J. Schmitz, "Notes of a Reconnaissance from Springfield, Mo., into Arkansas," *Trans. Amer. Inst. Min. Eng.*, February, 1898. W. H. Seamon, "Zinciferous Clays of Southwest Missouri," *Amer. Jour. Sci.*, iii., XXXIX., p. 38. H. S. Wicks, "The Joplin District," *Engineering Magazine*, February, 1894. Arthur Winslow, "Notes on the Lead and Zinc Deposits of the Mississippi Valley and the Origin of the Ores," *Jour. of Geol.*, I., 612, 1893. Rec. "Lead and Zinc Deposits of Missouri," *Trans. Amer. Inst. Min. Eng.*, XXIV., 634 and 931. Rec. "Report on Lead and Zinc," *Missouri Geol. Survey*, VI. and VII., 1894. Rec. See also pamphlet on "Missouri at the World's Fair," 1893. "Historical Sketch of Lead and Zinc," *Eng. and Min. Jour.*, November 17, 24, 1894; January 19, 1895.

KANSAS.—G. P. Grimsley, "Kansas Mineral Products," *Eleventh Biennial Report Kansas Board of Agriculture*, 1897–98, 502. E. Haworth, "A Contribution to the Geology of the Lead and Zinc Mining District of Cherokee County, Kan., Oskaloosa, Ia.," 1894, privately printed. R. Hay, "Geological and Mineral Resources of Kansas," *Eighth Biennial Report State Board of Agriculture*, 1891–92, 25. B. F. Mudge, *Idem*, 1878. O. St. John, *Idem*, 1881–82. See also J. D. Robertson, cited under Missouri.

ARKANSAS.—E. J. Schmitz, "Notes of a Reconnaissance from Springfield, Mo., into Arkansas," *Trans. Amer. Inst. Min. Eng.*, February, 1898. A Report on Lead and Zinc in Arkansas is now in press with the *State Geol. Survey* (1899).

mine and smithsonite, both crystallized and earthy or ochreous. They lie upon a limestone which is of very irregular surface, being so deeply pitted by superficial decay that it projects in knobs and pillars, and sinks in intervening depressions. These are shown very graphically in Figs. 82 and 83, where they are left in relief by the stripping. They are mantled and rounded off by the overlying residual clay, which may be 50 to 75 feet deep. The ore lies in crusts and chunks or as a powdery mass upon or near the limestone in the clay, and is won either by stripping this, or by shafts and drifts. (See Fig. 80.) According to Boyd, in one section there are 486 feet of strata impregnated with zinc and lead sulphides, with some pyrite. At the Wythe Company's mines both the oxidized ores and the unchanged sulphides of zinc and lead in the underlying limestone are exploited, but at the Bertha mines there is practically no lead, the product being a very pure spelter. More or less limonite is

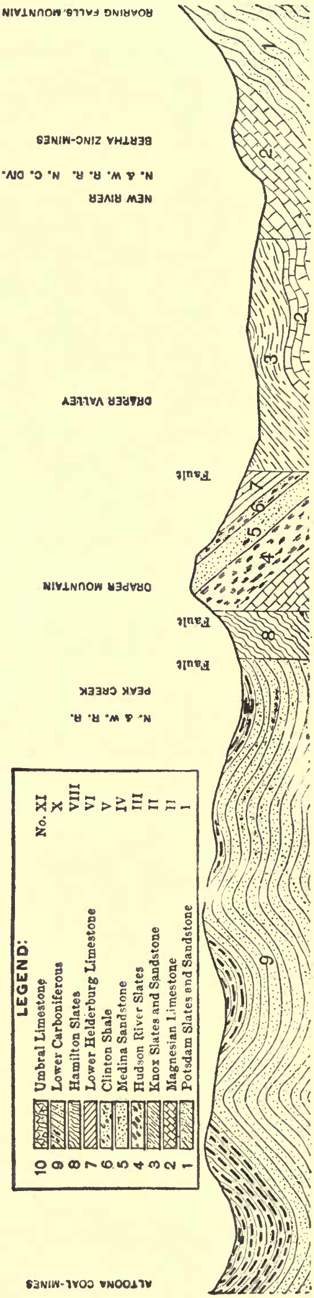

FIG. 81.—*Geological section, Altoona coal mines to Bertha zinc mines. After W. H. Case, Trans. Amer. Inst. Min. Eng., XXII., p. 514.*

FIG. 82.—*View of open cut in the Bertha Zinc Mines, Va. From a photograph by J. F. Kemp, 1895.*

FIG. 83.—*View of open cut in the Wythe Zinc Mines, Va. From a photograph by J. F. Kemp, 1895.*

obtained from all these surface workings, and is sent to neighboring blast furnaces.

Near Bonsacks the gossan of the ore was exposed, but not recognized for a long time, in a cut of the Norfolk and Western R. R. The mine yielded rich earthy oxidized ores, which, however, passed in depth into a very intimate and rebellious mixture of zinc-blende and pyrite. These deposits extend over a wide stretch of country, running from near Roanoke, one hundred miles westward.[1]

Related deposits occur in eastern Tennessee, and have furnished more or less ore, chiefly calamine. They are not large as a rule.[2] They occur in the Knox dolomite, at the base of the Lower Silurian, and favor its contact with the underlying Cambrian Conasauga shale[3] in the area of the Cleveland folio cited below.

2.06.12. Blende is a frequent associate of galena in the Rocky Mountains, but it has been only recently worked for any zinc product, and then largely as a by-product in extracting silver. (See 2.07.10.)

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[1] C. R. Boyd, "Resources of Southwest Virginia," p. 71. "Mineral Wealth of Southwest Virginia," *Trans. Amer. Inst. Min. Eng.*, V., 81; *Ibid.*, VIII., 340. "The Wythe Lead and Zinc Mines, Va.," *Eng. and Min. Jour.*, June 17 and 24, 1893. W. H. Case, "The Bertha Zinc Mines at Bertha, Va.," *Trans. Amer. Inst. Min. Eng.*, Vol. XXII., p. 511, August, 1893. H. Credner, *Zeitsch. fur die gesammten Naturwissenschaften*, 1870, XXXIV., p. 24. F. P. Dewey, "Note on the Falling Cliff Zinc Mine (Bertha Company)," *Trans. Amer. Inst. Min. Eng.*, X., 111. A. v. Groddeck, *Typus Austin. Lehre von den Lagerstätten der Erze*, p. 103.

[2] J. M. Safford, *Geology of Tennessee*, p. 482. W. H. Gildersleeve, "Zinc Ores in Tennessee," *University Scientific Magazine*, August, 1896. Quoted by the *Eng. and Min. Jour.*, September 18, 1897, 336.

[3] Cleveland Folio, by C. W. Hayes. *U. S. Geol. Survey*, Morristown Folio. Arthur Keith, *Idem.*

CHAPTER VII.

ZINC ALONE, OR WITH METALS OTHER THAN LEAD.

2.07.01. Zinc commonly occurs in association with lead, but there are one or two exceptional deposits in this country which are without lead, and which have no parallel in other parts of the world. The minerals containing zinc at Franklin Furnace and Ogdensburg, N. J., are known elsewhere only as rarities, although they are found in vast amounts in New Jersey.[1]

ZINC SERIES.

	Zn.	*S.*	*Fe.*	*SiO_2.*	*Mn.*
Sphalerite (commonly call blende) ZnS	67	33	....	....	...
Zincite, ZnO	80.3	..	....	....	...
Franklinite, $(Fe.Zn.Mn)O(Fe.Mn)_2O_3$ (variable)	5.54	..	51.8	....	7.5
Willemite, $2ZnO.SiO_2$	58.5	..	....	27.0	...
Calamine, $2ZnO.SiO_2$, H_2O	54.2	..	....	25.0	...
Smithsonite, $ZnO.CO_2$	52.0	..	....	....	...

2.07.02. Example 27. Saucon Valley, Pennsylvania. Zinc-blende and its oxidation products, calamine and smithsonite, filling innumerable cracks and fissures in a disturbed, magnesian limestone, thought to belong to the Chazy stage. The ore bodies occur in the Saucon Valley near the town of Friedensville, about four miles south of Bethlehem. The limestone is inclosed between two northerly spurs of the South Mountain, and has apparently been tilted and shattered by the upheaval of the latter. The shattering and disturbances decrease as the South Mountain is left and the dip decreases. There are three principal mines, the Ueberroth, the Hartman, and the Saucon, the first named being in the portion which is

[1] F. L. Clerc, "Zinc in the United States," *Mineral Resources*, 1882, p. 358. W. R. Ingalls, "The Nomenclature of Zinc Ores," *Trans. Amer. Inst. Min. Eng.*, XXV., 17 and 955, 1895.

tilted nearly to a vertical dip, and is much disturbed, while the next is where the dip has gradually decreased to 35°. The mines are on a belt some three-quarters of a mile long. At the Ueberroth an enormous quantity of calamine was found on the surface, but it passed in depth into blende and was clearly an oxidation product. In the others the blende came nearer the surface. The ore follows the bedding planes, and the joints normal to these throughout a zone varying from 10 to 40 feet across, and fills the cracks. At their intersection the largest masses are found. Six larger parallel fissures were especially marked at the Ueberroth. This mine proved in development to be very wet, and a famous pumping engine, the largest of its day, was built to keep it dry. The Hartman and Saucon are less wet. A little pyrite occurs with the blende, and thin, powdery coatings of greenockite sometimes appear on its surface, but it is entirely free from lead and a very high grade of spelter is made from it. The mines were strong producers from 1853 to 1876, but little has been done since, although it has been reported that the great pumping engine might again start, and the mines may once more furnish considerable quantities of ore.

2.07.03. The veins were evidently filled by circulations from below that brought the zinc ore to its present resting place in the shattered and broken belt. Drinker considers it to have been derived from a disseminated condition in the limestone.[1]

2.07.04. Example 28. Franklin Furnace and Sterling, N. J. Bed veins consisting of franklinite, willemite, zincite, etc., in crystalline limestone, in many respects analogous to the magnetite of Example 13. The franklinite and zincite bedded deposits are in a belt of white, crystalline limestone which runs southwesterly from Orange County, New York, across northwestern New Jersey. It was considered metamorphosed Lower Silurian by H. D. Rogers, but its association with Archean gneiss is so intimate and involved that others have regarded it as likewise Archean. Blue Siluro-Cambrian limestone and

[1] F. L. Clerc, *Mineral Resources*, 1882, 361. Rec. H. S. Drinker, "On the Mines and Works of the Lehigh Zinc Company," *Trans. Amer. Inst. Min. Eng.*, I., 67. C. E. Hall, in Rep. D3, *Second Geol Survey, Penn.*, p. 239. *Die Gruben und Werke der Lehigh Zink Gesellschaft in Pennsylvanien, B. und H. Zeit.*, 1872, p. 51.

quartzite are also near. F. L. Nason has recently supported the Cambro-Silurian age of the white limestone, on the ground that the white and the blue varieties are inextricably involved, and that many intrusions of granite are present, which would account for the metamorphism of the latter. In one of the smaller areas of blue that was in the midst of the white, some fossils of the Olenellus fauna were discovered. J. E. Wolff and others in association with him have referred the white limestone to the Archean rocks, and have agreed that the blue was either mixed with it because of faults or because the quartzite had filled cavities in the former during the advance of the Cambrian sediments across the Archean rocks. Of the presence, however, of granites and other intrusions in the white limestone there is no doubt, but they are thought by Wolff to be pre Cambrian, and probably to be later than the ore. In limestones and ore at once so mashed and so old the relations

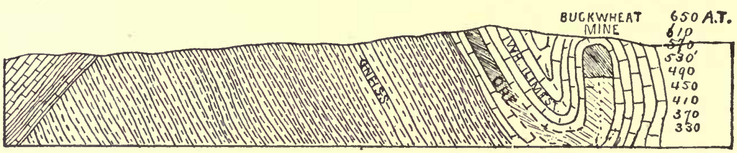


FIG. 84.—*Cross section at Franklin Furnace, N. J., corresponding to* AA. *of map* (FIG. 88), *and four times the scale of map. At the left is blue limestone and quartzite. After J. F. Kemp, Trans. N. Y. Acad. of Sciences, XIII.*, 86, 1893.

are obscure. At Franklin Furnace the crystalline limestone forms a low hill (Mine Hill) east of the upper waters of the Wallkill, and again at Ogdensburg, two miles south, another (Sterling Hill), on the west bank. There is a valley and unexposed strip between, so that the unbroken continuity without a possible intervening fault cannot be established. The bed at Franklin outcrops on the west side of the hill. It begins on the north just across the Hamburg road, and runs south 30° west as a continuous bed for about 2,500 feet. This portion is called the Front vein. It contains on the north the old Hamburg mine, then the Trotter mine, and in the southern portion belongs to the New Jersey Zinc and Iron Company. It runs from 8 to 30 feet broad at the outcrop, but swells below. It dips southeast 40 to 60° into the hill, and is interbedded in the limestone. In the Trotter mine a wedge or horse of hornblende,

FIG. 85.—*View of the west vein at Franklin Furnace looking south. The two shafts are at the Trotter Mine. Photographed by J. F. Kemp,* 1893.

FIG. 86.—*View of open-cut at south end of Mine Hill, Franklin Furnace, N. J., exposing the syncline of ore. From a photograph by J. F. Kemp, February 24, 1899.*

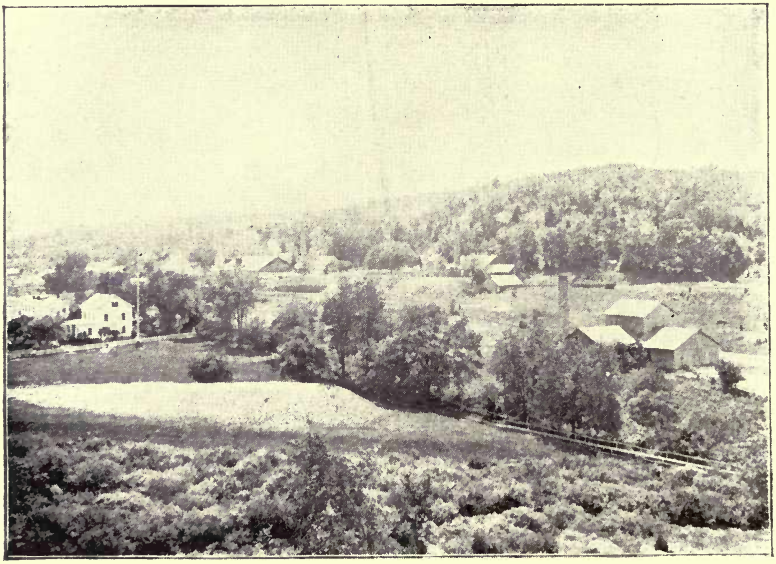


FIG. 87.—*View of Stirling Hill, Ogdensburgh, N. J., looking southwest from the N. Y., S. and W. R. R. embankment. The mines are at the foot of the hill. From a photograph by J. F. Kemp, 1892.*

augite, plagioclase, and various other silicates enters the bed a short distance. In this horse some of the most interesting minerals have been found, such as fluorite, rhodonite, blende (var. cleiophane), smaltite (var. cholanthite), axinite, etc. At the end of the Front vein—or, more properly, bed—a branch or bend strikes off at an angle of 30 to 40° to the east. This more easterly branch, which is called the Buckwheat mine, outcrops on the surface some 500 feet, and then, after being cut by a trap dike 22 feet wide, pitches down at an angle of 27° and passes under the limestone. The portion of the mine northeast of the dike furnishes the most and best ore. The surface outcrop of the Buckwheat was 25 to 30 feet across, but it swelled below to 52 feet, and in the second level, about 200 feet from the surface, it was penetrated by a cross-cut 125 feet without finding the wall. The character of the ore varies; for, while it is excellent at the point of the cross-cut, at 125 feet nearer the intersection with the front bed it becomes lean, while preserving its width lower. Beyond the dike the bed is likewise broad, and is mined out for 40 to 50 feet across. The workings are now some distance down on the pitch. The impression made by the arch of the roof and by the curving beds is that this is the crest of an anticline whose axis pitches north 27°, and whose central portion is formed by the franklinite bed being doubled up together on itself before the two parts diverge in depth. Its western portion probably is continuous in a synclinal trough with the front bed, and its eastern portion dips east at some unknown angle. It may, however, be merely a bulging termination of the bed and the results of deeper mining will be awaited with interest.

About 1890 deep drilling was instituted along the strike of the Buckwheat ore, and about one-third of a mile distant from it. The holes caught the ore at approximately 1,000 feet down, and a large shaft was at once installed which has since proved extremely productive. The workings have shown that the prolongation of the Buckwheat ore body flattens notably at this portion, and rounds out along the strike in a sort of spoon-bowl termination. To express the exact shape in this portion the stereogram Fig. 90 should be somewhat modified, still it illustrates the general shape fairly well. Apparently the ore is cut off by a fault to the northeast, but the relations are not yet fully demonstrated. The whole southern portion of the ore body, as far as the trap dike, is now being stripped of limestone preparatory to open-cut mining, and the geological relations are beautifully displayed.

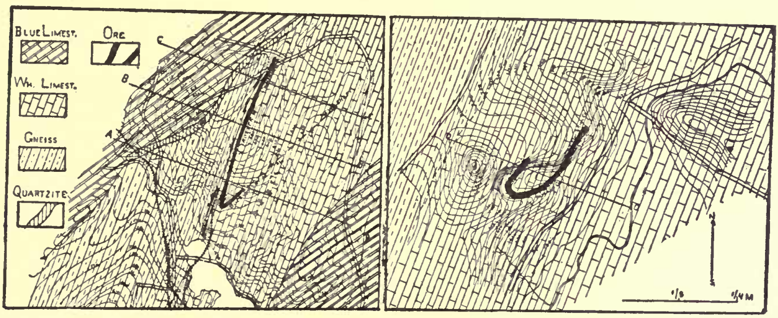
2.07.05. The ore consists of franklinite in black crystals, usually rounded and irregular, but at times affording a quite perfect octahedron combined with the rhombic dodecahedron and set in a matrix of zincite, willemite and calcite. The richest ore lacks the calcite and consists of the other three in varying proportions. The best ore is in largest amount in the Buckwheat mine, beyond the trap dike which cuts it. The limestone containing the ore has a notable percentage of manganese replacing the calcium, and where it is exposed to the atmosphere it weathers a characteristic brown. An analysis of a sample occurring with the ore at Sterling Hill afforded F. C. Van Dyck:

$CaCO_3$	80.23
$MnCO_3$	16.57
Fe_2O_3	0.50
SiO_2	0.20
H_2O	1.00
	100.50

The percentage of manganese is very high for a limestone.

2.07.06. The Sterling Hill outcrop is less extensive. It begins on the north with the New Jersey Zinc and Iron Company's property, and runs south 30° west for 1,100 feet. It then branches or bends around to the west and runs north 60° west for 30 feet, bending again to north 30° east, and pitches beneath the surface. Thus the general relations between the front and back beds are somewhat the same as at Mine Hill, and the dip and pitch are similar. The principal workings are on the Front vein, where there are two veins (beds), according to the older descriptions, one rich in franklinite and the other in zincite. It is doubtful if there really are two distinct beds, but probably one portion is richer in zincite than the other. The part mined is from two to ten feet. The foot-wall is corrugated and causes many pinches and swells, whose troughs pitch north. The limestone between the front and back outcrop is charged with franklinite and various silicates (jeffersonite, augite, garnets, etc.), and has been mined out in large open cuts now abandoned. A deposit of calamine was found in the interval about 1876, and has furnished many fine museum specimens.

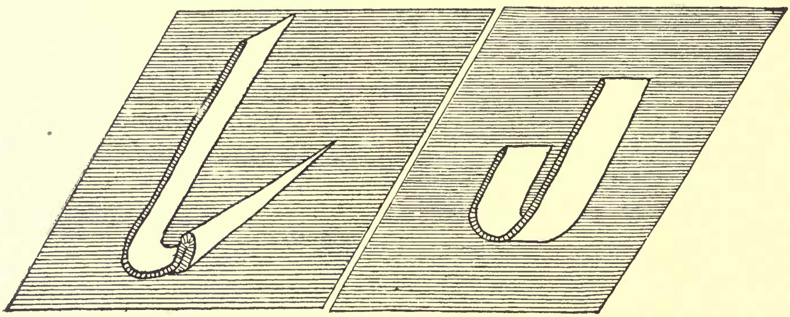
2.07.07. It is not clear that the Sterling Hill and Mine Hill deposits were once continuous. The bed at Mine Hill runs in the front portion close to the contact of the white limestone and the gneiss. The Sterling Hill bed is much farther away from the gneiss, and this would indicate that it is at a higher horizon. The evidence, too, of a pitching syncline is strong, but a pitching S-fold is not as clear. A faulting of the Archean rocks in an east and west line across their strike; and a subsequent tilting so as to give them a northerly pitch, is a very



FIGURES 88 and 89.—*Geological maps of Mine Hill and Sterling Hill, showing the relations of the ore-bodies. After J. F. Kemp, Trans. N. Y. Acad. of Sciences, XIII., pp* 81 *and* 85, 1893.

widespread phenomenon in the Highlands, and lends weight in this instance to the idea that a fault intervenes between the two hills.

2.07.08. The origin of these beds is very obscure. They are so unique in their mineralogical composition that very little direct aid is furnished by deposits elsewhere. At Mine Hill, below the franklinite bed a bed of magnetite was early discovered, and was mined for iron. It has since been met in the drill cores from the deep shaft of the northeast, and is therefore remarkably persistent beneath the zinc ore. There are many points of analogy between the franklinite beds and extended magnetite deposits. They are both minerals of the spinel group, and the spinels are a common result of metamorphic action. The presence of zincite and willemite complicates matters, however, and while an original ferruginous deposit might be conceived with a large percentage of manganese, such abundance of zinc is beyond previous experience. It is, however, suggestive that no inconsiderable amount of zinc is found in the Low Moor (Va.) limonites, as shown by the flue dust (see E. C. Means, "The Dust of the Furnaces at Low Moor, Va.," Buffalo meeting, *Amer. Inst. Min. Eng.*, XVII., p. 179), and this in the course of a protracted blast may amount to many tons, but it does not approach the Franklin Furnace ores. None the less, in the absence of a better explanation, the franklinite bed may be thought of as perhaps an original man-



FIGURES 90 and 91.—*Stereograms of the ore bodies at Mine Hill and Sterling Hill. After J. F. Kemp. Trans. N. Y. Assoc. of Sciences, XIII., pp.* 83 *and* 89, 1893.

ganese, zinc, iron deposit in limestone, much as many Siluro-Cambrian limonite beds are seen to-day, and that in the general metamorphism of the region it became changed to its present condition. Minerals of the spinel group occur all through this limestone belt, and in Orange County, New York, to the north, there is an old and prolific source of them.

2.07.09. As has been earlier stated, granite intrusions are common in the white limestones adjacent to or near the ore, and unless these are proved to be of later age than the ore, they may have been an important factor in the ore formation. It is very reasonable that the igneous intrusion should start ore-bearing currents along a certain stratum in the limestone, which would replace it with ore. Subsequent folding and metamorphism must then have changed these ores, whatever they were, to the present unusual minerals.

This view of the method of origin has been advocated by J. F. Kemp in the paper cited below, and more careful search, as well as the sinking of the new shaft on the strike of the back vein at Mine Hill, have served to bring to light more intrusions of granite than were previously known. Chondrodite, fluorite and other contact minerals occur near them. Nason has also shown by an interesting series of analyses that the limestone next the granites tends to be pure $CaCO_3$, shading gradually at a distance to dolomitic varieties. Victor Monheim, in discussing the vein of willemite worked in the forties at Stolberg, near Aachen, has urged that at temperatures sufficiently high the anhydrous silicate of zinc may separate directly from the solutions, while at lower temperatures the hydrous salt results. His experiments and conclusions give support to the view that the igneous, plutonic intrusions have played an important rôle in the ore deposition. (See V. Monheim, *Verh. d. Naturhist Ver. der preus. Rheinlande u. Westphalen*, V., 162, 1848; VI., 1, 1849.) Were this true we would not be compelled to assume an original bed of blende from which these oxidized compounds have been derived. It is a general experience, however, that hydrated oxidized ores of zinc have passed in depth into blende, and this fact, in connection with the almost entire absence of blende in these mines, adds to their puzzling character. Were they, however, at one time a thoroughly oxidized gossan containing the three metals specially prominent, the intrusions of granite are probably responsible for the change to their present combinations.[1]

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[1] F. Alger, "On the Zinc Mines of Franklin, Sussex Co., N. J.," *Amer. Jour. Sci.*, i., XLVIII., 252, 1845. Rec. J. Beco, De l'Etat actual. des Industries du Zinc, etc., aux Etats Unis d'Amerique, *Revue Universelle des Mines*, 1877, II., 129. W. P. Blake, in paper on "Zinc Ore Deposits of Southwestern New Mexico," *Trans. Amer. Inst. Min. Eng.*, XXIV., 187, 1894, gives notes on the "New Jersey Ore Bodies." N. L. Britton, *Ann. Rep. of the State Geologist, N. J.*, 1886, p. 89. An excellent cross-section of Mine Hill is given. G. H. Cook, "On the Probable Age of the White Limestone at the Sussex and Franklin Zinc Mines," *Amer. Jour. Sci.*, ii., XXXII., 208. *Geol. of New Jersey*, 669, 1868, with map. Rec. H. Credner, "On the Franklinite Beds," *Berg-u. Hütt. Zeitung*, 1866, 29; 1871, 369. Rec. E. F. Durre, 'Metallurgische Notizen aus New Jersey und

2.07.10. Blende is known in numerous places in the Rocky Mountains, and is often argentiferous. When mixed with lead silver ores it has generally proved a drawback, and has raised the smelting charges. Recently works have been erected at Cañon City, Col., for the treatment of such ores, and very considerable quantities of blende are there turned into zinc-white. While the local demand for this pigment is not so heavy in the West as in the East, any process which frees the

dem Lehigh Thal," *Zeitsch. des Vereins deutscher Ingenieure*, 1894, p. 184. B. K. Emerson, "On the Dykes of Micaceous Diabase, Penetrating the Bed of Zinc Ore at Franklin Furnace, Sussex Co , N. J.," *Amer. Jour. Sci.*, May, 1882, 376. Aug. F. Foerste, "New Fossil Localities in the Early Paleozoics of Pennsylvania, New Jersey and Vermont," etc., *Amer. Jour. Sci.*, iii., XLVI., 345. Discusses the local stratigraphy with a map. P. Groth, "Die Zinkerzlagerstätten von New Jersey," *Zeitschrift fur Praktische Geologie*, May, 1894, p. 230. W. H. Keating and L. Vanuxem, "Geology and Mineralogy of Franklin in Sussex County, N. J.," *Jour. Phila. Acad. Nat. Sci.*, II., 277, 1822. Rec. J. F. Kemp, "The Ore Deposits at Franklin Furnace and Ogdensburgh, N. J.," *Trans. N. Y. Acad. Sci.*, XIII., 76–98, 1893; gives a full bibliography and annotated list of minerals. Rec. F. L. Nason, *Ann. Rep. State Geol., N. J.*, 1890, p. 25; *Amer. Geol.*, VII., 241; VIII., 166; XII., 154. *Amer. Jour. Sci.*, iii., XXXIX., 407, 1890. "The Franklinite Deposits of Mine Hill, Sussex County, N. J.," *Trans. Amer. Inst. Min. Eng.*, February, 1894; *Eng. and Min. Jour.*, May 3, 1894, p. 197. Rec. "Chemical Composition of Some of the White Limestone in Sussex Co., N. J.," *Amer. Geol.*, March, 1894, p. 154. T. Nuttall, "Geological and Mineralogical Remarks on the Minerals of Paterson and on the Valley of Sparta," *N. Y. Med. and Phys. Jour.*, April, May and June, 1822. *Amer. Jour. Sci.*, i., V., 239, 1822. Jos. C. Platt, Jr., "The Franklinite and Zinc Litigation Concerning the Deposits of Mine Hill at Franklin Furnace, Sussex Co., N. J.," *Trans. Amer. Inst. Min. Eng.*, V., 580, 1876–77. H. D. Rogers, "Geology of New Jersey, 1849, pp. 63–71, with a list of Minerals by Dr. S. Fowler." Rec. G. C. Stone, "Analyses of Franklinite and Some Associated Minerals (two analyses of Zincite, four of Franklinite, five of Willemite, one of Tephroite)," *School of Mines Quarterly*, VIII., 148, 1887. G. Troost, "Observations on the Zinc Ores of Franklin and Sterling, Sussex Co., N. J.," *Jour. Phil. Acad. Nat. Sci.*, IV., 220, 1824. J. P. Wetherell, "The Mine Hill Ore Deposits in New Jersey and the Wetherell Concentrating Plant," *Eng. and Min. Jour.*, July 17, 1897. J. D. Whitney, "Metallic Wealth of the United States," p. 348, 1854. J. E. Wolff and A. H. Brooks, "The Age of the Franklin White Limestone of Sussex Co., N. J.," XVIII., *Ann. Rep. Dir. U. S. Geol. Survey*, Part II., pp. 425–457, 1899. J. E. Wolff, "Occurrence of Native Copper at Franklin Furnace, N. J.," *Proc. Amer. Acad. Arts and Sci.*, XXXIII., 429, 1898. "Hardystonite, a new Calcium-zinc Silicate from Franklin Furnace, N. J.," *Proc. Amer. Acad. Arts and Sci.* XXXIV., 479.

lead-silver or copper-silver ores of the objectionable zinc will operate favorably on many mines now handicapped. This has already proved to be the case with the refractory sulphides met in depth at Leadville.

Deposits of oxidized ores in southwestern New Mexico, near the town of Hanover, have recently been mined to a notable extent. The smithsonite and calamine as well as the blende, which is met in the same vicinity, are unmixed with galena, but the blende often contains intermingled pyrites. The ores occupy irregular caverns and seams in Paleozoic or Archean limestone, in close geological association with intrusive granite, contact zones and iron ores. A lenticular shape is often notable in the masses of blende. As remarked by Blake, the deposits show some interesting points of resemblance to those of New Jersey. The richest carbonates and calamine have been shipped to the East, but with the unavoidably high freights only the purest and best surface ores are available. (W. P. Blake, "Zinc-ore Deposits of Southwestern New Mexico," *Trans. Amer. Inst. Min. Eng.*, XXIV., 187.) Large deposits of hematite and magnetite have been worked to some extent in the same region, as a flux for lead-silver smelters, but their remoteness militates against their use as an iron ore.

2.07.11. A large amount of zinc ore is turned directly into zinc white and employed as a pigment. For this reason the statistics of the metal do not indicate all the ore mined. The accompanying figures are short tons. For detailed statistics see the annual volumes on "Mineral Industry" of the *Engineering and Mining Journal*, 1894, and the *Annual Reports of the U. S. Geological Survey.*

	1882.	1890.	1897.
Illinois and Indiana	18,201	26,243	38,680
Kansas	7,366	15,199	33,895
Missouri	2,500	13,127	18,412
Eastern and Southern States	5,698	9,114	9,900
	33,765	63,683	100,387

The amounts for 1882 and 1890 are from the *Mineral Resources of the United States*, 1889-90. p. 89, those for 1897 are from the *Mineral Industry*, VI., 661. The statistics give the metallurgical output for the several States, not the mining. Indiana has no zinc mines.

CHAPTER VIII.

LEAD AND SILVER.

2.08.01. There are two general methods of extracting silver from its ores, the one indirectly, by smelting with and for lead; the other by amalgamation, chlorination, or some such process. Hence under silver there are two classes of mines—lead-silver and high-grade silver ores. Both have almost always varying amounts of gold. The lead-silver mines furnish also, as noted above, by far the greater portion of the lead produced in the United States. Ores adapted to lead-silver metallurgical treatment form, in general, the oxidized alteration products of the upper parts (above permanent water level) of deposits of galena and pyrites. They may be well-marked fissure veins, chimneys, chambers, or contact deposits. Ores which of themselves are adapted to other processes are often worked in with the lead ores, and unchanged sulphides are artificially oxidized by roasting preparatory to smelting. The localities are taken up geographically from east to west.

2.08.02. LEAD-SILVER DEPOSITS IN THE ROCKY MOUNTAIN REGION AND THE BLACK HILLS.—The mines are described in order from south to north, beginning with New Mexico.

NEW MEXICO.

2.08.03. Example 29. The Kelley Lode. Oxidized lead ores, with some blende, calamine, etc., forming a contact deposit between slates and porphyry. The ore body is in the Magdalena Mountains, thirty miles west of Socorro, and has supplied the Billings smelter at that point. Numerous other ore bodies along the contact between sedimentary and eruptive rocks occur in the same region.

2.08.04. Lake Valley. Farther south in Doña Aña County the mines of Lake Valley are and have been worked upon deposits very closely analogous to those of Leadville, which furnish the principal type. They contain less lead, hardly enough, in fact, to be classed as lead-silver ores, according to the recent valuable paper of Ellis Clark, although earlier descriptions place greater emphasis on the presence of carbonates of this metal. According to Clark, the geological section involved includes quartzite and limestone, considered Silurian, 600 feet; Lower Carboniferous, black shale, 100 feet; green shale, 60 feet; nodular limestone, 48 feet; blue limestone, 24 feet; crinoidal limestone, 125 feet, and overlying limestone, 50 feet; about 1,000 feet in all. These are penetrated by four distinct eruptions of igneous rocks, hornblende-andesite, rhyolite, obsidian and porphyrite. The obsidian is comparatively

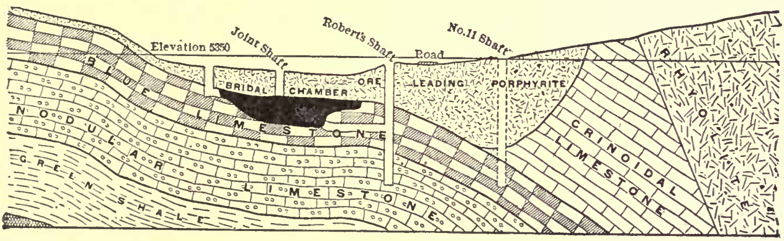

FIG. 92.—*Geological cross section at Lake Valley, New Mexico, to show the relations of the ore. The black mass is ore; the dark hachures in the lower left-hand corner are black shale. After Ellis Clark, Trans. Amer. Inst. Min. Eng., XXIV., p.* 155.

unimportant, and of the others the porphyrite is most intimately associated with the ore. The ore bodies are always connected with the blue limestone, and lie along the contact of this, either with the porphyrite or the overlying crinoidal limestone. They are in the nature of large chutes or elongated contact deposits, very similar, as the figure will indicate, to those at Leadville.

The ores are of several varieties but the general components, in addition to the silver, are silica, oxides of iron and manganese, limestone, some galena at times, and some zinc.

The varying percentages of the silica and bases afford basic, neutral and siliceous ores. In the bonanza called the Bridal Chamber, great masses of horn-silver were found. Many ores, and interesting metals, such as vanadinite, descloizite, etc., have made the district well known to collectors. Clark favors the view that the leaching of the porphyrite (which is argentiferous) during its exposure and erosion, by descending surface waters, has been the source of the ore. An earlier view attributed it to uprising currents.[1]

COLORADO.

2.08.05. Example 30. Leadville. Bodies of oxidized lead-silver ores, passing in depth into sulphides, deposited in much faulted Carboniferous limestone, in connection with dikes and sheets of porphyry. Leadville is situated in a valley which is formed by the head waters of the Arkansas River. The valley runs north and south, being confined below by the closing in of the hills at the town of Granite. It is about twenty miles long and sixteen broad, and even to superficial observation is seen to be the dried bottom of a former lake. The mountains on the east form the Mosquito range, a part of the great Park range, while those on the west are the Sawatch, and constitute the Continental Divide at this point. Leadville itself is on the easterly side, upon some foothills of the Mosquito range. The eastern slope of the Mosquito range rises quite gradually from the South Park to a general height of 13.000 feet. The range then forms a very abrupt crest, with steep slopes looking westward, which are due to a series of north and south faults whose easterly sides have been heaved upward as much as 7,500 feet. The faults pass into anticlines along their strike. The Mosquito range consists of crystalline Archean rocks, foliated granites, gneisses, and amphibolites, and of over 5,000 feet of Paleozoic sediments and igneous rocks. The former include Cambrian quartzite, 150 to 200 feet; Silurian white limestone, 160 feet, and quartzite, 40 feet; Carboniferous blue limestone, 200 feet (the chief ore-bearing stratum); Weber shales and sandstones, 2,000 feet; and Upper Carboniferous limestones, 1,000 to 1,500 feet. The igneous rocks are generally porphyries. The sedimentary rocks were laid down in Paleozoic time on the shores

[1] E. Clark, "The Silver Mines of Lake Valley, N. M.," *Trans. Amer. Inst. Min. Eng.*, XXIV., 138, 1894. *Rep. of Director of the Mint*, 1882, Lake Valley, p. 341; Kelley Lode, p. 376. B. Silliman, "Mineral Regions of New Mexico," *Trans. Amer. Inst. Min. Eng.*, X., 224.

of the Archean Sawatch Island, and were penetrated by the igneous rocks, probably at the close of the Cretaceous. They were all upheaved, folded, and faulted in the general elevation of the Rocky Mountains, about the beginning of the Tertiary period. The intrusion of the igneous rocks was the prime mover in starting ore deposition, and the solutions favored the under sides of the sheets, along their contacts with the blue Carboniferous limestone.

2.08.06. The early history of Leadville will be subsequently referred to in speaking of auriferous gravels. The lead-silver ores first became prominent in 1877, although discovered in 1874, and by 1880 the development was enormous. The region grew at once to be the largest single producer of these ores, and has remained such ever since. The mines are situated east of the city on the three low hills, Fryer, Carbonate and Iron, but recently a deep shaft in the city itself has found the extension of the ore chutes and opened up great future supplies. The ores have chiefly come in the past from the upper oxidized portions of the deposits. Of late years, however, the older and deeper workings have been showing the unchanged sulphurets. The ores are chiefly earthy carbonate of lead, with chloride of silver, in a clayey or siliceous mass of hydrated oxides of iron and manganese. In the Robert E. Lee mine silver chloride occurred without lead. Some zinc is also found, and a long list of rare minerals. Where the ore is in a hard, siliceous, limonite gangue it is called hard carbonate, but where it is sandy and incoherent it forms a soft carbonate, or sand carbonate. All the older mines produce small amounts of gold, but in some newer developments the gold is of more importance than the silver. A few ore bodies are found at other horizons than the Carboniferous. They also run in instances as much as 100 feet from the contact, and may likewise be found in the porphyry, doubtless replacing included limestone. They were all deposited as sulphides, and, according to Emmons, when the rocks were at least 10,000 feet below the surface.

In 1891 and 1892 great interest centered in the discovery and development of ore bodies, whose values in gold much exceeded those in silver, and which were situated further east from the city of Leadville than the older silver mines. The gold output has now proved very considerable, although lim-

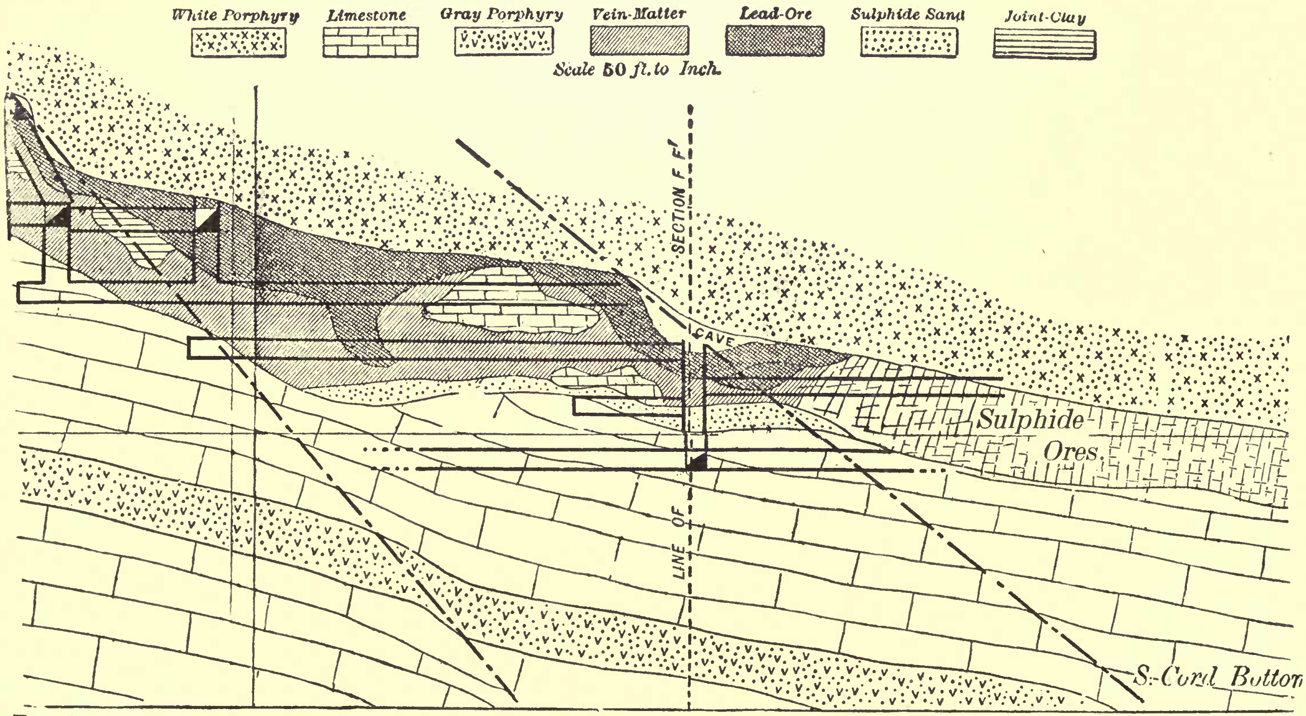

FIG. 93.—*Section of the White Cap chute, Leadville, showing the geological relations of the ore, and its passage into unchanged sulphides in depth. After A. A. Blow, Trans. Amer. Inst. Min. Eng., Vol. XVIII., Plate V.*

ited to but few mines. The geological associations are much the same as in the older workings, and indeed the gold ores occur on the extended lines of the older chutes, when projected to the eastward.

2.08.07. In the valuable monograph on the region, which is now a classic on the subject, and which is cited below, Emmons endeavors to prove the following points:

I. That the ores were deposited from aqueous solution.

II. That they were originally deposited mainly in the form of sulphides.

III. That the process of deposition involved a metasomatic interchange with the material of the rock in which they were deposited.

IV. That the mineral solutions or ore currents were concentrated along natural water channels, and followed, by preference, the bedding planes at a certain geological horizon, but that they also penetrated the adjoining rocks through cross joints and cleavage cracks.

These additional points are also advanced:

I. That the solutions came from above.

II. That they were derived mainly from the neighboring eruptive rocks.

2.08.08. The first four points are doubtless correct, and No. III. is an important application of the theory of replacement, frequently referred to in the introduction. The last two propositions merit less confidence. Seven additional years of mining have brought many new facts to light, and have led others (A. A. Blow in particular, whose valuable paper is cited below) to refer the ores to upward rising currents. Emmons foresaw this possibility and mentioned it on p. 584 of his monograph. The amount of the adjacent, igneous rocks is quite insufficient to afford the ore. In alteration the galena has passed through an intermediate stage of sulphate before changing to carbonate. These mines have been important not alone in their own metallic products, but in furnishing the smelters with oxidized lead ores, they have supplied a means of reduction for many other more refractory ones, which could be conveniently beneficiated through the medium of lead.[1] Much copper occurs with the sulphides now met in depth.

[1] F. M. Amelung, "The Geology of the Leadville Ore District," *Eng*

2.08.09. Example 30*a*. Ten Mile, Summit County. Bodies of argentiferous galena, pyrite, blende and their oxidized products replacing or impregnating beds of Upper Carboniferous limestone, or filling fissure veins. The geological section at Ten Mile resembles that of Leadville, which lies 15-20 miles south, but the productive strata are in the Upper Carboniferous or Maroon formation, instead of in the Lower Carboniferous or Leadville limestone. The Maroon formation is chiefly sandstones. It is estimated at 1,500 feet thick, and is separated from the Leadville blue limestone by 300 feet of Weber grits. It contains several thin beds of limestones in connection with which some of the ores are found. The ore bodies present at least two types. The first is illustrated by the Robinson mine, Fig. 94, in which the ore lies along two small faults and replaces the limestone between and on either side of them. In this as in the other mines the chief mineral in the unoxidized portion is pyrite, or marcasite or pyrrhotite. With one or the other of these are smaller amounts of galena and blende. The oxidized portions proved the richest, the others require concentration. The fissure vein type is illustrated by the Queen of the West mine, whose ores were found in several parallel fault

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and Min. Jour., April 16, 1880, p. 25. "On the Origin of the Ore," *Ibid.*, December 20, 1879. A. A. Blow, "The Geology and Ore Deposits of Iron Hill, Leadville, Colo.," *Trans. Amer. Inst. Min. Eng.*, XVIII., 145, 1889. Rec. *Ann. Rep. Colo. School of Mines*, 1887, p. 62. "The Leadville Gold Belt," *Eng. and Min. Jour.*, January 26, 1895. Rec. Maps. S. F. Emmons, "Geology and Mining Industry of Leadville," *Monograph 12, U. S. Geol. Survey.* Rec. *Second Ann. Rep. Director of U. S. Geol. Survey.* Rec. *Tenth Census*, Vol. XIII., p. 76. F. T. Freeland, "The Sulphide Deposits of South Iron Hill, Leadville," *Trans. Amer. Inst. Min. Eng.*, XIV., 181. C. Henrich, "The Character of the Leadville Ore Deposits," *Eng. and Min. Jour.*, December 27, 1879, p. 470. "Origin of the Leadville Deposits," *Eng. and Min. Jour.*, May 12, 1888, p. 43. "On the Evening Star Mine," *Ibid.*, May 7, 1881, p. 361. "Leadville Geology," *Ibid.*, June 3 and 10, 1882; "Historical," May 30, April 6, 13, 20, 27, 1878; also many other allusions, 1879–81. R. W. Raymond, "Report on the Little Pittsburg Mine," *Eng. and Min. Jour.*, June 28, 1879. L. D. Ricketts, "The Ores of Leadville," Princeton, 1883. C. M. Rolker, "Notes on Leadville Ore Deposits," *Trans. Amer. Inst. Min. Eng.*, XIV., 273, 949. F. L. Vinton, "Leadville and the Iron Mine," *Eng. and Min. Jour.*, February 15, 1879, p. 110; also June 28, p. 45. A series of short papers on "The Gold Belt" was published in 1894, by the Leadville Chamber of Commerce.

fissures, as shown in Fig. 95. The ores were rich in the oxidized zone, but grew lean in the sulphides. In the White Quail type the ores are somewhat less definitely circumscribed. They still form elongated replacements, but contain consider-

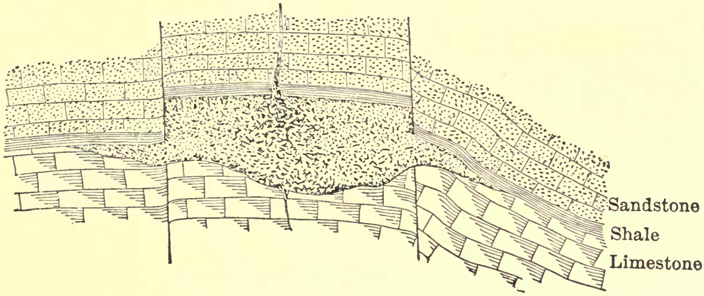

FIG. 94.—*Section through the No. 2 ore-chute of the Robinson mine, Ten-mile district, Colo. After S. F. Emmons, Ten-mile Special Folio, U. S. Geological Survey.*

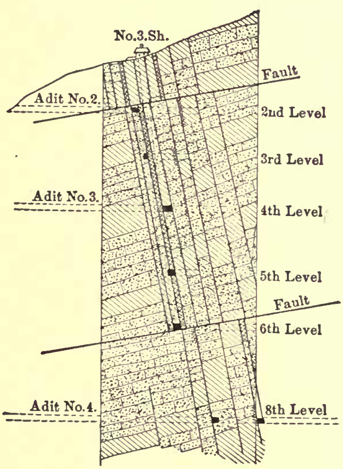

FIG. 95.—*Cross-section, Queen of the West mine, Ten-mile district, Colo. The rich ore appears in the darker vertical bands. After S. F. Emmons, Ten-mile Special Folio, U. S. Geological Survey.*

able quartz, calcite and barite. They shade out laterally into jasperoid quartz, which is succeeded by barren limestone. The amount of sulphides is enormous.[1]

[1] S. F. Emmons, *Tenth Census*, Vol. XIII., p. 73. Ten Mile Special Folio, 1899. Rec. The above description has been chiefly drawn from this folio.

2.08.10. Example 30*b*. Monarch district, Chaffee County. Oxidized lead-silver ores in limestone. The belt of limestones south from Leadville contains some notable ore bodies in Chaffee County. The Monarch district is the most important. It is situated at the head waters of a branch of the South Arkansas River. The ore lies in limestones whose age is not yet accurately determined. The Madonna mine is the best known and has shipped much ore to Pueblo.[1]

2.08.11. Example 30*c*. Eagle River, Eagle County. Galena and its alteration product, anglesite, in Carboniferous limestone, on the contact between it and quartzite or porphyry. The mines lie in the valley of Eagle River, on the western slope of the Continental Divide. The galena has changed to the sulphate, instead of carbonate, probably having been less completely oxidized than at Leadville, and marking the intermediate stage in the process. The wall rocks lie quite undisturbed, having a low dip of 15° north, and not being faulted. Lying lower than the lead-silver deposits, and in Cambrian quartzite, on the contact with an overlying sandstone, are found chutes carrying gold in talcose clay.[2]

2.08.12. Example 30*d*. Aspen, Pitkin County. Bodies of lead-silver ores, largely oxidized, occurring with much barite, chiefly at the intersections of a series of vertical cross-faults, with two bed faults in Carboniferous limestone and dolomite; but also in less important amounts, although in similar relations to faults, in strata both older and later. Aspen is on the western slope of the Continental Divide, in the valley of the Roaring Fork, just at the point, where it crosses the contact of crystalline Archean gneisses and Paleozoic sediments. The stream cuts them at right angles to the strike. Aspen Mountain lies on the south side, and Smuggler Mountain on the

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[1] S. F. Emmons, *Tenth Census*, Vol. XIII., p. 79. *Rep. Director of the Mint*, 1884, p. 181.

[2] S. F. Emmons, "Notes on some Colorado Ore Deposits," *Colo. Sci. Soc.*, Vol. II., Part II., p. 100. E. E. Olcott, "Battle Mountain Mining District, Eagle County, Colorado," *Eng. and Min. Jour.*, June 11, 1887, pp. 417, 436; *Ibid.*, May 21, 1892, p. 545. G. C. Tilden, "Mining Notes from Eagle County," *Ann. Rep. Colo. State School of Mines*, 1886, p. 29.

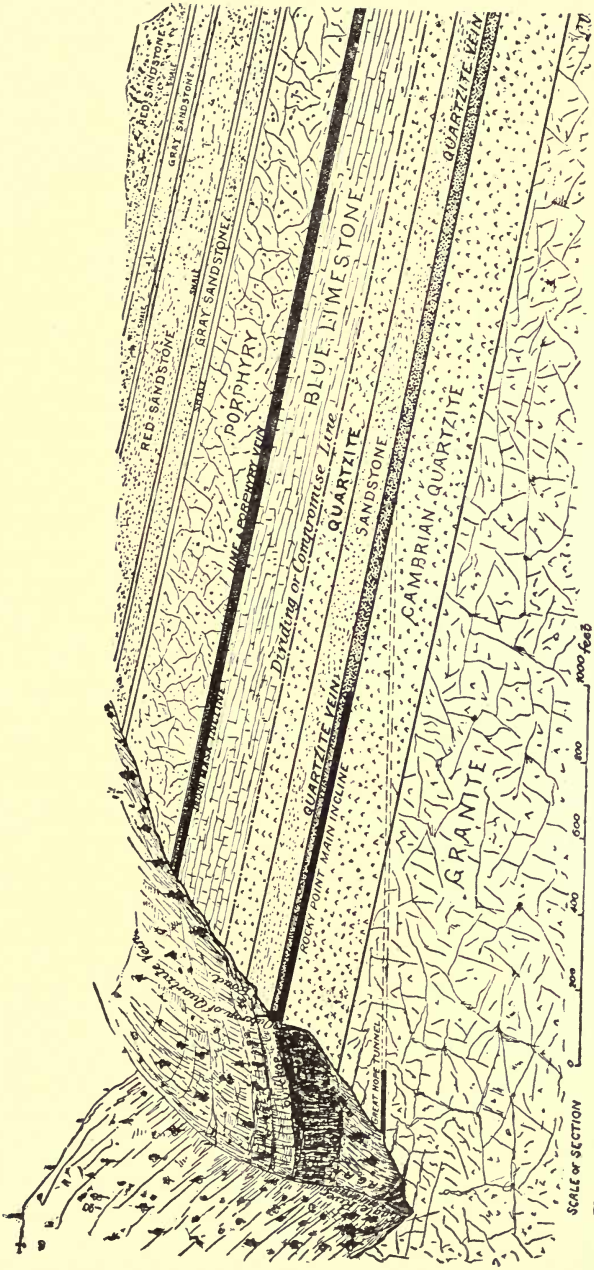

FIG. 96.—*Geological section at the Eagle River mines, Colo After E. E. Olcott, Engineering and Mining Journal. May 21, 1892, p. 544.*

north. The limestone belt continues north and south, and is prospected over a stretch of nearly forty miles.

2.08.13. The geological section at Aspen embraces the following strata, which have been carefully determined and measured by J. E. Spurr. Upon the Archean granite rests the Sawatch formation of the Cambrian, 200 to 400 feet thick. Beginning as a thin conglomerate, it passes into a quartzite and then into a sandy dolomite. The Yule formation of the Silurian is a dolomite, 250 to 400 feet in thickness. The Parting

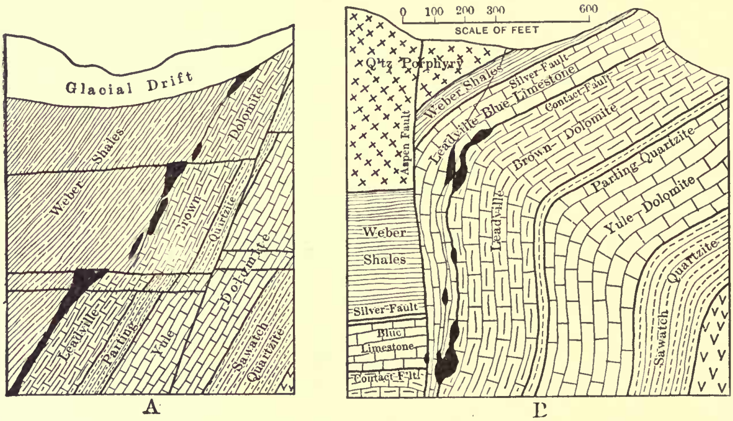

FIG. 97A.—*Cross section of the Della S. Mine, Smuggler Mountain, Aspen, Colo. After J. E. Spurr, Monograph XXXI. U. S. Geological Survey, Plate XLII.*, B. *Section through the Durant and Aspen Mines, by D. Rohlfing, Idem, Plate XL. The black is ore.*

Quartzite, Devonian, 60 feet thick, lies above. The Carboniferous has three members. The lowest is the Leadville limestone, of which 200 to 250 feet is a brown dolomite, and 100 to 150 feet a blue limestone, the two being separated by the "Contact" bed-fault. Above the Leadville limestone are the Weber shales and carbonaceous limestone, 1,000 feet or more; and the Maroon grits, 4,000 feet. The Mesozoic beds which rest on the last named are very thick, but have no important relation to the ore.

2.08.14. Aside from the Archean granite there are two eruptive rocks in the district. A diorite-porphyry forms a sheet at and below the Parting Quartzite, and thickest at the south, but thinning to the north. A quartz-porphyry, very like the "White Porphyry" at Leadville (compare Fig. 93), is 400 feet thick on Aspen Mountain, but it thins out both to the north and the south. It appears near the base of the Weber shales. The age of both the porphyries is probably late Cretaceous.

2.08.15. After the deposition of the Laramie beds, of the Cretaceous, a compressive force from the west developed an overturned anticline, which culminated in a great fault along Castle Creek, to the west of the mines. A syncline was produced on the east limb of the great anticline, and was later domed upward by an uplift, which gave the trough a marked pitch to the north. During the folding two faults were produced parallel with the bedding of the Leadville limestone. One runs along at the contact of the dolomite and the blue limestone (the "Contact" fault); the other follows the contact of the blue limestone and the Weber shales (the "Silver" fault). Many cross-faults were also formed at about this time, which intersected the bed-faults, but along which movement seems to be still in progress. At a certain stage ore-bearing solutions appear to have circulated along the bed-faults, and are thought by J. E. Spurr, to have been precipitated by other solutions in the cross-faults, so that the shattered rock at the intersections became replaced with ore.[1]

2.08.16. Example 30*e*. Rico, Dolores County. Contact deposits of lead-silver ores, in Carboniferous limestones, along

[1] D. W. Brunton, "Aspen Mountain: Its Ores and Mode of Occurrence," *Eng. and Min. Jour.*, July 14 and 21, 1888, pp. 22, 42. S. F. Emmons, "Preliminary Notes on Aspen," *Proc. Colo. Sci. Soc.*, Vol. II., Part III., p. 251. Rec. C. Henrich, "Notes on the Geology and on some of the Mines of Aspen Mountain," *Trans. Amer. Inst. Min. Eng.*, XVII., 156. A. Lakes, "Geology of the Aspen Mining Region," *Ann Rep. Colo. School of Mines,* 1886. W. E. Newberry, "Notes on the Geology of the Aspen Mining District," *Trans. Amer. Inst. Min. Eng.*, XVII., 273, 1889. Rec. L. D. Silver, "Geology of the Aspen (Colo.) Ore Deposits," *Eng. and Min. Jour.*, March 17 and 24, 1888. J. E. Spurr, "Geology of Aspen Mining District," *U. S. Geol. Survey,* Monograph XXXI., 1899. Rec.

intrusive porphyries. Considerable base bullion has been shipped. There are coals in the vicinity, but the operation of the smelter has been somewhat intermittent. The Newman Hill mines are mentioned under "Silver."[1]

NOTE.—Example 30*f* will be found after Example 31, which has been inserted for geographical reasons.

2.08.17. Example 31. Red Mountain, Ouray County. Oxidized lead-silver ores passing in depth into sulphides, in large and small cavities, in knobs of silicified andesite. The cavities have a close resemblance to caves, but differ from ordinary caves in not being in limestone. They permeate the mountain in an irregular way, and mark the courses of old hot spring conduits. The andesite is generally altered to a mass of quartz, but the process is thought by S. F. Emmons to have taken place at a considerable depth, and that the quartz is a residual deposit left by the removal of more soluble elements of the andesite. T. B. Comstock regards them as hot spring deposits.[2]

SOUTH DAKOTA.

2.08.18. Example 30*f*. Galena (town), in the Black Hills. Deposits of galena in part altered to carbonate, in Cambrian (Potsdam) sandstone, near intruded sheets of trachyte. The ore occurs in local enrichments distributed at irregular intervals through the sandstone. It is rarely found in the overlying limestones of the Carboniferous. The ore bodies are closely akin to the so-called "siliceous,"or "Potsdam" gold ores, later described. Galena and Carbonate are the best known localities.[3]

[1] M. C. Ihlseng, "Review of the Mining Regions of the San Juan," *Ann. Rep. Colo. School of Mines*," 1885, p. 43.

[2] T. B. Comstock, "Hot Spring Deposits in Red Mountain, Colorado," *Trans. Amer. Inst. Min. Eng.*, XVIII., 261. S. F. Emmons, "Notes on Some Colorado Ore Deposits," *Proc. Colo. Sci. Soc.*, Vol. II., Part II., p. 97. M. C. Ihlseng, "Review of the Mining Interests of the San Juan Region," *Ann. Rep. Colo. School of Mines*, 1885, p. 46. T. E. Schwartz, "The Ore Deposits of Red Mountain, Colorado," *Trans. Amer. Inst. Min. Eng.*, XVIII., 139, 1889; *Proc. Colo. Sci. Soc.*, Vol. III., Part I., p. 77.

[3] F. R. Carpenter, "Ore Deposits of the Black Hills of Dakota," *Trans. Amer. Inst. Min. Eng.*, 1889, Vol. XVII., p. 570. See also report by Dr. Carpenter on the geology, etc., of the Black Hills, to the trustees of the Dakota School of Mines, 1888, p. 124. S. F. Emmons, *Tenth Census*, Vol. XIII., p. 91.

MONTANA—IDAHO.

2.08.19. Example 32. Glendale, Beaver Head County. Ore bodies of argentiferous galena, zincblende, copper and iron pyrites, and their oxidation products, occurring parallel with the stratification planes of a blue-gray limestone, of age not yet determined. These deposits constitute the Hecla mines, and are in the southwestern part of the State. They offer some parallel features with those of southeastern Missouri. (Example 23.) They differ from Example 30 in not being associated, so far as known, with igneous rocks.[1]

2.08.20. Example 32*a*. Wood River, Idaho. Bodies of argentiferous galena and alteration products, irregularly distributed in limestone, of age as yet undetermined. Southwestern Idaho is largely formed of granite, southeastern is covered by the immense fissure outpourings of basalt along the Snake River. North of these, and on the flanks of the granite, are slates and limestones, especially on the Wood River. The latter contain the lead-silver ores. They are not in immediate association with igneous rocks, and from published descriptions appear to be somewhat irregularly distributed, although possibly connected with fissures. The stuctural relations with Example 23 may again be referred to. The neighboring slates and granite contain gold and silver veins, which are taken up later on. Several small smelters have been erected in the region, and have been intermittently operated. The country is really in the northern end of the Great Basin.[2]

2.08.21. Example 33. Wickes, Jefferson County, Mont. Fissure veins near the contact of granite and liparite, but cutting both rocks and carrying in a gangue of quartz the ores, galena, zincblende, copper and iron pyrites, and mispickel. The liparite is said by Lindgren to be Cretaceous or Tertiary Wickes is just south of Helena, and was one of the first places in the West to establish successful concentration. There are two companies, the Helena and the Gregory, both large producers.

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[1] S. F. Emmons, *Tenth Census*, Vol. XIII., p. 97.

[2] G. F. Becker, *Tenth Census*, Vol. XIII., p. 55. *Eng. and Min. Jour.*, July 2, 1887, p. 2. *Rep. Director of the Mint*, 1882, p. 198. G. H. Eldredge, XVI.; *Ann. Rep. Dir. U. S Geol. Survey*, II., 264. Rec. J. B. Hastings *Eng. and Min. Jour.*, March 25, 1895, 268.

2.08.22. Example 34. Cœur d'Alêne, Idaho. Galena and very subordinate alteration products, in a mineralized zone having a well-marked footwall and an impregnated, brecciated hanging of the same rock. The ore is in large chutes, which fill innumerable small fractures in the rock. The mines are in Wardner Canon, in the Bitter Root Mountains, northern Idaho. The rocks are quartzite, and thin beds of schists, much folded along east and west axes. In this way they became faulted and shattered, and in the principal mineral belt afforded an opportunity for the ore to deposit. The gangue is siderite. The mines are extremely productive and are the chief sources of ore supply for lead smelters in Montana and on the Pacific coast.[1] Detailed descriptions are much needed.

UTAH.

2.08.23. Example 35. Bingham and Big and Little Cottonwood Cañons, Utah. Bed veins, often of great size, containing oxidized lead-silver ores above and galena and pyrite below the water level, in Carboniferous limestones, or underlying quartzite, or on the contact between the two. The mines are situated in the Oquirrh and Wasatch Mountains, southwest and southeast of Salt Lake City, in cañons well up toward the summits. The region is much disturbed, and there are great faults and porphyry dikes and knobs of granite associated with the sedimentary rocks. The ores occur in belts, extending considerable distances, and these in places have the rich chutes or chimneys of oxidized products. In Bingham Cañon an immense bed of auriferous quartz is found, overlying the lead zone and next the hanging. Some peculiarity about the gold prevents its easy treatment, but much of the rock is very low grade. Recently very extensive deposits of copper ore have been found in the Highland Boy. Other fissure veins in the massive rock of the region are known, but are of less importance. The general geological relations suggest the deposits mentioned under Example 30 and subtypes. The mines were the occasion of the first development of the lead-silver smelters in the West, and have made Salt Lake City an important cen-

[1] J. E. Clayton, "The Cœur d'Alêne Silver-lead Mines," *Eng. and Min. Jour.*, February 11, 1888, p. 108.

FIG. 98.—*View of the Bunker Hill and Sullivan Mines, Wardner, Idaho. The vein dips toward the observer, and outcrops on each hill, right and left. From a photograph furnished by E. E. Olcott.*

Fig. 99.—*View of the town of Mammoth, Tintic district, Utah. From a photograph by L. E. Riter, Jr.*, 1898.

Fig. 100.—*Bullion and Beck Mine and Mill, Eureka, Tintic district, Utah. From a photograph by L. E. Riler, Jr.*, 1898.

ter of the industry. The Telegraph group, the Emma, Flagstaff, and others were famous mines in their day. As will appear, nearly all the Utah mines are productive of lead-silver ores.

2.08.24. Example 35*a*. Tooele County. Bed veins in limestone, or between it and quartzite, and containing lead-silver ores with others, in rich chutes. The deposits occur in the west side of the Oquirrh range, in Ophir and Dry cañons, over the divide from Bingham. The principal mine is the Honorine. Fissure veins also occur in the region, but are of less importance. The Deep Creek district, near the Nevada line, is mentioned under 2.11.04.[1]

2.08.25. Example 35*b*. Tintic District. Ore beds or belts, three in number, and one to three miles long, generally parallel with the stratification of vertical blue limestones, but sometimes running across them. The ore-bearing zone is from 300 to 600 feet wide in at least one belt, and bears in places rich chutes of carbonate ore. The Crismon-Mammoth has been referred to under "Copper" (Example 20*g*), as it contains much copper. The ore is thought by Hollister to have replaced the limestone.[2]

Passing mention should also be made that lead-silver ores occur in Summit County, at the Crescent and other mines.

2.08.26. Example 30*g*. Horn Silver Mine, Beaver County. A great contact fissure between a rhyolite hanging wall and a limestone footwall, and carrying, at the Horn Silver mine, oxidized lead-silver ores, chiefly anglesite, with considerable

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[1] W. P. Blake, "Brief Description of the Emma Mine," *Amer. Jour. Sci.*, ii., II., 216. C. E. Fenner, "The Telegraph Mine," *School of Mines Quarterly*, July, 1893. O. J. Hollister, "Gold and Silver Mining in Utah," *Trans. Amer. Inst. Min. Eng.*, XVI., 3. Rec. D. B. Huntley, *Tenth Census*, Vol. XIII, p. 407. G. Lavagnino, "The Old Telegraph Mine," *Trans. Amer. Inst. Min. Eng.*, XVI., 25. "Little Cottonwood and Bingham, Utah," *Eng. and Min. Jour.*, August 14, 1880, p. 106; also July 19, 1889. J. S. Newberry, *School of Mines Quarterly*, 1884, p. 329. R. W. Raymond, *Mineral Resources West of the Rocky Mountains*, 1868–76, and J. R. Brown, *Ibid.*, 1867–68 *Ann. Reps. of Director of the Mint.* B. Silliman, "Geological and Mineralogical Notes on Some Mining Districts of Utah," *Amer. Jour. Sci.*, iii., III., 195.

[2] D. B. Huntley and O. J. Hollister, as above, under last footnote. J. S. Newberry, *Eng. and Min. Jour.*, September 13 and 20, 1879. A report on the district is in press with the U. S. Geological Survey.

barite, and with many other rarer minerals. The town of Frisco, containing the mine, is at the southern end of the Grampian Mountains. The great fissure is known for two miles, but is proved valuable only between the lines of the Horn Silver mine. It strikes north and south and dips 70° east. In the neighborhood of the vein the rhyolite is largely altered to residual clay. The mine is very dry, and the entire region lacks good water. The vein in general varies from 20 to 60 feet, but has pinched twice in going down, and of late years has largely ceased producing, although there may yet be much ore below. The ores are smelted near Salt Lake, and the base bullion is refined at Chicago. Some free milling ore has been afforded.[1]

2.08.27. Example 33*a*. Carbonate Mine, Beaver County. A fissure vein in hornblende andesite, filled with rounded fragments of wallrock, which are cemented by residual clay and galena. Some oxidized products occur near the surface. The mines are two and a half miles northeast of Frisco, but are in a different eruptive rock from that forming the walls of the Horn Silver. The literature is the same as for Example 30*g*, especially Hooker, l. c. p. 470.

2.08.28. Example 32*b*. Cave Mine, Beaver County. Chambers irregularly distributed in the limestone, and more or less filled with limonite and oxidized lead-silver ores. Small leaders of ores, which mark old conduits, connect the chambers. Up to 1880 five large and fifteen small chambers had been found. They are of very irregular shape, and have a vacant space of from one to ten feet between the ore and the roof. This deposit was the typical one cited by Newberry as illustrating the chamber or cave form of deposit. According to this view, the chambers were formed before the ore was brought in.

It is also possible that the ore bodies have been deposited by replacement of the limestone with sulphides, as is known abundantly elsewhere, and that the alteration of these to oxides has occasioned the apparent caves. The products of the mine afford but 5 to 7% lead, but are valuable as an iron flux to the

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[1] O. J. Hollister, "Gold and Silver Mining in Utah," *Trans. Amer. Inst. Min. Eng.*, XVI., 3. Rec. W. A Hooker, Report quoted in the *Tenth Census*, Vol. XIII., p. 464.

neighboring smelters. The mines are in the Granite range, seven miles southeast of Milford.[1]

NOTE.—Although the larger part of the Utah mines are for lead and silver, several others of great importance will be taken up under "Silver" itself.

NEVADA.

2.08.29. Example 36. Eureka. Bodies of oxidized lead-silver ores in much faulted and fractured Cambrian limestone, with great outbreaks of eruptive rocks near. The Eureka geological section is one of the most interesting in the entire country, and involves some 30,000 feet of Paleozoic strata, divided as follows: Cambrian quartzite, limestone, and shale, 7,700 feet; Silurian limestone and quarztite, 5,000 feet; Devonian limestone and shale, 8,000 feet; Carboniferous quartzite, limestone, and conglomerate, 9,300 feet. These have afforded some extremely valuable materials for comparative studies with homotaxial strata in the East. The ore occurs especially in what is called the Prospect Mountain limestone of the Cambrian, one smaller deposit being also known in Silurian quartzite. The limestone has been crushed and shattered along a great fault, and through its substance ore solutions have circulated, replacing it in part with large bodies of sulphides which have afterward become oxidized to a depth of 1,000 feet. The ore bodies were puzzling as regards their classification, and a famous mining suit, with many interpretations from various experts, resulted. The alteration of the ore has caused shrinkage, and the formation of apparent caves over it. But there are many empty caves, formed by surface waters long after the ore was deposited, and J. S. Curtis very clearly shows that the ore bodies originated by replacement. All are connected with more or less strongly marked fissures which formed the conduits. Mr. Curtis made a careful series of assays of the neighboring igneous rocks to find some indication of the source of the ore. A quartz porphyry gave significant results, and to this the metals are referred, the portions of the mass at a great

[1] O. J. Hollister, "Gold and Silver Mining in Utah," *Trans. Amer. Inst. Min Eng.*, XVI., 3. D. B. Huntley. *Tenth Census*, Vol. XIII., p. 474. J. S. Newberry, *School of Mines Quarterly*, March, 1880. Reprint. p. 9. Cf. also J. B. Kimball. "The Silver Mines of Eulalia, Chihuahua," *Amer. Jour. Sci.*, ii., XLIX., 161.

depth are considered to have furnished them. Eureka was one of the first places in this country where the hypothesis of replacement was applied to ores in limestone. The district is now far less productive than it was fifteen or twenty years ago.[1]

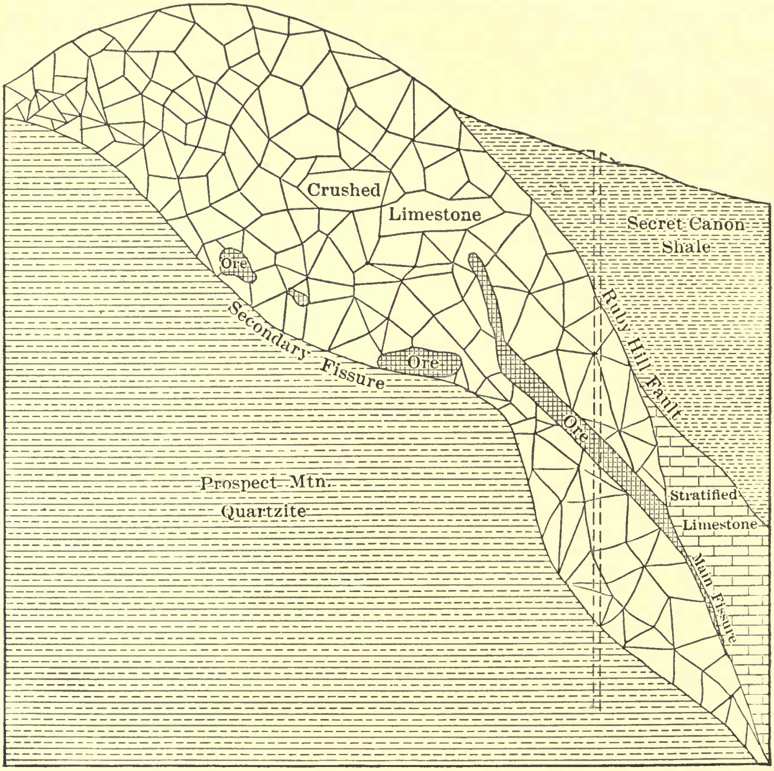

FIG. 101.—*Section at Eureka, Nev. Reproduced in line work after colored plate by J. S. Curtis, Monograph VI., U. S. Geol. Survey.*

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[1] G. F. Becker, *Tenth Census*, Vol. XIII., p. 32. Rec. W. P. Blake, "The Ore Deposits of the Eureka District, Nevada," *Trans. Amer. Inst. Min. Eng.*, VI., 554. J. S. Curtis, "Silver-lead Ore Deposits of Eureka. Nev.," *Monograph VII., U. S. Geol. Survey.* A. Hague, "Geology of the Eureka District," *Monograph XX., U. S. Geol. Survey.* Abstract in *Third Ann. Rep. Director U. S. Geol. Surveg.* W. S. Keyes, "Eureka Lode of Eureka, Nev.," *Trans. Amer. Inst. Min. Eng.*, VI., 344. J. S. Newberry, *School of Mines Quarterly*, March, 1880. R. W. Raymond, "The Eureka-Richmond Case," *Trans. Amer. Inst. Min. Eng.*, VI., 371. C. D. Walcott, "Paleontology of the Eureka District," *Monograph VIII., U. S. Geol. Survey.*

ARIZONA—CALIFORNIA.

2.08.30. Comparatively small amounts of lead ores are shipped from Arizona from time to time, chiefly from Cochise County (Tombstone region) and Pima County (Tucson region). They will be mentioned under "Silver." Insignificant amounts are also afforded by California (about $2,000 in 1889), mostly from Inyo County. (See *Eleventh Census*, *Bull. No. 80*, June 18, 1891.)

CHAPTER IX.

SILVER AND GOLD.—INTRODUCTORY: EASTERN SILVER MINES AND THE ROCKY MOUNTAIN REGION OF NEW MEXICO AND COLORADO.

2.09.01. The two "precious" metals are so generally associated that they cannot be separately treated. While endeavoring to preserve the distinctive impression given by examples, it is practically impossible to set forth all the widely varying phenomena of the silver-gold veins of the West in any other than an approximate way. Hence geographical considerations are placed first and where markedly similar ore bodies in different States are to be grouped together cross references are given. The following general examples have been made because their individual features are based on those geological relations which are most vitally concerned with questions of origin.

2.09.02. Example 37. Veins containing the precious metals usually with pyrite, galena, chalcopyrite, and less common sulphides, sulpharsenides, sulphantimonides, etc., in igneous rocks. No special subdivision is made on the character of the gangue, which may be quartz, calcite, barite, fluorite, etc., one or all. The first named is commonest. A great and well-defined original fissure is not necessarily assumed, but some crack, or joint or crushed strip must have directed the ore-bearing solutions, which may have then replaced the walls in large measure. For other structural features see the discussion of veins (1.05.01); compare also Example 17, Butte, Mont.

Example 37*a*. Replacements more or less complete of igneous dikes, which have usually been described as porphyry. Compare Example 17*a* under "Copper" (Gilpin County, Colorado), and Example 20*d* (Santa Rita, N. M.). Ore and gangue, where the matrix is not the dike rock, as in Example 37.

Example 38. Contact deposits between two kinds of igneous rock or between two different flows. Ore and gangue as in Example 37.

Example 39. Agglomerates of rounded, eruptive boulders, bombs, etc., in abandoned volcanic necks or conduits, and coated with ores. The Bassick mine of Custer County, Colorado, is the only example of an ore deposit of this kind yet identified.

Example 40. Contact deposits between igneous and sedimentary rocks. No subdivisions are made on the kind of rocks. Ore and gangue as in Example 37. The ore body may replace a calcareous rock along the under side of an intruded sheet. Compare also Example 20, "Arizona Copper"; Example 21*a*, "Triassic Copper"; Example 30, "Leadville"; and Example 30*g*, "Horn Silver Mine."

Example 41. Veins in sedimentary rocks, generally cutting the bedding, but at times parallel with it. Lateral enlargements are frequent. The ore body may be largely due to the replacement of some calcareous rock, such as limestone or lime-shales, beneath some relatively impervious bed. Ore and gangue as in Example 37.

Example 42. Veins cutting both sedimentary and igneous rocks, and therefore due to disturbances after the intrusion of the latter. Ore and gangue as in Example 37.

No special examples are made for metamorphic rocks.

2.09.03. Minerals containing silver or gold.

	Ag.	*S.*	*As.*	*Sb.*	*Cl.*
Native silver	100.	....	....	....	....
Argenite (silver glance), Ag_2S	87.1	12.9	....	....	....
Prousite (light ruby silver), $3Ag_2S.As_2S_3$	65.5	19.4	15.1	....	....
Pyrargerite (dark ruby silver), $3Ag_2S.Sb_2S_3$	60.	17.8	....	22.2	....
Stephanite (brittle silver), $5Ag_2S.Sb_2S_3$	68.5	16.2	....	15.3	....
Cerargerite (horn silver), AgCl	75.3	....	....	....	24.7

Silver also occurs with galena (Cf. "Lead") and with tetrahedrite (Cf. "Copper"). Gold occurs combined with tellurium in tellurides; mechanically mingled with pyrites; and as the uncombined native metal. From a metallurgical point of view the ores of the precious metals are divided into two classes. 1. Those whose amount of precious metal amalgamates readily with quicksilver, and is thus obtained with comparative ease—the free milling ores. 2. Those which require roasting or some previous treatment before amalgamation, chlorination, or similar process, or which must be smelted primarily for lead or copper, from which the precious metals are afterward extracted—the rebellious ores. In the subsequent description the endeavor has been made to work from the distinctively silver mines to those of gold, where geographically possible.[1]

The precious metals seem to have been derived in almost all cases from deep-seated sources, and presumably from igneous rocks, even though they may now be found in sediments or metamorphic rocks. The valuable and thorough researches of J. R. Don upon the Australian gold-bearing reefs, the neighboring wall rocks, and the sea water as a possible source of the precious metal have led to increased faith in its derivation by uprising solutions. Both Blake and Merrill have discovered

[1] *Ann. Reps. Directors of the Mint.* Rec. W. P. Blake, "The Various Forms in which Gold Occurs in Nature," *Rep. Director of the Mint*, 1884, p. 573. Rec. "Gold in Granite and Plutonic Rocks," *Trans. Amer. Inst. Min. Eng.*, XXVI., 290, 1896. Brown, Raymond, and others, 1868 to 1876, "Mineral Resources West of the Rocky Mountains.' Annual. T. C. Chamberlin, "On the Geological Distribution of Argentiferous Galena," *Geol. of Wis.*, Vol. IV. Cumenge and Robellaz, "L'Or dans la Nature." Paris, 1879. L. De Launay, "Contribution a l'étude des Gites Métalliféres, *Annales des Mines*, August, 1897, 108. J. R. Don, "The Genesis of Certain Auriferous Lodes," *Trans. Amer. Inst. Min. Eng.*, XXVII., 564, 1897. Rec. J. F. Kemp, "Geological Occurrence and Associates of the Telluride Gold Ores," *The Mineral Industry*, VI., 295–320, 1898. Clarence King, "Production of the Precious Metals in the United States," *Second Ann. Rep. Director U. S. Geol. Survey*, p. 333. A. G. Lock, *Gold*, 1882. G. P. Merrill, "Gold in Granite," *Amer. Jour. of Sci.*, April, 1896, 309. *Mineral Resources of the U. S.;* annual publication of the Geological Survey. R. I. Murchison, "General View of the Conditions under which Gold is Distributed," *Quar. Jour. Geol. Soc.*, VII., 134. Also in *Siluria* and *Amer. Jour. Sci.*, ii., XVIII., 301. J. S. Newberry, "On the Genesis and Distribution of Gold," *School of Mines Quarterly*, III., No. 1, and *Eng. and Min. Jour.*, December 24 and 31, 1881, pp. 416, 437. R. Pearce, "On the Ores of Gold," etc., *Colo. Sci. Soc.*, III., p. 237. J. A. Phillips, *Ore Deposits*, 1884. *The Mining and Metallurgy of Gold and Silver*, 1867. *Tenth Census Report on the Precious Metals.* Albert Williams, "Popular Fallacies Regarding Precious Metal Ore Deposits," *Fourth Ann. Rep. Dir. U. S. Geol. Survey*, 1884. J. H. L. Vogt, *Zeitschrift für prakt. Geologie*, September, 1898, 321. "Ueber die Bildung des Gediegen Silbers," etc., *Idem*, April, 1899, 113.

gold in granite, and Möricke, as earlier cited, 1.03.06, observed it in obsidian.

2.09.04. Example 22*a*. Atlantic Border. Already mentioned (2.05.02), the region is only of historical interest as affording silver, although lately some attention has been directed to Sullivan, Me., where the veins have pyrite and probably stephanite, in a quartz gangue, in slates, associated with granite knobs and trap dikes, which are of later age than the veins. Some silver is generally found in the galena of the Eastern States, but the ores have never yet proved abundant enough to be important.[1]

Mention may also be made at this point of the argentiferous galena veins along the Ouachita uplift of Arkansas. A few are known, usually with Trenton shales or slates for walls. They are low grade, and though once the basis of a small excitement, their production has never been serious. Additional reference to the region will be found under "Antimony." Some mines of the latter metal are stated by W. P. Jenney to show low-grade, argentiferous ores in depth.[2]

2.09 05. Example 42. Silver Islet, Lake Superior. A fissure vein carrying native silver, argentite, tetrahedrite, galena, blende, and some nickel and cobalt compounds in a gangue of calcite, in flags and shales of the Animikie (Algonkian) system, and cutting a large trap dike, within which alone the vein is productive. Silver Islet is or was originally little more than a bare rock some 90 feet square, lying off the north shore of Lake Superior just outside of Thunder Bay, and within the Canadian boundaries. The native silver was detected outcropping beneath the water. The vein was productive to a depth of 800 or 1,000 feet, but below this it yielded little. The trap dike has usually been called diorite, but is determined to be norite by Wadsworth (*Bull. 2, Minn. Geol. Survey*, p. 92), and gabbro by Irving (*Monograph V., U. S. Geol.*

[1] C. W. Kempton, "Sketches of the New Mining District at Sullivan, Me.," *Trans. Amer. Inst. Min. Eng.*, VII., 349. M. E. Wadsworth, "Theories of Ore Deposits," *Proc. Boston Soc. Nat. Hist.*, 1884, p. 205. *Eng. and Min. Jour.*, May 17, 1884. *Bull. Mus. Comp. Zoöl.*, 3, Vol VII., 181.

[2] T. B. Comstock, *Ann. Rep. Geol. Survey of Arkansas*, 1888, Vol. I., "Gold and Silver."

Survey, p. 378). Some $3,000,000 were obtained from the mine, yet the expenses were so great in keeping up the surface works against winter gales and ice that but little profit was realized. The vein has been traced 9,000 feet, but is nowhere else productive. Considerable graphite has been found in the workings, and some curious pockets of gas.[1]

2.09.06. Example 42. Thunder Bay, Canada. The mainland near Silver Islet contains many similar veins. They have furnished considerable silver, as argentite in a gangue of quartz, barite, calcite and fluorite, and associated with zinc-blende, galena, and pyrite.[2]

THE REGION OF THE ROCKY MOUNTAINS AND BLACK HILLS.

NEW MEXICO.

2.09.07. *Geology.*—The general topography and geology of New Mexico were outlined in the introduction. Much remains to be done in developing its geology. The eastern part belongs to the prairie region, and is very dry. A few rivers, notably the Pecos and the Rio Grande, afford water for irrigation, the former of which is now being utilized on a grand scale, and for the latter plans have been prepared. In the central portion many subordinate north and south ranges of mountains are found, which are less elevated than those of Colorado. The Colorado ranges virtually die out at the northern boundary. The northwestern portion comes in the great Colorado plateau, and has been quite fully described by Captain Dutton (*Eighth Ann. Rep. Director U. S. Geol. Survey*). In numerous localities

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[1] R. Bell, *Eng. and Min. Jour.*, January 8 and 15, 1887. See also May 14, 1887. W. M. Courtis, "On Silver Islet," *Eng. and Min. Jour.*, December 21, 1873, and *Trans. Amer. Inst. Min. Eng.*, V., 474. E. D. Ingall, *Ann. Rep. Can. Geol. Survey*, 1887–88, Part II., p. 14. F. A. Lowe, "The Silver Islet Mine and its Present Development," *Eng. and Min. Jour.*, December 16, 1882, p. 321. T. MacFarlane, "Silver Islet," *Trans. Amer. Inst. Min. Eng.*, VIII., 226. *Geol. of Canada*, 1863, 717. *Canadian Naturalist*, Vol. IV., p. 37. McDermott, *Eng. and Min. Jour*, Vol XXIII., Nos. 4 and 5.

[2] R. Bell, "Silver Mines of Thunder Bay," *Eng. and Min. Jour.*, January 8 and 15, 1887. E. D. Ingall, *Ann. Rep. Can. Survey*, 1887–88, Part II., p. 1H. Rec. See also *Eng. and Min. Jour.*, May 14, 1887; February 18, 1888, p. 123; May 26, 1888, p. 383. W. M. Courtis, "Animikie Rocks and their Vein-phenomena as shown at the Duncan Mine," *Trans. Amer. Inst. Min. Eng.*, XV., 671; see also V., 473.

throughout the Territory volcanic action has been rife, and in places is but recently extinct. The eastern part is largely Cretaceous, and also the northwestern plateau, which contains much valuable coal. The mountain ranges often have nuclei of Archean crystalline rocks, with successive strata of Carboniferous, Permian, Triassic, Jurassic and Cretaceous on the flanks. The mining regions are in these ranges of mountains.[1]

2.09.08. The southwestern county is Grant, whose lead-silver deposits have been briefly referred to. North of Silver City are quartz veins of gold and silver ores, in diabase and quartz porphyry (Example 37), and again, west of Silver City, are ferruginous deposits with chlorides and sulphides of silver in limestone. In the Burro Mountains are silver ores in limestones, apparently Lower Silurian. The Santa Rita Mountains contain, in addition to the copper (Example 20*d*), silver and gold in quartz veins in eruptive rocks (Example 37). Lake Valley, in Doña Aña County, has been mentioned (2.08.04). In Lincoln County gold ores are reported from the White Oak district. The principal mines of Socorro County have been

[1] W. P. Blake, *Proc. Bost. Soc. Nat. Hist.*, 1859, Vol. VII., p 64. "Geology of the Rocky Mountains in the Vicinity of Santa Fé," *Amer. Asso. Adv. Sci.*, 1859. A. R. Conkling, "Report on Certain Foothills in Northern New Mexico," *Wheeler's Survey, Rep. of Chief of U. S. Engineers*, 1877, II., 1298. E. D. Cope, "Report on the Geology of a Part of New Mexico," *Wheeler's Survey*, 1875; Appendix G1. C. E. Dutton, "Mount Taylor and the Zuni Plateau," *Sixth Ann. Rep. U. S. Geol. Survey*, pp. 111–205. S. F. Emmons, *Tenth Census*, Vol. XIII., 100. O. Loew, "Report on the Geology and Mineralogy of Colorado and New Mexico." *Wheeler's Survey*, 1875; Appendix G2, p. 27. J. Marcou, "The Mesozoic Series of New Mexico," *Amer. Geol.*, IV., 155, 216. R. E. Owen and E. J. Cox, "Report on the Mines of New Mexico," Washington, 1865, 60 pp., *Amer. Jour. Sci.*, ii., XL., 391. G. F. Runton, "On the Volcanic Rocks of New Mexico," *Quar. Jour. Geol. Soc.*, Vol. VI., p. 251, 1850. B. Silliman, Jr., "The Mineral Regions of Southern New Mexico," *Trans. Amer. Inst. Min. Eng.*, X., 424. F. Springer, "Occurrence of the Lower Burlington Limestone in New Mexico," *Amer. Jour. Sci.*, iii., XXVII., 97. J. J. Stevenson, "Geological Examinations in Southern Colorado and Northern New Mexico," *Wheeler's Survey*, 1881. "Geology of Galisteo Creek," *Amer. Jour. Sci.*, iii., XVIII., 471. "On the Laramie Group of Southern New Mexico," *Amer. Jour. Sci.*, iii., XXII., 370. For the Bibliography of the Geology of the Territory in general, see *Bulletin of the U. S. Geol. Survey*, 127 (literature up through 1891); 130 (1892–1893); 135 (1894); 146 (1895); 149 (1896); 156 (1897), and annual issues.

mentioned (Example 29), and the copper in Permian sandstone under Example 21*c*. There are other silver-bearing lodes in the Socorro Mountains near the town of Socorro. Henrich has described (l. c.) a curious deposit of quartz carrying gold and silver (the Slayback Lode) on the contact between the older bedded eruptions and a later siliceous dike in the Mogollon range (Example 38). In Santa Fé County are important placer mines (Example 44) and thin veins of galena in rhyolite. In Bernalillo County are placers on the slopes of the Sandia Mountains. In Colfax County, in the Rocky Mountains, are other placers, and reported gold and silver mines.[1]

COLORADO.

2.09.09. *Geology.*—The eastern portion contains plains and is a region lacking water. It consists of Quarternary and Cretaceous rocks. The plains rise in the foothills, which are chiefly upturned Jura-Triassic and Cretaceous strata. The Paleozoic is relatively limited, although known. It rests on the crystalline rocks of the Archean. There are some minor uplifts, running out at right angles to the Front range, that divide the foothill country into basins, and are especially important in connection with coal. Next come the easterly ranges of the Rocky Mountains, in linear north and south succession. They consist largely of dome-shaped peaks of granite, with great local developments of volcanic rocks. To the west follow the several parks, chiefly consisting of Mesozoic strata. They are bounded by ranges again on the west, some of which, like the Mosquito range (see under Example 30), mark great lines of post-Cretaceous upheaval, and are accompanied by immense igneous intrusions. On the east and west flanks of the Sawatch range (the granitic Continental Divide) are Paleozoic strata in considerable thickness, but to the west

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[1] W. P. Blake, "Gold in New Mexico," *Proc. Bost. Soc. Nat. Hist.*, VII., p. 16, July, 1859. "Observations on the Geology, etc., near Santa Fé," *Amer. Asso. Adv. of Sci.*, XIII., 314, 1860. S. F. Emmons, *Tenth Census*, XIII., p. 101. C. Henrich, "The Slayback Lode, New Mexico." *Eng. and Min. Jour.*, July 13, 1889, p. 27. R. E. Owen and E. T. Cox, *Rep. on the Mines of New Mexico*, Washington, 1865. *Rep. Director of the Mint*, 1882, p. 339. B. Silliman, "Mineral Resources of Southern New Mexico," *Trans. Amer. Inst. Min. Eng.*, X., 424. *Eng. and Min. Jour.*, October 14 and 21, 1882, pp. 199, 212.

they dip under the vastly greater development of Mesozoic terranes, which shade out into the Colorado plateau. In northern, central and southwestern Colorado are vast developments of igneous rocks that have attended the geological disturbances.[1]

2.09.10. The San Juan region includes several counties in southwestern Colorado, in whole or in part, viz.: Ouray, Hinsdale, San Juan, Dolores, and La Plata. The chain of the San Juan Mountains consists of great successive outflows of eruptive rocks, andesite, diabase, diorite, basalt, etc., which cover up the Archean and later sedimentary terranes, except in a few scattered exposures. Considerable masses of rocks formed of fragmental ejectamenta are also known. All these are crossed by immense vertical veins, largely with quartz gangue, and containing argentiferous minerals of the usual species, galena, tetrahedrite, pyrargerite, and native silver, as well as bismuth compounds. Gold has been quite subordinate, although late developments near Ouray have shown some peculiar and interesting deposits. R. C. Hills, as quoted by S. F. Emmons, 1885, traced three systems of veins. (1) Silver bearing, narrow (six inches to three feet), nearly vertical veins, with base metal ores

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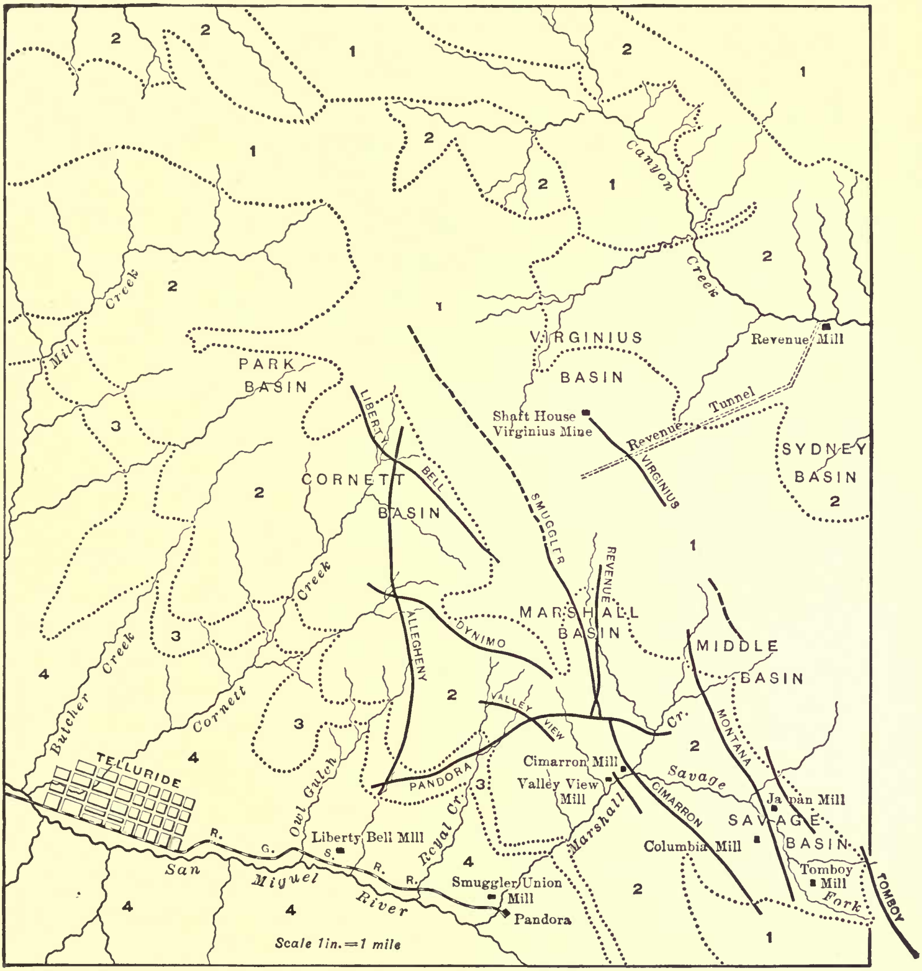
[1] G. L. Cannon, "Quaternary of the Denver Basin," *Proc. Colo. Sci. Soc.*, III., 48. See also III., 200. "Geology of Denver and Vicinity," *Idem*, IV., 235. Rec. W. Cross, "The Denver Tertiary Formation," *Amer. Jour. Sci.*, iii., XXXVII., 261. "Pike's Peak," Atlas Folio, *U S. Geol. Survey*, No. 7. Rec. "On a Series of Peculiar Schists near Salida," *Proc. Colo. Sci. Soc.*, IV., 286. Rec. "The Laccolitic Mtn. Groups of Colorado, Utah and Arizona," *Ann. Rep. Dir. U. S. Geol. Survey*, XIV., 165. Rec. G. H. Eldredge, "On the Country about Denver, Colo.," *Proc. Colo. Sci. Soc.*, III., 86. See also 140. S. F. Emmons, "Orographic Movements in the Rocky Mountains," *Geol. Soc. of America*, I., 245–286. F. M. Endlich, "On the Eruptive Rocks of Colorado," *Tenth Ann. Rep., Hayden's Survey.* H. Gannett, "Report on the Arable and Pasture Lands of Colorado," *Hayden's Survey*, 1876, p. 313. H. C. Freeman, "The La Plata Mountains," *Trans. Amer. Inst. Min. Eng.*, XIII, 681. G. K. Gilbert, "Colorado Plateau Province as a Field for Geological Study," *Amer. Jour. Sci.*, iii., XII., 16, 85. J. D. Hague, *Fortieth Parallel Survey*, Vol. III., p. 475. F. V. Hayden, *Reps. of Hayden's Survey*, 1873, 1874, p. 40; 1875, p. 33; 1876, pp. 5, 70. R. C. Hills, "Preliminary Notes on the Eruptions of the Spanish Peaks," *Proc. Colo. Sci. Soc.*, III., 24, 224. "The Recently Discovered Tertiary Beds of the Huerfano River Basin," *Proc. Colo. Sci. Soc.*, III., pp. 148, 217. "Jura-Trias of Southeastern Colorado," *Amer. Jour. Sci.*, iii., XXIII., p. 243. "Orographic and Structural Features of Rocky Mountain Geology," *Proc. Colo. Sci*

and no selvage. (2) Large, strong, gold-bearing veins dipping 60° with selvages and intersecting (1). (3) Like (1), but larger and more persistent, and carrying occasional bismuth and antimonial ores with gold and little or no silver. T. B. Comstock (*Trans. Amer. Inst. Min. Eng.*, XV., 218) has classified the veins in three radiating systems. (1) The northwest, with tetrahedrite (freibergite). (2) The east and west, with bismuth and less often nickel and molybdenum. (3) The northeast, with tellurides and antimony and sulphur compounds of the precious metals. Quite recently a series of small caves near Ouray, in quartzite overlaid by bituminous shales have been found to contain native gold, and have excited great interest. It is thought by Endlich that they represent inclusions of shale, now dissolved away, and that the gold was precipitated on the walls. If this view is correct, they mark one of the very few illustrations of chamber deposits which are known. More extended mining work has proved them to be in all cases connected with a supply fissure from which small leaders guide the miners to the chambers.

In the vicinity of Telluride there is a very interesting development of veins. One of the most remarkable and persistent

Soc., III., 362. Rec. "Types of Past Eruptions in the Rocky Mountains," *Idem*, IV., 14. Rec. A. Lakes, "Extinct Volcanoes in Colorado," *Amer. Geol.*. January, 1890, p. 38. Oscar Loew, "Report on the Minerals of Colorado and New Mexico," *Wheeler's Survey*, 1875, p. 97. "Eruptive Rocks of Colorado," *Wheeler's Survey*, 1873. C. A. H. McCauley, "On the San Juan Region," *Rep. Chief of U. S. Engineers*, 1878, III., p. 1753. C. S. Palmer, "On the Eruptive Rocks of Boulder County," etc., *Proc. Colo. Sci. Soc.*, III., p. 230. A. C. Peale, "On the Age of the Rocky Mountains in Colorado," *Amer. Jour. Sci.*, iii., XIII., p. 172; Reply to the above by J. J. Stevenson, *Amer. Jour. Sci.*, iii., XIII., 297. T. A. Rickard, "Gold Resources of Colorado," *The Mineral Industry*, II., 325; IV., 315. S. H. Scudder, "The Tertiary Lake Basin at Florissant," *Hayden's Survey*, 1878, p. 271; see also 1877. J. A. Smith, *Catalogue of the Principal Minerals of Colorado*, Central City, 1870. J. J. Stevenson, "Notes on the Laramie Group of Southern Colorado," *Amer. Jour. Sci.*, iii., XVIII., 129. "The Mesozoic Rocks of Southern Colorado," *Amer. Geol.*, III., p. 391. P. H. Van Diest, "Colorado Volcanic Cones," *Proc. Colo. Sci. Soc.*, III., p. 19. C. A. White, "On Northwestern Colorado," *Ninth Ann. Rep. Director U. S. Geol. Survey*, 683–710. For the complete geological bibliography of the State, see *Bulletins U. S. Geol. Survey*, 127 (1732–1891); 130 (1892–93); 135 (1894); 146 (1895); 149 (1896); 156 (1897), and current annuals.

is the Smuggler, recently described by J. A. Porter. It is known for a stretch of four miles and cuts the high divide that



Not Classified as to Geologic Age.	1	Rhyolites and Andesites.	Eocene?	3	San Miguel Conglomerate
	2	San Juan Formation Andesitic Breccia	Jurassic and Cretaceous	4	Shales and Sandstones.

FIG. 102.—*Geological sketch-map of the Telluride district, Colorado. After Arthur Winslow, Trans. Amer. Inst. Min. Eng., February,* 1899.

separates the Marshall basin near the town of Telluride, on the south, in the drainage area of the San Miguel River, from the valleys of Cañon Creek, a tributary of the Uncompahgre River, that lies to the north. (See Fig. 102.) The summit of the divide is 13,200 feet above tide. Whitman Cross has been mapping an atlas sheet for the U. S. Geological Survey in the vicinity of Telluride, and has prepared in advance of its issue a sketch of the local geology. ("The San Miguel Formation, Igneous Rocks of the Telluride District," *Proc. Colo. Sci. Soc.*, September, 1896.) The formations of interest in connection with the vein, begin with the San Miguel conglomerate, which is probably of closing Cretaceous or early Eocene age. On this is the San Juan formation, 2,000 feet thick, of bedded volcanic andesitic tuffs, the chief wall rocks. Above follow sheets of various andesites and rhyolites, which are cut by the highest parts of the vein. The fissure containing the ore body has cut this series and is known for 3,500 feet vertically, but what its character is in the San Miguel conglomerate is not yet demonstrated. The gangue is chiefly quartz, with some rhodochrosite, calcite, siderite and barite. The values in silver are highest at the north, and yield to gold values to the south. Two other notable veins cross and fault the Smuggler, one the Pandora, containing auriferous quartz, the other the Revenue, with considerable lead. So constant is the character of the Smuggler that stoping ground has been broken for a mile without a break. (J. A. Porter, "The Smuggler-Union Mines, Telluride, Colo.," *Trans. Amer. Inst. Min. Eng.*, XXVI., 449.) The region is indeed one of remarkably persistent and clear-cut fissures,[1] which are shown on Fig. 102.

Placer gold mines (Example 44) are quite extensively worked in San Miguel County J. B. Farish has described the veins at Newman Hill, near Rico, in a valuable paper cited below. The lowest formation exposed is magnesian limestone, supposed to be Carboniferous. It contains large ore bodies of low grade, and is also, strangely enough, heavily charged with carbonic acid gas. Above this for 500 feet are alternating sandstones and shales, and then a narrow stratum of limestone 18 to 30 inches thick. This is followed by about

[1] C. W. Purington, "Preliminary Report on the Mining Industries of the Telluride Quadrangle," *Eighteenth Ann. Rep. Director U. S. Geol. Survey.* Arthur Winslow, "The Liberty Bell Gold Mine, Telluride, Colorado," *Trans. Amer. Inst. Min. Eng.*, February, 1899.

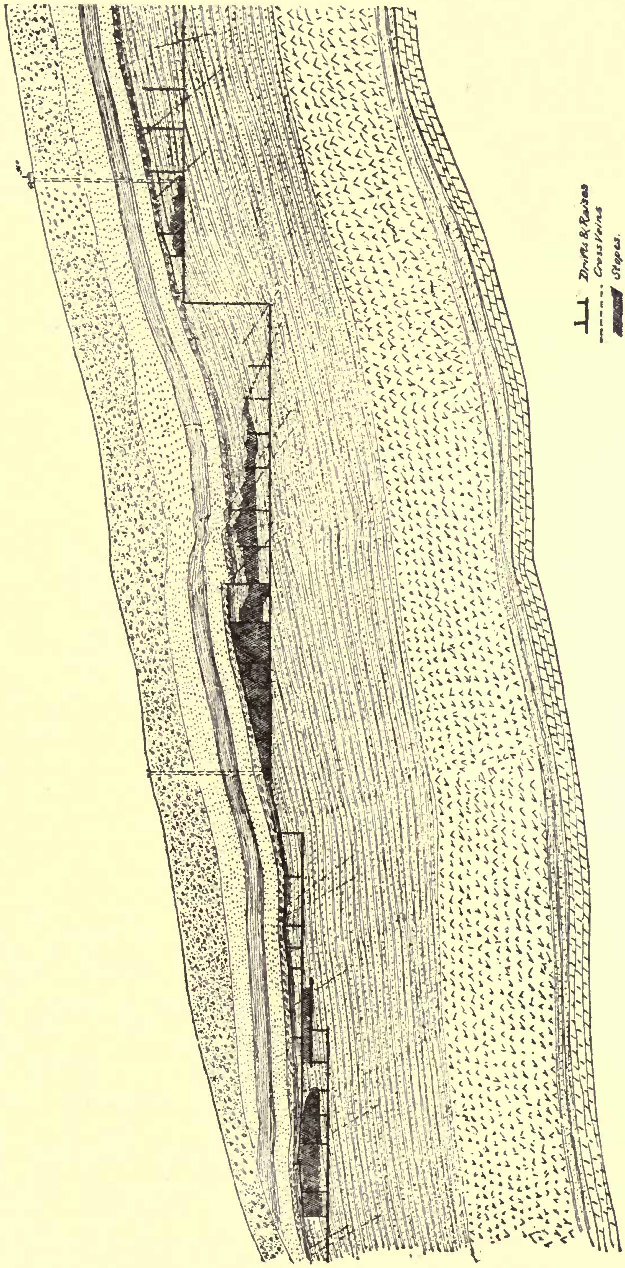


FIG. 103.—*Geological cross sections of strata and veins at Newman Hill, near Rico, Colo. After J. B. Farish, Proc. Colo. Sci. Soc., April 4, 1892.*

500 feet additional of shales and sandstone, regarded as Carboniferous. Fifty feet above the lowest limestone a laccolite of porphyrite has been intruded. Two sets of fissures are present—one nearly vertical and striking northeast, the second dipping 30 to 45° northeast, and striking northwest. The former are the richest, are rudely banded and persistent, being worked in one case for 4,000 feet. The flatter fissures are less rich. The principal ore bodies, however, occur as horizontal enlargements of both these sets of veins. Just over the thin bed of limestone mentioned above the ores have spread out into sheets from 20 to 40 feet wide, and from a few inches to three feet thick. They consist of solid masses of the common sulphides, galena, pyrite, gray copper, etc., and are very rich. Above

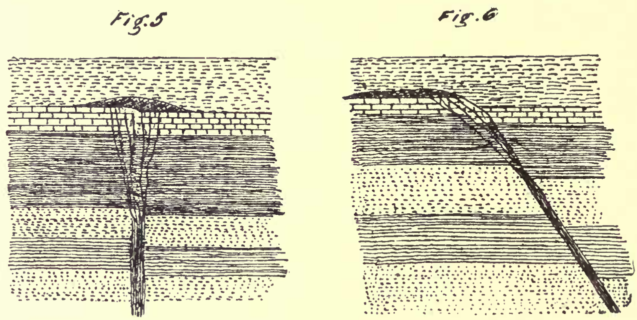


FIG. 104.—*Geological cross sections of strata and veins at Newman Hill, near Rico, Colo. After J. B. Farish, Proc. Colo. Sci Soc., April* 4, 1892. *See also Figures* 5 *and* 6.

them the fissures apparently cease, or at least are tight. Two hundred feet down from them the vein filling becomes nearly barren, glassy quartz. These are most remarkable ore bodies, and would appear to have been formed by uprising solutions, which met the tight place and spread sidewise, depositing their minerals; but as Mr. Farish advances no explanation, it is hardly justifiable for others, less familiar than himself with the phenomena, to do so. T. A. Rickard has also written of them, and has illustrated the details of vein structure in a very significant series of plates, which show the banding to be irregular and not persistent. He has also introduced some corrected interpretations of the faults.

The lead-silver ores of Red Mountain and Rico have already been mentioned (2.08.17). Silverton and Ouray are the principal towns of the San Juan.[1]

2.09.11. The new mining region of Creede, now decided to be in Saguache County, should be mentioned in this connection. It is situated near the junction of Saguache, Ouray and Hinsdale counties, and some ten or twelve miles from Wagon Wheel Gap. There is a great development of igneous rocks as well as of Carboniferous limestone, but the veins as yet developed are in the former. They appear to be fissure veins, and have quartz, in large part amethyst, with some manganese minerals as a gangue, and, with these, oxidized silver ores. The mines are on two mountains, Bachelor and Campbell, which are on opposite sides of Willow Creek Cañon.[2]

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[1] T. B. Comstock, "The Geology and Vein Structure of Southwestern Colorado," *Trans. Amer. Inst. Min. Eng.*, Vol. XV., 218; also XI., 165, and *Eng. and Min. Jour.*, numerous papers in 1885. "Hot Spring Formation in the Red Mountain District, Colorado," *Trans. Amer. Inst. Min. Eng.*, XVII., 261. S. F. Emmons, "On the San Juan District," *Eng. and Min. Jour.*, June 9, 1883, p. 332. "Structural Relations of Ore Deposits," *Trans. Amer. Inst. Min. Eng.*, XVI., 804. Rec. *Tenth Census*, Vol. XIII., p. 60. F. M. Endlich, "Origin of the Gold Deposits near Ouray," *Eng. and Min. Jour.*, October 19, 1889. "San Juan District," *Hayden's Survey*, 1874, p. 229. *Ibid.*, 1875, *Bull. III.*, *Amer. Jour. Sci.*, iii., X., 58. J. B. Farish, "On the Ore Deposits of Newman Hill, near Rico, Colo.," *Colo. Sci. Soc.*, April 4, 1892. Rec. W. H. Holmes, "La Plata District," *Hayden's Survey*, 1875; *Amer. Jour. Sci.*, iii., XIV., 420. M. C. Ihlseng, "Review of the Mining Interests of the San Juan Region," *Rep. Colo. State School of Mines*, 1885, p. 27. G. E. Kedzie, "The Bedded Ore Deposits of Red Mountain Mining District, Ouray County, Colorado." *Trans. Amer. Inst. Min. Eng.*, XV., 570. Rec. G. A. Koenig and M. Stocker, "Lustrous Coal and Native Silver in a Vein in Porphyry, Ouray County, Colorado," *Trans. Amer. Inst. Min. Eng.*, IX , 650. T. A. Rickard, "Vein Structure in the Enterprise Mine," *Proc. Colo. Sci. Soc.*, Adv. Sheets, Vol. V. T. E. Schwartz, "The Ore Deposits of Red Mountain, Ouray County, Colorado," *Trans. Amer. Inst. Min. Eng.*, XVIII., 139, 1889. J. J. Stevenson, "On the San Juan," *Wheeler's Survey*, III., p. 376. "The San Juan Region," *Eng. and Min. Jour.*, August 27, 1881, p. 136; September 24, 1881, p. 201; July 17, 1880; December 20, 1879; and many other references in 1879 and 1880. P. H. Van Diest, "Notes on a Trip to Telluride, San Miguel Co., Colo.," *Proc. Colo. Sci. Soc.*, II., 28, 1885; *Idem*, January, 1886.

[2] E. B. Kirby, "The Ore Deposits of Creede and their Possibilities," *Eng. and. Min. Jour.*, March 19, 1892, p. 325. Rec. T. R. MacMechen, "The Ore Deposits of Creede," *Eng. and Min. Jour.*, March 12, 1892, p 301. Rec.

2.09.12. The Gunnison region lies on the western slope of the Continental Divide, and embraces both mountains and plateaus. West of the main and older range are the later Elk Mountains, in which several mining districts are located. Aspen has already been mentioned, and the long series of ore bodies in the Carboniferous limestones. The other principal districts are Independence, Ruby, Gothic, Pitkin and Tin Cup. The ores at Independence are sulphides with silver, in the Archean granite rocks. In the Tin Cup district the Gold Cup mine is in a black limestone and contains argentiferous cerussite and copper oxide. In the Ruby district the ores are in the Cretaceous rocks, and in the Forest Queen they are ruby silver and arsenopyrite, partly replacing a porphyry dike. On Copper Creek, near Gothic, a series of nearly vertical fissures traverse eruptive diorite. They contain sulphide of silver and native silver. The Sylvanite is one of the principal mines. Arthur Lakes has described some very curious veins in Gunnison Co., the Vulcan and Mammoth, that contain opaline silica and native sulphur together with pyrites.[1]

2.09.13. Eagle County. The lead-silver mines of Red Cliff have already been mentioned (Example 30*c*), and also the underlying gold deposits. The Homestake mine, northwest of Leadville, over toward Red Cliff, is on a vein of galena in granite, and was one of the first openings made in the region.[2]

2.09.14. Summit County. The Ten-Mile district, which is the principal one, has been mentioned under Example 30*a*. Lake County, containing Leadville, has been treated under Example 30. Mention should also be made of the placer depos-

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[1] F. Amelung, "Sheep Mountain Mines, Gunnison County, Colo.," *Eng. and Min. Jour.*, August 28, 1886, p. 149. F. M. Chadwick, "The Tin Cup Mines, Gunnison County, Colorado," *Eng. and Min. Jour.*, January 1, 1881, p. 4. See also Example 12*d* for iron mines. J. R. Holibaugh, "Gold Belt of Pitkin, Gunnison Co., Colo.," *Eng. and Min. Jour.*, December 12, 1896, p. 559. Arthur Lakes, "Sketch of a Portion of the Gunnison Gold Belt," etc., *Trans. Amer. Inst. Min. Eng.*, XXVI., 440.

[2] F. Guiterman, "On the Gold Deposits of Red Cliff," *Proc. Colo. Sci. Soc.*, 1890. "On the Battle Mountain Quartzite Mines," *Mining Industry*, Denver, January 10, 1890, p. 28. E. E. Olcott, "Battle Mountain Mining District, Eagle County," *Eng. and Min. Jour.*, June 11 and 18, 1887, pp. 417, 436; May 21, 1892. G. C. Tilden, "Mining Notes from Eagle County," *Ann. Rep. Colo. State School of Mines*, 1886, p. 129.

its in California Gulch, which first attracted prospectors to the region in 1860. In its eastern part Summit County borders on Clear Creek County, and at Argentine are some veins related to those of the latter. They are high up on Mount McClellan, and are remarkable for the veins of ice that are found in them.[1]

2.09.15. Park County, which lies east of Lake County and embraces the South Park, has some mines on the eastern slope of the Mosquito range, and in the Colorado range, to the northwest. The latter are similar in their contents to the Georgetown silver ores, mentioned under Clear Creek County, but the former are bodies of argentiferous galena and its alteration products in limestone and quartzite. Pyrite is also abundant, and at times a gangue of barite appears. The mines are in the sedimentary series, resting on the granite of the Mosquito range, and are pierced by porphyry intrusions, as at Leadville. The placer deposits at Fairplay deserve mention, as it was from these that the prospectors spread over the divide to the site of Leadville in 1860.[2]

2.09.16. Chaffee County, on the south, contains the iron mines referred to under Example 12*d*. There are some other gold-bearing veins near Granite and Buena Vista. The lead-silver deposits of the Monarch district are mentioned under Example 30*b*. In Huerfano County, in the Spanish Peaks, veins of galena, gray copper, etc., are worked to some extent.[3]

2.09.17. Rio Grande County. In the Summit district are a number of rich gold mines, of which the Little Annie is the best known. The gold occurs in the native state, in quartz on the contact between a rhyolite and trachyte breccia and andesite. The deposits are thought by R. C. Hills to be due to a silicification of the rhyolite along those lines, probably by the sulphuric acid, which brought the gold. Then the rocks were folded. Oxidation and impoverishment of the upper parts fol-

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[1] E. L. Berthoud, "On Rifts of Ice in the Rocks near the Summit of Mount McClellan," etc., *Amer. Jour. Sci.*, iii., II., 108. Ten-Mile Special Folio, *U. S. Geol. Survey*, by S. F. Emmons. Rec.

[2] J. L. Jernegan, "Whale Lode of Park County," *Trans. Amer. Inst. Min. Eng*, III., 352.

[3] R. C. Hills, "On the Eruption of the Spanish Peaks," *Proc. Colo. Sci Soc.*, III., pp. 24, 224.

lowed, forming bonanzas below. The paper has a very important bearing on the formation of many replacements.[1]

2.09.18. Conejos County. Some deposits of ruby silver ores have recently been developed in this county, near the town of Platoro. The county lies near the middle of the southern tier.

2.09.19. Custer County affords some of the most interesting deposits in the West. Rosita and Silver Cliff are the principal towns, and are situated in the Wet Mountain Valley, between the Colorado range on the north and the Sangre de Cristo on the south. In the northern portion of the area immediately concerned with the mines gneisses of undetermined but probably very ancient age outcrop, which, to the south, are buried beneath an extensive development of igneous (mostly volcanic) rocks, and Pleistocene gravels, alluvium and lake beds. The igneous rocks embrace rhyolite, trachyte, dacite, three varieties of andesite, diorite, agglomerate and tuffs. The volcanic rocks were derived from outbreaks that took place during the Eocene, as nearly as can be determined by some fossil leaves which are buried in the tuffs. It is interesting to note that the Cripple Creek volcanic center lies about 40 miles north. The volcanic rocks are chiefly represented in the Rosita Hills near the town of the same name, and in the flow of rhyolite north of Silver Cliff. In addition to the volcanics there are syenite, granite and diabase in the gneisses. Several different forms of ore body have been developed, each of which possesses exceptional claims to interest, and one of which forms a quite unique type, at least, so far as American experience has yet gone.

2.09.20. Example 39. The Bassick Mine. An explosive volcano seems to have broken out at the situation of the Bassick mine, and to have produced an elliptical pipe or conduit about 1,500x1,000 feet in the fundamental gneiss of the district, and to have subsided, leaving the tube filled with rounded boulders, which are chiefly andesite, but which embrace also granite, gneiss and even carbonized wood. A small dike of basaltic rock (limburgite) is also known to be present. A portion of the agglomerate in the shape of one and perhaps more, nearly vertical pipes or chimneys, has been impregnated

[1] R. C. Hills, *Proc. Colo. Sci. Soc.*, March, 1883. Abstract by S. F. Emmons in the *Eng. and Min. Jour.*, June 9, 1883, p. 332.

with rich ores of gold and silver, which coat the rounded boulders in successive shells of metallic minerals. The first coat is a mixture of lead, antimony and zinc sulphides, and is always present. A second, somewhat similar, but of lighter color and richer in lead and the precious metals, is sometimes seen. A third is chiefly zincblende, rich in silver and gold, and is the largest of all. A fourth, of chalcopyrite, sometimes occurs, and lastly, a fifth, of pyrite. Some lots of ore also yielded rich tellurides of the precious metals. On the Bassick chimney the workings have gone to 1,400 feet in depth, without losing the ore, which was roughly elliptical and 100x20 to 30 feet. From the seventh level downward cross-cuts opened up a second chimney lying 150 feet east. The Bassick has been considered by the earlier observers to be a geyser tube in which the bowlders were tossed about, rounded and coated with ore. Whitman Cross has, however, satisfactorily demonstrated the existence of the agglomerate, and S. F. Emmons has reached the conclusion that the ores have come in through fissures which can be detected in the mine. At the intersection of two which cross each other, the chief ore body has been found. The ores are of such a nature that Emmons regards their introduction in the form of vapors as possible, although at depths these vapors were probably confined in the liquid state. The ores would then be fumarolic impregnations which have replaced the interstitial filling of the agglomerate.

Example 39*a*. The Bull Domingo Mine. The Bull Domingo lies north of Silver Cliff and some miles northwest from the Bassick. The country rock is the ancient gneiss, but near the mine dikes of granite and syenite are known. The ore was found in an elliptical chimney, of variable size, but at the 150 foot level, 90x40 feet. It has been exploited down to the 550 level. The ore consists of rounded boulders of gneiss, syenite and granite, which are coated with successive shells of coarsely crystalline galena, somewhat fibrous zincblende, and specks of pyrite. Outside these are in order shells of white dolomite, ankerite or siderite, calcite, and chalcedony. There is abundant evidence of extensive fracturing of the rocks at the mine, and the evidence points, according to S. F. Emmons, rather to a shattered mass of country rock, whose brecciated fragments have been rounded, replaced and coated with ore by uprising solutions, than to an explosive volcanic outbreak or geyser, as had been previously thought. The general similarity in structure of the ore to that of the Bassick suggested quite naturally a similar origin to the earlier observers. It is interesting to

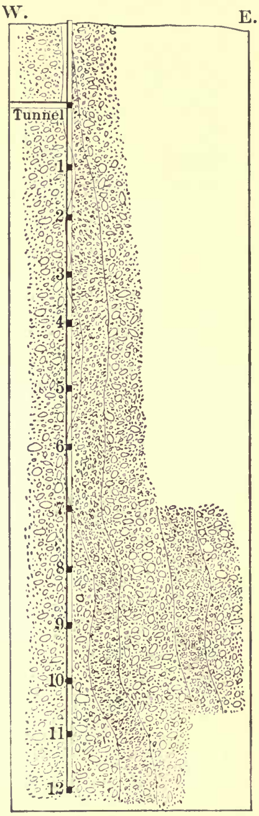

FIG. 105.

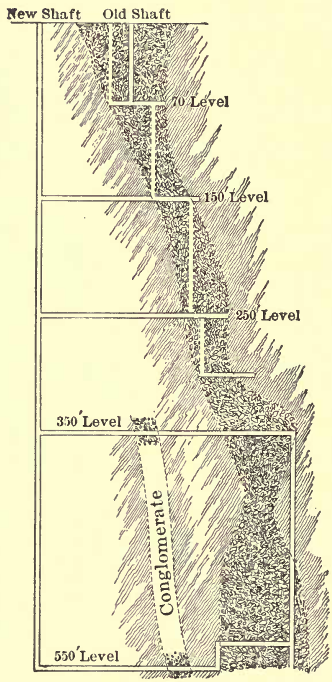

FIG. 106.

FIG. 105.—*Cross section of the Bassic Mine, near Rosita. After S. F. Emmons, XVII. Ann. Rep. U. S. Geol. Survey, Part II., p.* 434.

FIG. 106.—*Cross section of the Bull-Domingo Mine, near Silver Cliff, Colo. After S. F. Emmons, XVII. Ann. Rep. U. S. Geol. Survey, Part II., p.* 442.

compare the two chimneys of the Bassick and Bull Domingo with that of the Annie Lee at Victor in the Cripple Creek district. Specimens and notes given the writer by E. J. Chibas would indicate a similar deposit at the mines of the Darien Gold Mining Company, Cana, Columbia. (See also E. R. Woakes, *Amer. Inst. Min. Eng.*, Atlantic City meeting, February, 1898.)

2.09.21. Humboldt-Pocahontas. This vein is one of several which have been discovered near Rosita. It is a fissure vein which cut in its upper portion a mass of andesite and andesite breccia, but which at the fourth level, as shown in Fig. 107, forked into several feeders. Above this point it was one of the most regular and clear-cut fissures ever mined in the West. The ore was tetrahedrite in a gangue of barite and

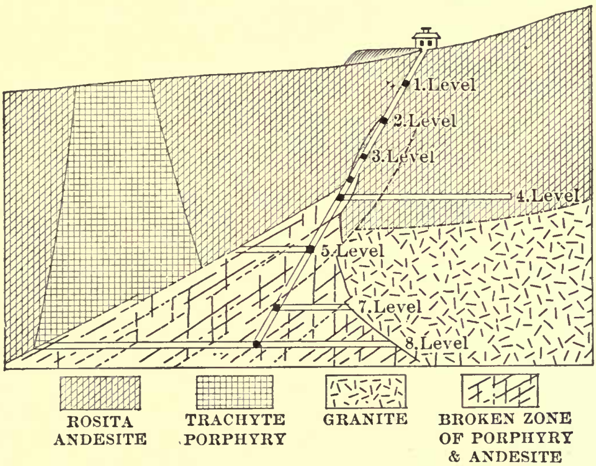

FIG. 107.—*Cross section of the Humboldt-Pocahontas vein, near Rosita, Colo. After S. F. Emmons, XVII. Ann. Rep. U. S. Geol. Survey, Part II., p.* 427

decomposed wall rock, with which were associated chalcopyrite, pyrite, galena and antimonial sulphides of silver. In the lower levels the vein broke up into several small fissures and troubles, such that operations ceased.

2.09.22. Silver Cliff. At Silver Cliff there is a large flow of porous rhyolite just north of the town, which was early found to be impregnated along small fissures, with chloride of silver and black manganese minerals. For a time free-milling ore was quarried. Later a deep shaft was sunk in the Geyser mine, which at 1,850 feet found the faulted contact with the

Archean gneiss and 200 out into the rhyolitic tuff a cross-cut encountered a vein that proved productive of rich silver ore. This deep shaft afforded some interesting samples of deep and vadose waters, which have been analyzed by W. H. Hillebrand, as given in Emmons' paper (see above p. 31). The rhyolite also afforded in the surface workings some extraordinarily large spherulites which have been described by Cross. Assays of fresh and unaltered samples of the country rocks, which were made for S. F. Emmons, indicated the presence of silver in five out of nine, viz.: trachyte, 0.007 oz. per ton; Fairview diorite, 0.01 oz. per ton; rhyolite, 0.402 oz. per ton; red granite, 0.005 oz. per ton; black granite, 0.025 oz. per ton; bisilicates of the granite, 0.04 oz. silver per ton, and 0.045 per cent. lead.[1]

2.09.24. Teller County. The region of Cripple Creek is the only one of serious importance in this county, but the remarkable developments of the last few years have placed it in a very important position. The productive mines are situated in the foothills of Pike's Peak, about ten miles west from the peak itself. The summit is clearly visible from many of them, as are also the peaks of the Sangre de Cristo range, many miles to the south. The town of Cripple Creek lies in the valley of the small stream of the same name, which is a branch of Oil Creek, itself a tributary of the Arkansas River. The valley is an open and moderately broad upland, but the approaching depressions are narrow defiles, that have presented great difficulties to railways. The general country rock of the region is the red granite of Pike's Peak. This contains masses of still older mica schists, presumably caught up in its intrusion. The

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[1] R. N. Clark, "Humboldt-Pocahontas Vein," *Trans. Amer. Inst. Min. Eng.*, VII., 21. "Silver Cliff, Colorado," *Eng. and Min. Jour.*, November 2, 1878, p. 314. W. Cross, "Geology of the Rosita Hills," *Proc. Colo. Sci. Soc.*, 1890, p. 269. Rec. *Seventeenth Ann. Rep. U. S. Geol. Survey*, Part II., 269. Rec. S. F. Emmons, "The Genesis of Certain Ore Deposits," *Trans. Amer. Inst. Min. Eng.*, XV., 146. *Tenth Census*, Vol. XIII., p. 80. "The Mines of Custer County, Colo.," *Seventeenth Ann. Rep. U. S. Geol. Survey*, Part II., 411. Rec. L. C. Graybill, "On the Peculiar Features of the Bassick Mine," *Trans. Amer. Inst. Min. Eng.*, XI., p. 110; *Eng. and Min. Jour.*, October 28, 1882, p. 226. Rec. O. Loew and A. R. Conkling, "Rosita and Vicinity," *Wheeler's Survey*, 1876, p. 48. See also Stevenson in the Report for 1873.

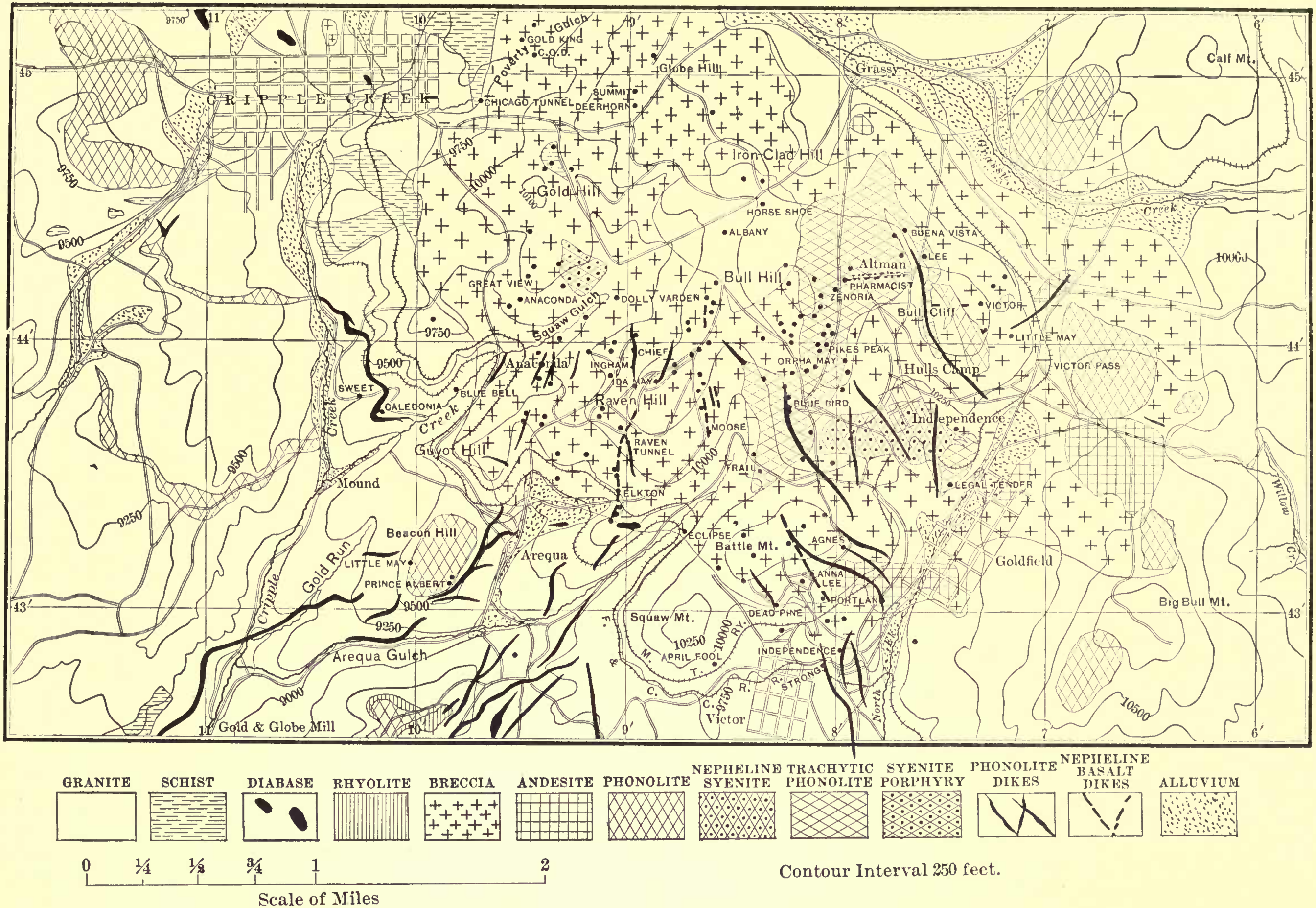


Fig. 108.—*Geological map of Cripple Creek, Colorado, redrawn in line-work after the special (colored) map of Cripple Creek in the Pike's Peak Folio, U. S. Geological Survey, Geology by Cross and Matthews. The mines are indicated by round dots*

schists are pre-Cambrian, as are the granites and certain diabase dikes that occur in the streets of Cripple Creek and on Mineral Hill, but that are of no importance in connection with the ores. At the close of the Eocene or in the Miocene times a small volcanic center broke out in the granite hills now lying east of the town, and perhaps elsewhere. It was marked at first by explosive activity that besprinkled the neighboring region with a breccia made up of fragments of granite and andesite. Later came eruptions of phonolite of one or two varieties that form many dikes associated with the ore bodies. Some minor outcrops of nepheline-syenite and syenite-porphyry are possibly deep-seated and coarsely crystalline representatives of the phonolite magma. Explosive eruptions of this phase seem also to have contributed some phonolite to later breccias. Last of all, dikes of several kinds of basalt, including nepheline basalt, feldspar basalt, and limburgite, closed the eruptive phenomena. The breccias, after their formation, became in many cases silicified, so as to produce a very firm rock, and as a rule are so altered that their original rock is to be recognized more by its physical texture than its mineralogy. In areal distribution the breccias are the most prominent rocks near the mines; next follows the granite, while through both are intruded the dikes of phonolite and basalt.

The ores are almost entirely productive of gold, for although some little silver often occurs with it, and although lead, zinc and copper minerals are met in one or two mines, the former is of slight economic account and the latter are rareties. Iron pyrites is very widespread, but it is not a great carrier of gold. The real source is the telluride of gold, calaverite, from which more or less of the native metal has been derived in the uppor parts of the veins by oxidation. The gangue minerals are quartz, fluorite and decomposed country rock. When the latter is granite, it has lost its mica and often its quartz, leaving a cellular rock more or less impregnated with fresh or decomposed telluride. The wash of these veins has yielded some placer diggings, especially on Mineral Hill.

The ore deposits are true veins that have been formed along lines of displacement whose amount is, as a rule, slight. The fissures themselves are often insignificant in appearance, but the impregnations of the wall rock with ore to a width of from

FIG. 109.—*View of Cripple Creek, Colorado, from Mineral Hill; Gold Hill in the background. From a photograph by J. F. Kemp, July,* 1895.

FIG. 110.—*View of Battle Mountain, Victor, Colorado. From a window in Victor. The Portland group of mines is on the left in the background. The Independence mine is on the extreme right. From a photograph by J. F. Kemp, July,* 1895.

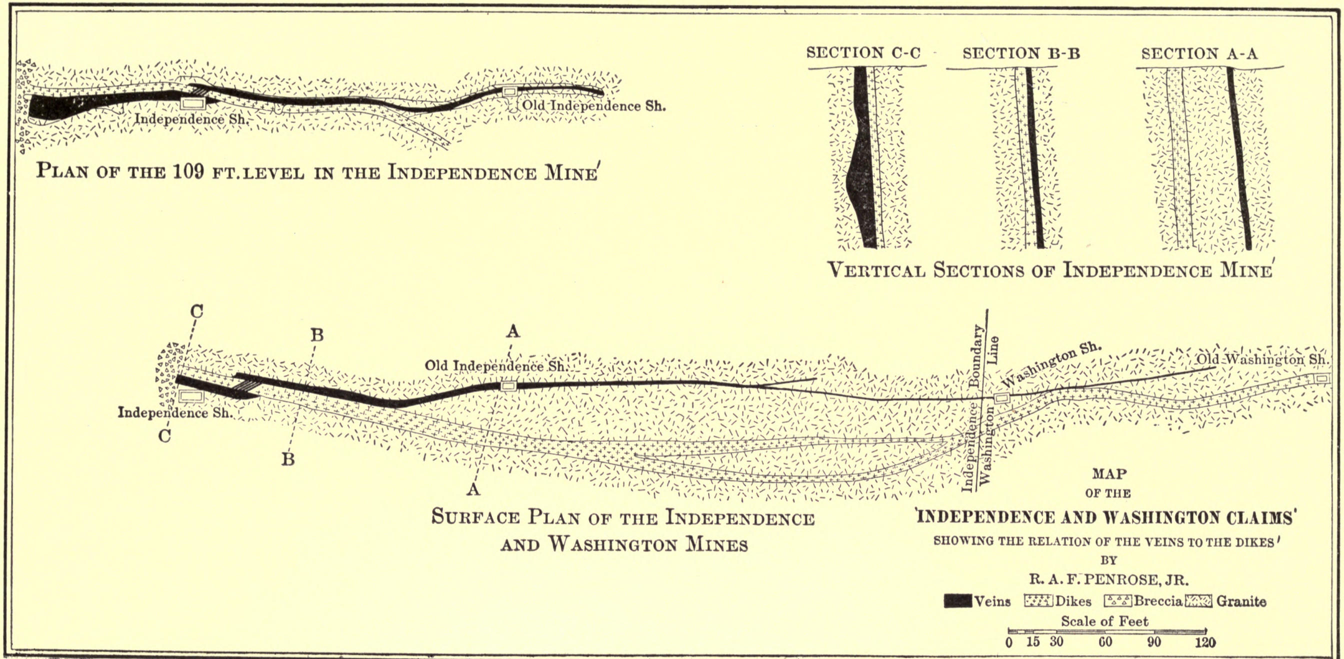
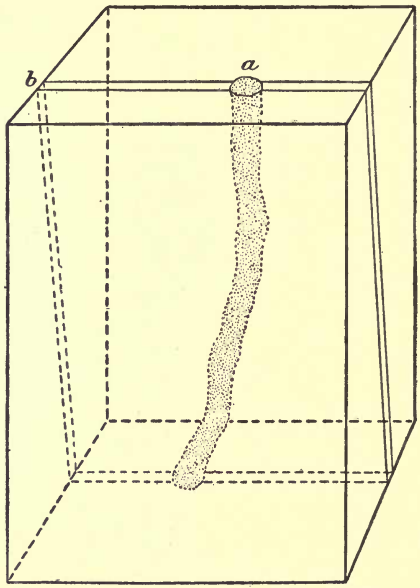


FIG. 111.—*From the XVI. Ann. Rep. U. S. Geol. Survey, Part II., p. 200.*

one to several feet afford very rich and valuable ore bodies. The fissures frequently follow the courses of dikes, but are clearly later than the latter because they cross them, leave them, return to them, and behave in a more or less independent way. Yet the presence of dikes is in a measure a favorable thing, because the dike itself has filled a fissure, and because it, being an offshoot from a larger body of heated rock, and with lines of weakness along the contacts with its walls, doubtless has often exercised a directing influence on solutions. The



[FIG. 112.—*Stereogram of the Annie Lee ore-shoot, Victor, Colo. After R. A. F. Penrose, XVI. Ann. Rep. U. S. Geol. Survey, Part II., p. 206.*

accompanying map, from the timely and valuable report of Cross and Penrose, which, with the Pike's Peak Atlas Sheet of the U. S. Geological Survey, should be consulted by all who are especially interested in the region, will give the main features of the geology. The veins are not large, but they have yielded in the aggregate great amounts of high grade ore. As elsewhere the ores follow shoots in the veins, and the shoots approximate the vertical. Small cross fractures have often exercised an influence upon them. The veins themselves are also often in a series of small parallel fissures, rather than in a single one, and impregnate the intervening walls. Ore has been found in blind veins, outside the main lines of deposition, so that frequent cross-cuts are desirable to make sure of the country. The most productive section is on Battle Mountain, just above Victor. The Portland group and the famous Independence, of which a cut is here reproduced from Penrose's report, are in this hill. Fig. 112 illustrates the Annie Lee ore-body, a very curious one that forms a chimney in a basaltic dike. Bull Mountain, with its spur, Bull Cliff, contains a considerable number around the town of Altman. The fissure on which the Buena Vista, Lee and Victor mines are located is one of the most extended in the district. Raven Hill, Gold Hill, Globe Hill and various minor spurs have also yielded important bodies of ore.[1]

It has been customary to send the ores up to $20 to the ton to the stamp mills, for which treatment, however, they are not well adapted, as the losses are heavy. Ores from $20—$40 go to the cyanide mills, and above $40 to the smelters.

2.09.22. Gilpin County has already been mentioned under "Copper" (2.04.08). The general geology of the veins is much like that of Clear Creek, although the ores are quite different.

[1] W. P. Blake, "The Gold of Cripple Creek," *Eng. and Min. Jour.*, January 13, 1894. Whitman Cross, Pike's Peak Atlas Folio of the U. S. Geol. Survey; to be obtained by sending 25 cents to the Director of the Survey, Washington, D. C. Rec. Whitman Cross and R. A. F. Penrose, Jr., "Geology and Mining Industries of the Cripple Creek District, Colorado," *Sixteenth Ann. Rep. of the Director of the U. S. Geol. Survey*, 1894–95. Rec. W. F. Hillebrand, "Chemical Composition of Calaverite from Cripple Creek," in *Cross and Penrose's Report*, p. 133. W. H. Hobbs, "Goldschmidtite, a New Mineral," *Amer. Jour. Sci.*, May, 1899, 357. F. C Knight, "On the Composition of the Cripple Creek Telluride," *Proc. Colo. Sci. Joc.*, October 1, 1894. H. L. McCarn, "Notes on the Geology of the Gold Field of Cripple Creek, Colo.," *Science*, January 19, 1894, p. 31. R. Pearce, "The Mode of Occurrence of Gold in the Cripple Creek District," *Proc. Colo. Sci. Soc.*, January 8, 1894; *Eng. and Min. Jour.*, March 24, 1894. "Further Notes on Cripple Creek Ores," *Proc. Colo. Sci. Soc.*, April 5, 1894. S. L. Penfield, "On Calaverite Crystals from Cripple Creek," *Cross and Penrose's Report*, p. 135. E. Skewes and H. J. Eder, "The Victor Mine, Cripple Creek, Colo.," *Eng. and Min. Jour.*, August 19, 1893, p. 193. E. Skewes, "The Ore Shoots of Cripple Creek," *Trans. Amer. Inst. Min. Eng.*, September, 1896. G. H. Stone, "The Granitic Breccias of the Cripple Creek Region," *Amer. Jour. Sci.*, January, 1898, 21.

R. Pearce has shown the existence of bismuth in the ore, and gives reasons for believing that the gold is in combination with it. Clear Creek County contains veins on a great series of jointing planes in gneiss (granite), and in large part replacements of the wall. Others are replacements of porphyry dikes or of pegmatite segregations. The ores are chiefly galena, tetrahedrite, zincblende, and pyrite, and the gangue is the wall rock. The curious decrease of value in depth of a series of parallel veins in Mount Marshall was earlier referred to (1.05.05). Georgetown is the principal town and mining center. Others of importance are Idaho Springs and Silver Plume.[1]

2.09.23. Boulder County contains veins along joints or faulting planes in gneiss, or granite, or associated with porphyry dikes, or pegmatite segregations, and carrying tellurides of the precious metals more or less as impregnations of the country rock. The prevalent country rock is called by Emmons a granite-gneiss. Van Diest distinguishes four successive terranes of massive and schistose rocks along three principal axes and two side ones, and states that the mines are on the sides of the folds. The country is very generally pierced by porphyry dikes, with which the ore bodies are often associated. A large number of species of telluride minerals have been determined from the region, especially by the late Dr. Genth, of Philadelphia. The mines afford very rich ores, somewhat irregularly distributed.[2]

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[1] S. F. Emmons, *Tenth Census*, Vol. XIII., p. 70. Rec. F. M. Endlich, *Hayden's Survey*, 1873, p. 293; 1876, p. 117. P. Fraser, *Hayden's Survey*, 1869, p. 101. J. D. Hague, *Fortieth Parallel Survey*, Vol. III., p. 589. Rec. R. Pearce, *Proc. Colo. Sci. Soc.*, Vol. III., pp. 71, 210. "The Association of Gold with Other Metals in the West," *Trans. Amer. Inst. Min. Eng.*, XVIII., 447, 1890. Forbes Rickard, "Notes on the Vein Formation and Mining of Gilpin County, Colo.," *Trans. Amer. Inst. Min. Eng.*, February, 1898. J. J. Stevenson, *Wheeler's Survey*, Vol. III., p. 351. F. L. Vinton, "The Georgetown (Colo.) Mines," *Eng. and Min. Jour.*, September 13, 1879, p. 184.

[2] Bergrath Burkart, "Ueber das Vorkommon Verschiedener Tellur-Minerale in den Vereinigten Staaten von Nordamerika," *Neues Jahrbuch*, 1873, 476; April, 492, 1874, 30. Whitman Cross, "A List of Specially Noteworthy Minerals of Colorado," *Proc. Colo. Sci. Soc.*, I., 134, 1884; cites Tellurium, Melonite, Altaite, Hessite, Coloradoite, Sylvanite, Tellurite. A. Eilers, "A New Occurrence of the Telluride of Gold and Silver," *Trans. Amer. Inst Min. Eng.*, I., 316, 1872. Red Cloud Mine. S. F. Emmons,

2.09.25. The resources of the remaining counties of Colorado are chiefly in coal.

"Sketch of Boulder County," *Tenth Census*, Vol. XIII., p. 64, 1885. F. M Endlich, "Tellurium Ores of Colorado," *Eng. and Min. Jour.*, XVIII, 133, 1874. F. M. Endlich, "Minerals of Colorado Territory," *Hayden's Survey*, 1873, 352. J. B. Farish, "Interesting Vein Phenomena in Boulder County, Colo." (Golden Age Mine), *Trans. Amer. Inst. Min. Eng.*, XIX., 541, 1890, "A Boulder County Mine" (*The Golden Age and Sentinel*), *Proc. Colo. Sci. Soc.*, III., 316, 1890 (same as above). F. A. Genth, "On Tellurides from Red Cloud and Uncle Sam Lodes," *Proc. Amer. Phil. Soc.*, XIV., 225, 1874. "Tellurides from Keystone, Mountain Lion, and John Jay Mines," *Idem,* XVII., 115, 1877. J. K. Hallowell, "Boulder County as It Is," Denver, 1882. Worthless. N. P. Hill, "Announces Tellurides at Red Cloud Mine," *Amer. Jour. Sci.*, V., 387, May, 1873. W. F. Hillebrand, "Melonite Forlorn Hope Mine, Boulder County," *Proc. Colo. Sci. Soc.*, I., 123, 1884. E. P. Jennings, "Analyses of Some Tellurium Minerals" (Native Tellurium from John Jay Mine; Sylvanite, Smuggler Mine), *Trans. Amer. Inst. Min. Eng.*, VI., 506, 1877. A. Lakes, "On Boulder County" Geology of Colorado Ore Deposits, c. 1888. A. R. Marvin, "Metamorphic Crystalline Rocks of the Front Range." *Hayden's Survey*, 1873. "On Boulder County," pp. 144, 147–152, 685. Map. C. L. Palmer, "Eruptive Rocks of Boulder County, Colorado," *Proc. Colo. Sci. Soc.*, III., 230, 1889. C. L. Palmer and Henry Fulton, "The Quartz Porphyry of Flagstaff Hill, Boulder, Colorado," *Idem,* 351, 1890. R. Pearce, "Remarks on Gold Ores of Rocky Mountains," R. Pearce, In Discussion of Paper by P. H. Van Diest, *Proc. Colo. Sci. Soc.*, IV., 349, 1893. B. Silliman, "Mineralogical Notes; Tellurium Ores in Colorado," *Amer. Jour. Sci.*, July, 1874, 25–33. Reprinted in *Hayden's Report*, 1873, 688. J. Alden Smith, quoted by P. H. Van Diest as mentioning Boulder County Mines in his Biennial Report for 1880. P. H. Van Diest, "Notes on Boulder County Veins," *Proc. Colo. Sci. Soc.*, II., 50, 1886. "The Mineral Resources of Boulder County, Colorado," *Biennial Rep. State School of Mines*, 1886, 25. P. H. Van Diest, "Evidence Bearing on the Formation of Ore Deposits by Lateral Secretion; The John Jay Mine at Boulder County, Colorado," *Proc. Colo. Sci. Soc.*, IV., 340, 18.

CHAPTER X.

SILVER AND GOLD, CONTINUED.—ROCKY MOUNTAIN REGION, WYOMING, THE BLACK HILLS, MONTANA, AND IDAHO.

WYOMING.

2.10.01. *Geology.*—The southeastern part of Wyoming is in the region of the Great Plains, the southwestern in the Colorado Plateau. The Rocky Mountains shade out more or less on leaving Colorado, but are again strongly developed in northern Wyoming. The northwestern portion contains the great volcanic district of the National Park, and the northeastern, a part of the Black Hills. The Cretaceous and Tertiary strata chiefly form the plains and plateaus. Granite and gneiss constitute the central portion of some of the greater ranges. Paleozoic rocks are very subordinate. The resources in precious metals so far as yet developed are small, consisting chiefly of gold in quartz veins in the gneisses, schists and granites of Sweetwater County. The great mineral wealth of the State is in coal. The iron mines have already been mentioned (2.03.09), and the copper (2.04.27).[1]

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[1] H. M. Chance, "Resources of the Black Hills and Big Horn Country, Wyoming," *Trans. Amer. Inst. Min. Eng.*, XIX., p. 49. T. B. Comstock, "On the Geology of Western Wyoming," *Amer. Jour. Sci.*, iii., VI., 426. S. F. Emmons, *Tenth Census*, Vol. XIII., p. 86. F. M. Endlich, "The Sweetwater District," *Hayden's Survey*, 1877, p. 5; "Wind River Range Gold Washings," p. 64. A. Hague, "Geological History of the Yellowstone National Park," *Trans. Amer. Inst. Min. Eng.*, XVI., 783, and Yellowstone Park Folio, *U. S. Geol. Surv.* See also F. V. Hayden, *Amer. Jour. Sci.*, iii., III., 105, 161. F. V. Hayden, *Rep. for* 1870–72. p. 13; also *Amer. Jour. Sci.*, ii., XXXI., 229. A. C. Peale, "Report on the Geology of the Green River District." *Hayden's Survey*, 1877, p. 511. Raymond's *Statistics West of the Rocky Mountains.* W. C. Knight, *Bull. 14, Wyo. Exp't Station*, October, 1893.

SOUTH DAKOTA.—THE BLACK HILLS.

2.10.02. *Geology.*—The Black Hills lie mostly in South Dakota. They consist of a somewhat elliptical core of granite and metamorphic rocks, with a north and south axis, and on these are laid down successive strata of Cambrian, Carboniferous, Jura-Trias, and Cretaceous rocks. There are some igneous intrusions. The principal product of the Black Hills is gold. The lead-silver deposits have already been described (2.08.18), and the tin, etc., will be mentioned later.[1]

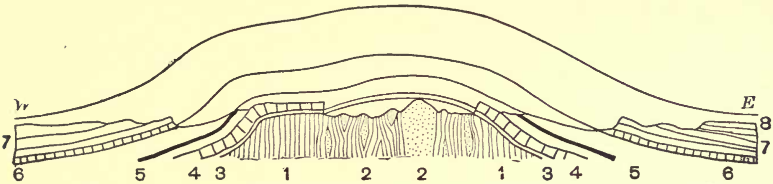

FIG. 113.—*Geological section of the Black Hills. After Henry Newton Report on the Black Hills, p.* 206.

1. Schists. 2. Granite. 3. Potsdam sandstone. 4. Carboniferous. 5, 6, Jura-Trias. 7. Cretaceous.

2.10.03. The gold occurs in stream placers of Quarternary and recent age, and of no great importance; in supposed, old beach or channel placers in the Cambrian (so-called Potsdam), conglomerates, the "cement" deposits; in impregnations of the

[1] F. R. Carpenter, "Ore Deposits in the Black Hills," *Trans. Amer. Inst. Min. Eng.*, XVII., 570. *Prelim. Rep. on the Geol. of the Black Hills*, Rapid City, So. Dakota, 1888. W. O. Crosby, "Geology of the Black Hills," *Bost. Soc. Nat. Hist.*, XXIII., p. 89. P. Frazer, "Notes on the Northern Black Hills of South Dakota," *Trans. Amer. Inst. Min. Eng.*, XXVII., 204, 1897. John D. Irving, "A Contribution to the Geology and Ore Deposits of the Northern Black Hills, South Dakota," *Annals N. Y. Acad. Sciences*, XII., Part II., 1899. Rec. Newton and Jenney, *Report on the Black Hills*, Washington, 1880. F. C. Smith, "The Occurrence and Behavior of Tellurium in Gold Ores, more particularly with Reference to the Potsdam Ores of the Black Hills," *Trans. Amer. Inst. Min. Eng.*, XXVI., 485, 1103, 1896. "The Potsdam Gold Ores of the Black Hills of South Dakota," *Idem*, XXVII., 404, 428, 1897. Rec. C. R. Van Hise, "The Pre-Cambrian Rocks of the Black Hills," *Bull. Geol. Soc. Amer.*, I., 203–244. N. H. Winchell, "Report on the Black Hills," *Rep. Chief. of U. S. Engineers*, 1874, Part II., p. 630. The U. S. Geological Survey is preparing a report on the Black Hills, S. F. Emmons and T. A. Jaggar being in charge of the work.

Cambrian lime-shales, with siliceous gold ores in the neighborhood of intruded dikes and sheets of phonolite; in crevices in the heavy Carboniferous limestone, now filled with siliceous gold ores; and in broad zones or fahlbands of Algonkian slaty and mica schists, carrying auriferous pyrites. The above are

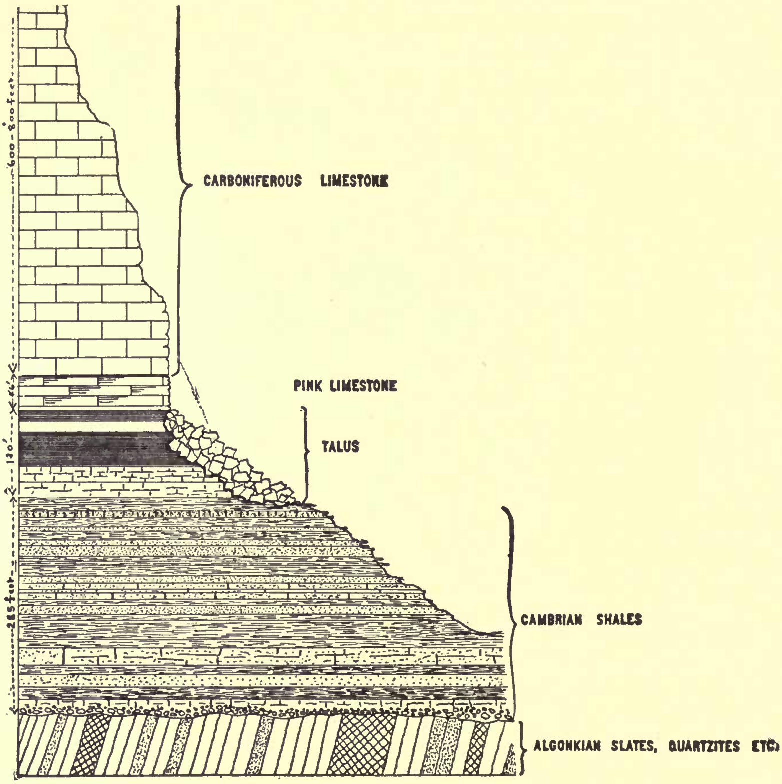

FIG. 114.—*Geological section of the strata in the Northern Black Hills, S. D. After John D. Irving, Annals of the New York Academy of Sciences, XII., Part II.,* 1899.

found in the northern Hills. In the central portion pegmatites have recently proved gold-bearing. The Quarternary and recent gravels were effective in attracting prospectors in the early days of settlement. They are scarcely worked to-day. The ancient beach gravels are still followed beneath the caps of porphyry in some small mines in Deadwood Gulch. As described by W. B. Devereux in 1882, the gravels were regarded as having derived their gold by the beating of the waves of the Cambrian Ocean against the auriferous schists described below, but later work has made it probable that they are impregnations like the Potsdam siliceous ores. The pay gravel now runs as a shoot under the later lava sheets. The impregnations of the Cambrian, locally called Potsdam, lime-shales with tellu-

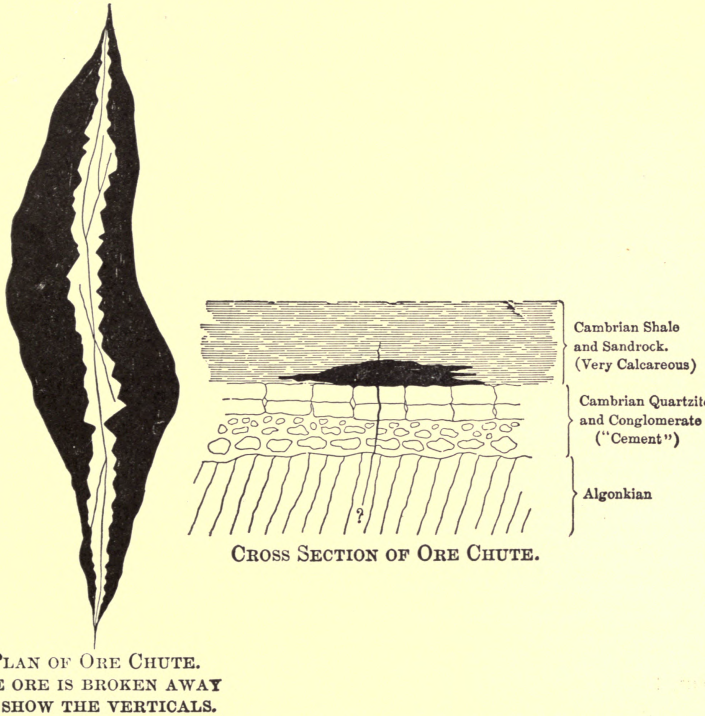

FIG. 115.—*Plan and cross-section of a Cambrian, siliceous gold-ore deposit in the Black Hills, S. D. After John D. Irving, Annals N. Y. Academy of Sciences, XII., Part II.*, 1899.

rides and pyrites, constitute a form of ore body that has been of rather recent development, but that is now the leading producer. The mines, as indeed nearly all the gold developments, are in the northern Hills, and are especially abundant around Terry Peak. The Cambrian lies flat, and is penetrated very abundantly by dikes and sheets of trachyte and phonolite. The igneous rocks have themselves sometimes been impregnated, when they lie near an ore body. Associated with the ore shoots and usually bisecting that portion of the floor that lies beneath them are found cracks, called "verticals," that run down to unknown depths, but that are not accompanied by any notable, if, indeed, by any appreciable faulting. The verticals have directed, or have served to introduce the solutions, which have then spread laterally into beds of lime-shales and have replaced

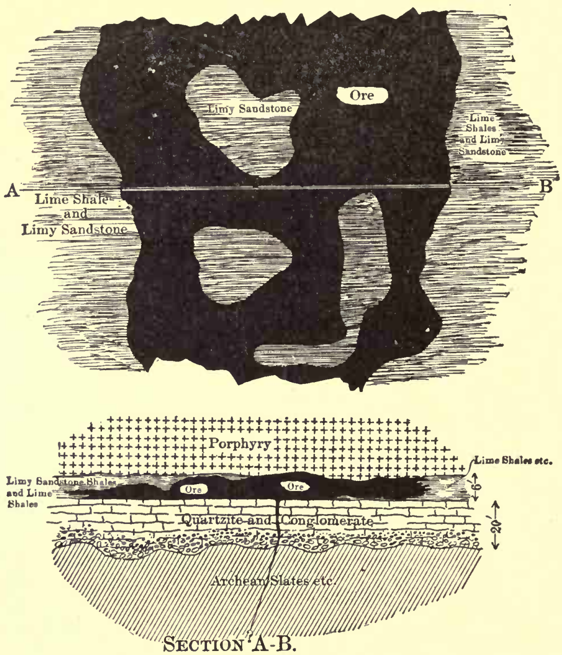

FIG. 116.—*Plan and section, Mail and Express Mine, to illustrate the siliceous gold ores of the Black Hills, S. D. After John D. Irving, Annals N. Y. Academy of Sciences, XII., Part II.,* 1899.

the calcareous portion of them with ore and silica. Those beds of lime-shales have proved most favorable which rest upon a floor of hard quartzite, and this association is so constant that the miners, in regions of phonolite sheets, sink to the quartzite, and then explore for ore. The ore runs in long shoots on the strike of the verticals.

The ores contain as gangue quartz, fluorite and the unreplaced residue of the lime-shales. The metallic minerals are

FIG. 117.—*Green Mountain. Black Hills, S.D.; a laccolite of phonolite, with the mines of siliceous ore on the so-called "upper contact" around its foot. Photographed by John D. Irving,* 1898.

FIG. 118.—*View of the Union Mine, in siliceous ore, near Terry. in the Black Hills, S. D. Photographed by John D. Irving,* 1898.

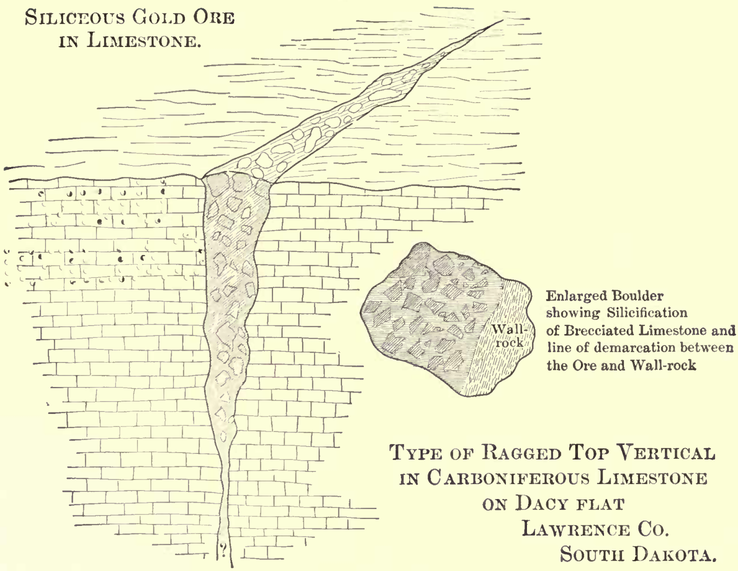

FIG. 120.—*Perspective cross-section of siliceous gold ore in Carboniferous limestone, Dacy Flat, Black Hills. After John D. Irving, Annals N. Y. Academy of Sciences, XII., Part II.,* 1899.

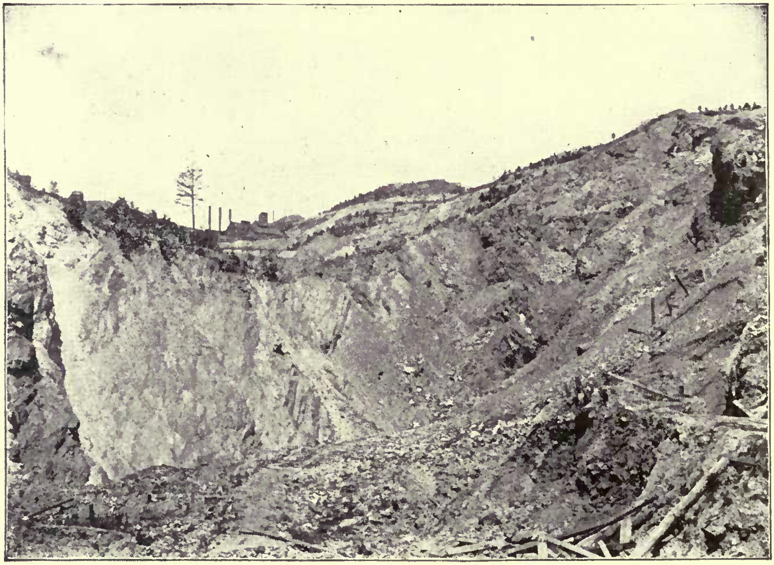

FIG. 121.—*View of the Golden Star open cut, Lead City, S. D. From a photograph by J. F. Kemp,* 1896.

pyrite and a supposed telluride of gold, whose presence is indicated by analysis, but which has not been actually seen. Thorium has also been detected by F. C. Smith. There are two varieties, red, or oxidized, ores, and blue, or unoxidized. They are collectively known as siliceous or Potsdam ores. The presence of tellurium, of fluorite, and of phonolite is highly suggestive of Cripple Creek, Colo., and of several newer districts in Montana. At times the vertical may lie alongside of an intruded dike as shown in Fig. 119, and then the ore follows the dike and may impregnate it more or less.

The intruded igneous rocks have seldom been able to pierce the heavy cap of Carboniferous limestone, but the laccolites

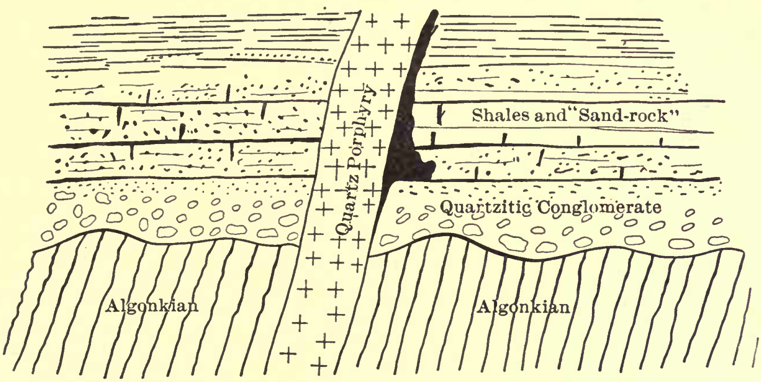

FIG. 119.—*Cross-section of a siliceous gold-ore body lying next to a prophyry dike, Black Hills, S. D. After John D. Irving, Annals N. Y. Academy of Sbiences, XII., Part II.,* 1899.

have served to dome it up, and to fissure it more or less. In the vicinity of the Ragged Top laccolite, on Dacy Flat, these fissures or crevices have been the seat of the deposition of rich, siliceous ores. The ores have replaced and cemented into a hard aggregate, the brecciated limestone that filled the fissure before their introduction. (See Fig. 120.)

The older, and formerly the chief source of gold in the Black Hills, is in the great zone or fahlband of schists near Lead City, which carries little lenses and veinlets of quartz, with auriferous pyrites. The pay is thought to lie in the schists. The ores are free-milling, and are controlled by the Homestake Company. They are situated in and near Lead City, in hills which form steep divides between the narrow gulches. The schists strike about N. 20 W., and dip 60 E., and in the Golden Star are stoped out in a cross-section over 450 feet. Porphyry dikes cut the schists, and have spread laterally, so as in their present eroded condition to appear like surface caps of lava. They may have exercised an important influence in the enrichment of the schists, but it seems certain that gold was present in them in the Cambrian times, because the Cambrian sediments when carefully panned almost always afford some trace of the yellow metal. The special local enrichment of the schists may have been influenced by the porphyry. The ores are low grade, running \$3—\$4 or less. The Old Abe, Golden Star, Deadwood-Terra and Father de Smet are the chief locations.[1]

In addition to the types of ore body described above, there are found throughout the schists of the Hills occasional quartz veins, of the old so-called "segregated" variety, that have yielded a little gold. Recently pegmatites near Harney Peak have proved productive, affording ores similar in their geology to those described by Hussak from Ouro Preto, Brazil,[2] and to some in the Transvaal.

MONTANA.

2.10.04. *Geology.*—The eastern part of the State belongs to the region of the Great Plains, which is, however, in portions greatly scarred by erosion, forming the so-called Bad Lands. The approaches to the Rocky Mountains are not abrupt and sudden as in Colorado, but are marked by numbers of outlying ranges of both eruptive and sedimentary rocks. The chain of the Rockies takes a northwesterly trend in Wyoming, and so continues across Montana. It is rather the prolongation of the Wasatch than of the Colorado Mountains, whose strike is for the Black Hills. The character of the ranges is also very dif-

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[1] A. J. Bowie, "Notes on Gold Mill Construction," *Trans. Amer. Inst. Min. Eng.*, X., 87, 1881. W. B. Devereux, "The Occurrence of Gold in the Potsdam Formation," *Idem*, X., 465; *Eng. and Min. Jour.*, December 23, 1882, p. 334. H. O. Hoffman, "Gold Mining in the Black Hills," *Trans. Amer. Inst. Min. Eng.*, XVII., 498; also in preliminary report cited under Carpenter, under Geology. See, in addition, references on page 309.

[2] E. Hussak. "Der goldführende, kiesige Quarzlagergang von Passagem in Minas Geræs, Brasilien," *Zeits. für prakt. Geologie*, October, 1898, 345.

ferent. They are less elevated, and have broad and well-watered valleys between, that admit of considerable agriculture. Geologically the country is in marked contrast with Colorado. While in the latter the lower Paleozoic is feebly developed, in Montana it is important. Special interest attaches to the Lower Cambrian or perhaps pre-Cambrian quartzites and associated sediments that are present in great thickness in the northwestern part of the State, and along the Idaho line. Fossils have recently been reported by C. D. Walcott from a very low horizon. On the east of the Continental Divide the gneisses and schists of the Archean are succeeded by metamorphosed sediments of the Algonkian, involving 7,000 feet or more, and known as the Cherry Creek formation of the U. S. Geologists. Unconformably upon this lies the Belt formation, of 6,000 to 10,000 feet of sediments, which are doubtfully referred to the Algonkian. Still above come the true Cambrian, 1,000 to 1,500 feet; Siluro-Devonian (of which the latter alone is identified by fossils), 200 to 600 feet; Carboniferous limestones, 800 to 1,000 feet, followed by a quartzite and shale series of 200 to 600 feet; Jura-Trias up to 500 feet; and then some thousands of feet of Cretaceous and Tertiary. Great batholites of granite, in part at least post-Carboniferous, have been intruded as set forth earlier under Butte, 2.04.05. They have basic phases on the margins, and locally, within the masses, as at Butte. The above grouping modifies somewhat the section given in earlier editions of this work, and has resulted from the more recent work of W. H. Weed and A. C. Peale of the U. S. Geological Survey, whose folios should be consulted for local details so far as available. East of the main chain of the Rockies there are peculiar isolated groups of mountains of a laccolite character, such as the Highwoods, the Judith, and the Little Rockies. They rise like huge blisters of sedimentaries, forced up by lenticular sheets of intrusives, and pierced by dikes in vast numbers. They are rocks prevailingly rich in soda, and present many rare and interesting types and some striking parallels with the Black Hills.[1]

[1] S. Calvin, "Iron Butte: Some Preliminary Notes," *Amer. Geol.*, IV., 95. G. E. Culver, "A Little Known Region of Northwestern Montana," *Wis. Acad. of Sci.*, December 30, 1891. W. M. Davis, "The Relation of the Coal of Montana to the Older Rocks," *Tenth Census*, Vol. XV., p. 697. Rec.

2.10.05. Montana took the lead of all the States in 1887 in the production of silver, was second in gold, and first in the total production of the two. It is now second to Colorado in silver, and fourth on the list in gold, but in copper it is first. In its mineral wealth it yields to no other State in the Union. The mining districts are mostly in the western central and western portions. Developments have progressed so rapidly that all the desirable data are not available.

2.10.06. Madison County. The chief product is gold. Near Virginia City the gold-bearing quartz forms veins in schists; in the northeastern part of the county the veins occur in gran-

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J. Eccles, "On the Mode of Occurrence of Some of the Volcanic Rocks of Montana," *Quar. Jour. Geol. Sci.*, XXXVII., 399. G. H. Eldridge, "Montana Coal Fields," *Tenth Census*, Vol. XV., p. 739. S. F. Emmons, *Tenth Census*, Vol. XIII., 97. Rec. *Hayden's Survey, Ann. Rep.*, 1871–72. J. F. Kemp, "On Tellurides in Montana," see *The Mineral Industry*, VI., 312, 1898. W. S. Keyes, in Brown's first report on mineral resources, etc., last part, *Amer. Jour. Sci.*, II., 46, 431. Rec. W. Lindgren, "Eruptive Rocks," *Tenth Census*, Vol. XV., p. 719, forming Appendix B of Davis's first paper. See also *Proc. Cal. Acad. Sci.*, Second Series, Vol. III., p. 39. J. S. Newberry, "Notes on the Surface Geology of the Country Bordering on the Northern Pacific Railroad," *Annals N. Y. Acad. Sci.*, Vol. III., 242; *Amer. Jour. Sci.*, iii., XXX., 337. "The Great Falls Coal Fields," in Geol. Notes, *School of Mines Quarterly*, VIII., 327. A. C. Peale, Three Forks Folio, *U. S. Geol. Survey*, 1896. Rec. F. Rutley, "Microscopic Character of the Vitreous Rocks of Montana," *Quar. Jour. Geol. Sci.*, XXXVII., 391. See Eccles, above. C. D. Walcott, "Pre-Cambrian Fossiliferous Formations," *Bull. Geol. Soc. Amer.*, X., 199, 1899. Rec. W. H. Weed, "The Cinnabar and Bozeman Coal Fields of Montana," *Idem*, II., 349–364 *Eng. and Min. Jour.*, May 14 and 21, 1892. "Montana Coal Fields," *Bull. Geol. Soc. Amer.*, III., 301–330. Livingston Folio, *U. S. Geol. Survey.* Butte Special Folio, *Idem;* Little Belt Folio, *Idem;* Bull Folio (in preparation). Weed and Pirsson, "Highwood Mountains of Montana," *Bull. Geol. Soc. Amer.*, VI., 389, 1895. "The Bearpaw Mountains of Montana, *Amer. Jour. Sci.*, May, 1896, 283; June, p. 301; September, p. 136; October, p. 188. "Geology of the Little Rocky Mountains," *Jour. Geol.*, IV., 399. "The Castle Mountain Mining District," *Bulletin 139, U. S. Geol. Survey*, 1896. "The Judith Mountains," *Ann. Rep. Dir. U. S. Geol. Survey*, XVIII., 1899, Part III., 437. All these are Rec. R. P. Whitfield, "List of Fossils from Central Montana," *Tenth Census*, Vol. XV., p. 712; Appendix A to Davis's paper. J. E. Wolff, "Notes on the Petrography of the Crazy Mountains," etc., *Northern Trans. Survey.* "Geology of the Crazy Mountains," *Bull. Geol. Soc. Amer.*, III., 445. H. Wood, "Flathead Coal Basin," *Eng. and Min. Jour.*, July 16, 1892, p. 57. H. R. Wood, "Mineral Zones in Montana," *Idem*, September 24, 1892, p. 292.

ite; at Rochester the gold is associated with galena; at Sheridan tetrahedrite and chalcopyrite are found in quartz veins and are rich in gold and silver.[1] An interesting vein with tellurides has been discovered at the Mayflower mine in the Tobacco Root Mountains.[2] It is a fault fissure nearly parallel to the bedding of upturned Cambrian limestones. The ore has replaced the limestone and is largely oxidized. Placers were of extreme importance in this county in early days, and are still somewhat worked. Alder Gulch, near Virginia City, proved extraordinarily rich.

2.10.07. Beaverhead County. Near Bannack City quartz veins with auriferous pyrite on the contact between the limestone and so-called granite. At Glendale, in the northern part of the county, are the Hecla mines, referred to under "Lead-silver" (Example 32). Auriferous quartz veins are reported farther north.[3]

2.10.08. Jefferson County. There are many varieties of ore bodies in this county, but the commonest type is similar to that at Butte, *i.e.*, veins in granite along fissures of slight displacement. The ore is altered country rock, which is mineralized with quartz, pyrite, arsenopyrite and galena. Rich sulphides of silver have been met in the upper portions. The Alta mine near Wickes was located on a vein in andesite. The Ruby mine, on Lowland Creek, appears to be a chimney of boulders of rhyolite, which are coated with gold-bearing silver-sulphides. It resembles the Bassick mine of Colorado (2.09.20) in geological relations. One of the largest mines yet opened in the county is the Elkhorn. The ore-deposits resemble the "saddles" of the Bendigo Field, Victoria, Australia.[4] They

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[1] For these notes the writer is especially indebted to Mr. W. H. Weed, of the U. S. Geological Survey. See also S. F. Emmons, *Tenth Census*, XIII., 97. The northeastern portion of Madison County has been mapped by A. C. Peale—Three Forks Folio, *U. S. Geol. Survey*—by whom are also given notes on the mines Rec.

[2] R. Pearce, "Notes on the Occurrence of Tellurium in an Oxidized Form in Montana," *Proc. Colo. Sci. Soc.*, November 2, 1896.

[3] S. F. Emmons, *Tenth Census*, XIII., 97. R. W. Barrell, "The Mineral Formation at the Golden Leaf Mines," *Eng. and Min. Jour.*, July 17, 1897, 64.

[4] E. J. Dunn, "Quarterly Report to the Mining Department of Victoria," December, 1888. T. A. Rickard, "The Bendigo Gold Field," *Trans. Amer Inst. Min Eng.*, XX., 463, 1891.

occur along the contact of Cambrian slate, and underlying limestone, and are replacements of the limestone at the crests of shattered anticlines. The ores are silver sulphides in a quartz gangue, but with occasional large bunches of galena, and very beautiful crystals of calamine.[1]

2.10.09. Silver Bow County. The mines around Butte are the chief if not the only ones of the county. Their general geology and distribution will be found described under "Copper" —in connection with the copper veins, and a map is there given of the local geology. The silver veins surround the copper ones on the north, southwest and west. Their geological rela-

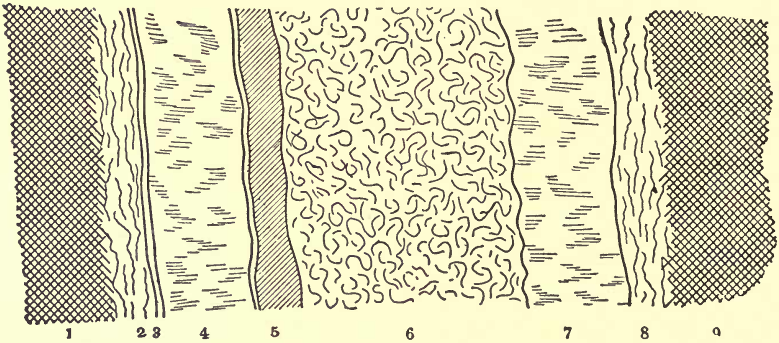

FIG. 124.—*Cross section af vein at the Alice mine, Butte, Mont. The width of vein is* 40 *feet. After W. P. Blake, Trans. Amer. Inst. Min. Eng., XVI., p.* 72.

1. Granite country. 2. Softened granite with small veins. 3. Clay wall with decomposed granite. 4. Quartz, broken and seamed. 5. Clay and decomposed granite. 6. Quartz and manganese spar—"curly ore." 7. Quartz and ore—"hard vein." 8. Soft granite with veinets. 9. Hard-colored, hard granite of the hanging-wall country.

tions and character are much the same, but in mineralogy and distribution they are different. The silver veins occur both in the basic (Butte) granite, and in the acidic (Bluebird) granite. They contain as gangue in addition to quartz, manganese compounds, rhodonite and rhodochrosite. The outcrops of the veins appear as blackened ledges of quartz, the stain being due to manganese oxides. The ores are sulphides of silver, galena, blende and pyrite, with almost no copper minerals whatso-

[1] The above notes were chiefly furnished by Mr. W. H. Weed. See also S. F. Emmons, *Tenth Census*, Vol. XIII., p. 97. J. S. Newberry, "On Red Mountain," *Annals N. Y. Acad. Sci.*, III., p. 251.

FIG. 122.—*Outcrop of the Wabash silver lode, projecting above the granite, Butte, Montana. From a photograph by A. C. Beatty, 1896.*

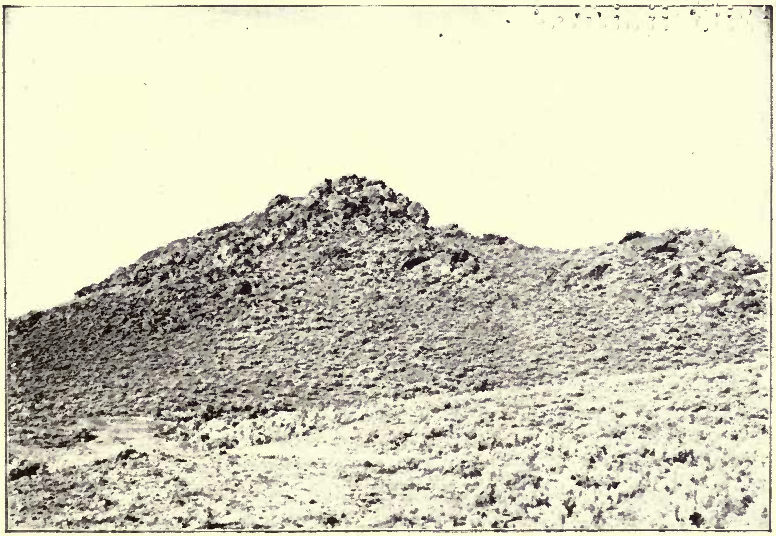

FIG. 123.—*Weathered granite, Butte, Montana. The boulders are due to the rounding off of blocks, produced by joints. From a photograph by J. F. Kemp, 1896.*

ever, except along the border between the copper territory and the silver. The veins display recognizable banding of ore and gangue. One series of locations embracing the Moulton, the Alice and the Magna Charta, has been called the Rainbow lode by J. E. Clayton from its crescentic sweep.

In other respects, as regards faults, relation to the walls and general origin, the remarks already recorded under "Copper" will hold good.

Auriferous gravels were early washed in the valley of Silver Bow Creek, and led to the discovery of the deep veins.[1]

2.10.10. Broadwater County has recently been organized, and contains quartz veins in slates near Winston, and auriferous pyrites in shattered granite at the Diamond Hill mines. Granite County, formerly a part of Deer Lodge, has important mines near Phillipsburg. The Granite Mountain mine is located on a fissure vein in granite, and yielded rich silver ores, with considerable gold. The vein adjoins sedimentary rocks, which are much metamorphosed by the granite.[2]

2.10.11. Deer Lodge County. Placers are numerous along the Deer Lodge River, and auriferous quartz veins are not

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[1] The Butte Special Folio of the U. S. Geological Survey is the best work of reference. It is by W. H. Weed, S. F. Emmons, and Geo. W. Tower. W. P. Blake, "Silver Mining and Milling at Butte, Mont.," *Trans. Amer. Inst. Min. Eng.*, XVI., 38. "Rainbow Lode, Butte, Mont.," *Idem*, XVI., 65. Rec. R. G. Brown, "The Ore Deposits of Butte City," *Idem*, XXIV., 543, 1894. Rec. S. F. Emmons, "Notes on the Geology of Butte, Mont.," *Idem.*, XVI., 49. C. W. Goodale, "The Concentration of Ores in the Butte District, Montana," *Idem*, XXVI., 599, 1896. Richard Pearce, "The Associations of Minerals in the Gagnon Vein, Butte City," *Trans. Amer. Inst. Min. Eng.*, XVI., 62. F. D. Peters, *Mineral Resources of U. S.*, 1883–84, p. 374. E. G. Spilsbury, "Placer Mining in Montana," *Eng. and Min. Jour.*, September 3, 1887, p. 167. Rec. "Silver Mines of Butte, Mont.," *Ibid.*, April 18, 1885, p. 261. Williams and Peters, on Butte, Mont., *Eng. and Min. Jour.*, March 28, 1885, p. 208. See also references under Butte Copper.

[2] H. M. Beadle, "The Condition of the Mining Industry in Montana in 1892," *Eng. and Min. Jour.*, February 11, 1893, p. 123. W. H. Dodds, "Granite Mountain Mine," *Colliery Engineer*, December, 1892. G. W. Goodale and W. A. Akers, "Concentration, etc., with Notes on the Geology of the Flint Creek Mining District," *Trans. Amer. Inst. Min. Eng.*, XVIII., 242, 1890. Rec. "The Granite Mountain Mine," *Eng. and Min Jour.*, December 10, 1887; November 23, 1889.

lacking. In the extreme eastern part are the veins of the Bald Butte group in slates and intrusive diorite.[1]

2.10.12. Lewis and Clarke County. The placer mines, near Helena (in Last Chance and Prickly Pear gulches), were the first in the county to attract attention. They were found by the prospectors who spread through the Rocky Mountains as the California gold diggings gave out. Since then many auriferous quartz veins in granite and slates have been developed. Some twenty miles north of Helena, in the town of Marysville, is the Drumlummon group of veins, which carry refractory silver and gold ores, in a quartz gangue, on the contact between a diorite boss and the surrounding metamorphic schists. There are also other veins in the granite. Dikes of intrusive rocks occur associated with the ore bodies.[2]

2.10.13. Meagher County contains the Castle Mountain mining district, once the heaviest producer of silver-lead ores in the State. The Castle Mountains embrace a geological section from and including the Algonkian to the present. Intrusions of granite, diorite, various porphyritic rocks and surface flows of considerable petrographical range are likewise present. In the closing years of the decade of the eighties discoveries were made of silver-lead ores in the Carboniferous limestones, in the neighborhood of intrusions of porphyry and sometimes in the contact zones. After several years of activity, which was maintained despite the remoteness from rail, the low price of silver caused their shutting down. The Cumberland mine, the largest opened, formed a chimney or tubular mass in the limestone, and was proved for over 500 feet in depth. Copper-bearing veins were also found in the Belt shales of the Algonkian in the northern portion of the area.[3]

In the extreme northern portion of Meagher County, and near the line with Cascade County, the two mining districts of

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[1] R. G. Brown, "Georgetown Mining District," *Eng. and Min. Jour.*, October 13, 1894, 345. E. G. Spilsbury, "Placer Mining in Montana," *Ibid.*, September 3, 1887, p. 167.

[2] J. E. Clayton, "The Drumlummon Group of Veins," etc., *Eng. and Min. Jour.*, August 4 and 11, 1888, pp. 85, 106. S. F. Emmons, *Tenth Census*, Vol. XIII., p. 97. L. S. Griswold, "The Geology of Helena, Mont., and Vicinity," *Jour. of the Assoc. Eng. Soc.*, XX., January 1898.

[3] Weed and Pirsson, "The Castle Mountain District, Montana," *Bull. 139, U. S. Geol. Survey*, 1896.

Neihart and Barker are located in the Little Belt Mountains, but their outlets are to the north at Great Falls. At Neihart there is a series of fissure veins running north and south, in metamorphic gneisses and schists which are cut by diorite. The veins are narrow and barren in the dark colored gneisses and the diorite, but carry large bodies of galena, with zinc-blende and pyrite in the feldspathic gneiss. The vein filling is replaced and altered country rock with quartz seams in it. The quartz seams in some mines contain much polybasite, pyrargerite and chalcopyrite, carrying very high values in gold and silver. Dikes and larger intrusions of quartz-porphyry also occur, but are unfavorable to the veins, as in them the latter split up and become barren, except within a hundred feet of the surface. At Barker the ores are chiefly silver-bearing galena and occur along the contact between granite-porphyry and limestone.[1]

2.10.14. Cascade County contains important coal mines and the smelting center at Great Falls. In Missoula County at Quigley, southeast of Missoula, there is auriferous pyrite in slates of Lower Cambrian or Algonkian age (W. H. Weed). At Iron Mountain operations were formerly carried on, but are now suspended, and there are various minor camps throughout the country.[2]

The latter statement applies as well to Ravalli County in the south. Within the limits of the Lewis and Clarke Timber Reserve there are occasional intrusions of porphyritic rocks in the Algonkian or Lower Cambrian shales and limestones, and in the neighborhood of the igneous rocks copper deposits are found.[3] The Reserve lies in several counties. Similar deposits are found amid the high peaks of the Continental Divide on the so-called "Roof of the Continent," along the line of Flathead and Teton counties.[4]

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[1] *The XX. Ann. Rep. of the Director of the U. S. Geol. Survey*, which will probably be issued in 1901, will contain a paper by W. H. Weed, on the "Mining Districts of the Little Belt Mountains." The above notes have been kindly furnished by Mr. Weed, in advance of his longer paper.

[2] F. D. Smith, "The Cedar Creek Placers," *Eng. and Min. Jour.*, February 4, 1899, 143.

[3] R. H. Chapman, "Geological Structure of the Rocky Mountains within the Lewis and Clarke Timber Reserve." Read at the New York meeting, Amer. Inst. Min. Eng., February, 1899.

[4] G. E. Culver, "Notes on a little known Region in Northwestern Montana," *Trans. Wis. Acad. of Science, Arts and Letters*, VIII., 187, 1891.

2.10.15. In Flathead County, in the extreme northwestern corner of the State, on Libbey Creek and the Yak River, there have been recently discovered large deposits of gold-bearing pyrrhotite in diorite similar in geological relations to the ores subsequently described at Rossland, B. C. Tellurides were reported some years ago at a little camp called Sylvanite.

2.10.16. Choteau and Fergus Counties. Very great scientific interest and considerable economic importance are attached to several new districts, that have been opened up in the small outlying groups of mountains, which rise from the plains well to the east of the main chain of the Rocky Mountains. They are all characterized by intrusions of igneous rocks, rich in alkalies, such as syenite-porphyries, phonolites, and related types. These are the rocks which are present in the Black Hills, where, in the Potsdam sandstones, tellurides of gold occur, associated with fluorite; and at Cripple Creek, Colo., where the ore and gangue are the same. Weed and Pirsson have described the geology of the Little Rocky Mountains. In the central portion of a roughly elliptical area of upheaval, crystalline Archean schists are seamed by intrusions of granite-porphyry, syenite-porphyry, and, near Landusky, by phonolite, Cambrian, Siluro-Devonian, Carboniferous and Jurassic strata mantle the edges. The ore and gangue are found coating the fragments of decomposed porphyry, but do not seem to lie along well-defined veins.[1] The parallelism with Cripple Creek is close. The Little Rockies are situated in Choteau County, 180 miles east of the main Rockies. The Judith Mountains, in Fergus County, nearer the central part of the State, are larger, but of much the same geological structure. A core of syenite-porphyry is surrounded by the sediments, which have been uplifted by its intrusion as a laccolite. It is associated with phonolite. Where the igneous rocks cut the sedimentaries and especially along their contacts with a white Carboniferous limestone free gold and tellurides with associated fluorite are

[1] W. H. Weed, "Ore Deposits of the Little Rocky Mountains," *Eng. and Min. Jour.*, May 2, 1896, 423. Weed and Pirsson, "Geology of the Little Rocky Mountains," *Jour. of Geol.*, IV., 399, 1896. See also E. S. Dana, in Col. Wm. Ludlow's "Report of a Reconnaissance from Carroll, Montana, to the Yellowstone National Park," War Dept., Washington. 1876. 127.

found in the brecciated limestone.[1] Lewiston and Maiden are the chief settlements.

The Sweet Grass Hills near the Canadian line in Choteau County are similar in geology and have been the scene of some placer mining. Other groups of mountain, such as the High wood and Bearpaw ranges, which are piles of volcanic lavas and tuffs, are known to contain richly alkaline, igneous rocks, but ore bodies have not yet been reported.[2]

IDAHO.

2.10.17. *Geology.*—The southern part of the State extends into the alkaline deserts of the Great Basin, and is dry and barren. North of this is the Snake River Valley, which is filled by a great flood of recent basalt, which stretches from the Wyoming line nearly across the State. North of the Snake River a large area of granite appears in the western portion, and contains many mines. Extensive deposits of gravel also occur. Metamorphic rocks and Paleozoic strata largely constitute the northern portion of the State, and are penetrated by many igneous intrusions. The eastern part lies on the western slopes of the Bitter Root Mountains, whose general geology was outlined under Montana. The geology of Idaho has been but slightly studied, and the few reliable records have resulted from the scattered itineraries of Hayden's survey, isolated mining reports, and the collections of the Tenth Census,[2]

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[1] W. M. Courtis, "Gold in Fossiliferous Limestone in the Judith Mountains," *Eng. and Min. Jour.*, June 28, 1884, 478. H. C. Freeman, "The Ammon Mines, Fergus Co., Mont.," *Idem*, May 4, 1895, 416. W. H. Weed, "Mineral Resources of the Judith Mines," *Idem*, May 23, 1896, 496. Weed and Pirsson, "Geology and Mineral Resources of the Judith Mountains," *XVIII. Ann. Rep. U. S. Geol. Survey*, Part III., p. 437.

[2] Weed and Pirsson, "Highwood Mountains of Montana," *Bull. Geol. Soc. Amer.*, VI., 389. "Bearpaw Mountains," *Amer. Jour. Sci.*, May, 1896, 283 ;June, 351; August, 136; September, 188.

[2] G. F. Becker, *Tenth Census*, Vol. XIII., 52. F. H. Bradley, *Hayden's Survey*, 1872, p. 208. G. H. Eldredge, "A Geological Reconnaissance across Idaho," *XVI. Ann. Rep. Dir. U. S. Geol. Survey*, II., 217. F. V. Hayden, *Ann. Rep.*, 1871, pp. 1,147; 1872, p. 20. W. Lindgren, "Mining Districts of the Idaho Basin and the Boise Ridge, Idaho," *XVIII. Rep. Dir. U. S. Geol. Survey*, Part III., p. 617. Rec. Boise Folio, *U. S. Geol. Survey*. Rec. Other folios are in preparation. An extended paper by Lindgren is in press for the *XX. Ann. Report of the U. S. Geol. Survey*, which will

but it is now receiving much attention from the U. S. Geological Survey.

2.10.18. The extreme northern portion of Idaho has assumed increasing interest in recent years on account of the notable mining developments in the neighboring parts of British Columbia, but discoveries are still largely in the nature of prospects. Kootenai County forms the so-called "pan-handle," and in it some gold-quartz veins and placers are known. The great silver-lead mines of Cœur d'Alêne in Shoshone County have already been described (2.08.22). Some scattered mining camps occur in Talah, Nez Perces and Idaho counties to the south. In the extreme southern tongue of Idaho County is the Sheep Mountain district. The country rock is granite, with associated schists and slates in larger or smaller masses, often as inclusions. There are also dikes of quartz-porphyrites and diorite-porphyrites. The ores are impregnations of zones of the schists or slates, with silver-bearing galena, and antimonial and arsenical sulphides.[1]

2.10.19. In Lemhi County is the famous old gold diggings at Leesburg, which had a large population in 1859--60, but which are now practically abandoned except for an extensive hydraulic workings at California Bar, further down Napias Creek. In the western side of Lemhi County is Yellow Jacket, with gold ores associated with a complex series of intruded igneous rocks, in metamorphic schists.[2] The ores lie along fractured zones and in the Columbia properties are chiefly gold-bearing chalcopyrite. H. H. Armstead, Jr., informs the writer that tellurides have also been detected. In the Yellow Jacket mines the ore is free-milling quartz. In northeastern Lemhi County is Gibbonsville, where auriferous pyrite occurs in quartz veins in slates.[3]

2.10.20. Custer County lies south of Lemhi and contains several well-known mines. The Ramshorn is in metamorphic

probably be issued in 1901. J. S. Newberry, "Notes on the Geology and Botany along the Northern Pacific Railroad," *Annals, N. Y. Acad. Sci.*, III. 252. Raymond's *Reports on Mineral Resources West of the Rocky Mountains.* O. St. John, *Hayden's Survey*, 1877, p. 323; 1878, p. 175.

[1] G. H. Eldredge, XVI. *Ann. Rep. U. S. Geol. Survey.* Part II., p. 258.

[2] G. H. Eldridge, "A Geological Reconnaissance Across Idaho," *XVI Ann. Rep. U. S. Geol. Survey*, II., 259.

[3] B. MacDonald, *Eng. and Min. Jour.*, October 3, 1896, 319.

FIG. 125.—*The old gold diggings on Napias Creek, Leesburg, Idaho, illustrating an abandoned placer camp. From a photograph by J. F. Kemp,* 1896.

FIG. 126.—*View on Napias Creek, below California Bar, Idaho, after a freshet. From a photograph by J. F. Kemp,* 1896.

slates on a fissure vein that has rich chutes of high-grade silver ores in a siderite gangue. The Custer and the Charles Dickens are farther west, near Bonanza City, and afford both silver and gold in quartz gangue from veins in porphyry. Smelting ores occur in the region, and have been used in some operations based on this treatment. Boise and Elmore counties, on the west and southwest of Custer, contain very important mining districts. Lindgren has shown the extensive development of a gray, rather basic granite, having close affinities with the quartz-mica-diorites. It is penetrated by numerous dikes of porphyries and minettes and is covered by Tertiary lake beds and effusive rocks. The granite has suffered considerable faulting, usually on a small scale, and in a number of districts the fissures thus formed have been the scene of ore deposition. Their general characters are shown by Fig. 127. They may occur as single and isolated fissures, as parallel series, or as lines of crushing with disjointed vein fillings. Quartz is the almost invariable gangue, calcite being very subordinate. The metallic minerals are pyrite, gold, arsenopyrite, zincblende and galena. These sulphides likewise impregnate the wall rock, but they are then low in the precious metals. Silver is invariably present, and in the Banner district in Elmore County, it is the chief source of value. At Atlanta, likewise in Elmore County, the lode is of quite extraordinary size, being known for two and one-half miles, with an average width of seventy-five feet, and with many spurs. The pay ore occurs in four or five shoots in the main vein, which are of moderate widths. Silver predominates over gold. In the neighborhood of the gold-bearing veins in granite, placers have been and are extensively operated, and indeed, led to the settlement of the country. The principal deep-mining localities are the Idaho City belt, the Quartzburg-Grimes Pass belt, both within the depression known as the Idaho Basin; and then in the mountains to the west, called the Boise ridge, there are the Neal, Black Hornet, Boise, Shaw Mountain, Willow Creek and Rock Creek districts.[1]

[1] J. E. Clayton, "Atlanta District," *Trans. Amer. Inst. Min. Eng.*, VI., 468. G. H. Eldridge, "A Geological Reconnaissance Across Idaho," *XVI. Ann. Rep. U. S. Geol. Survey*, 217. W. Lindgren, "Mining Districts of the Idaho Basin and the Boise Ridge, Idaho," XVIII, *Idem*, Part III., p. 617. Rec. The Boise Folio, *U. S. Geol. Survey.* Rec. An important paper may be expected in the *XX. Ann. Rep. of the Survey.*

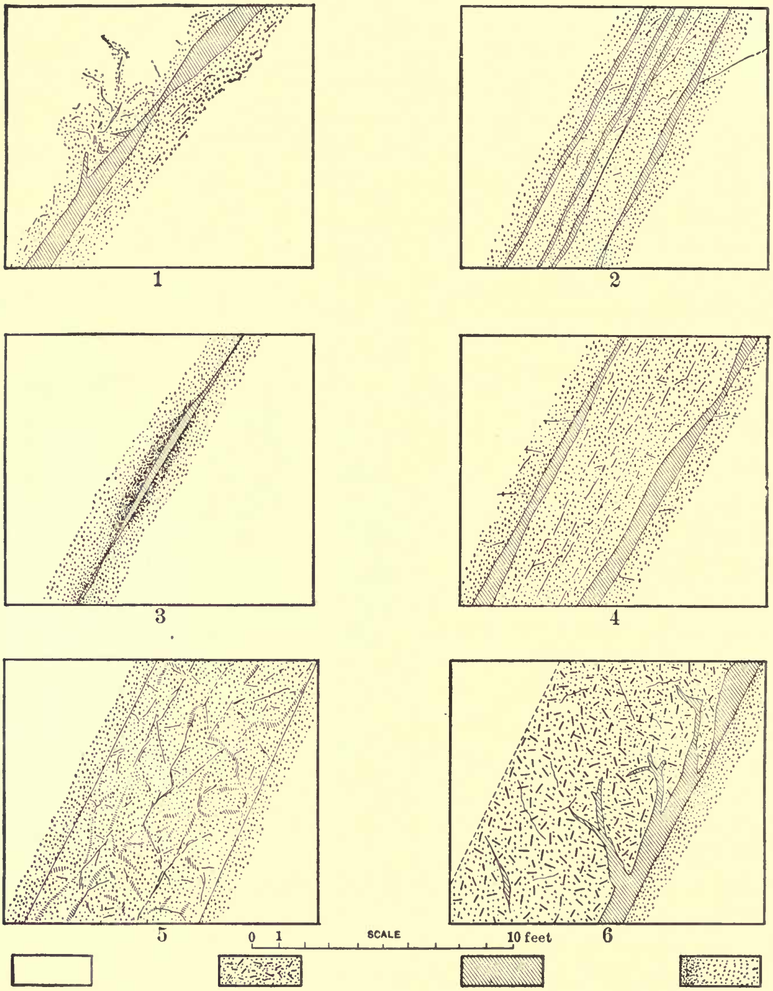

FIG. 127.—*Sections to illustrate typical gold veins in the Boise granite region, Idaho. After W. Lindgren, XVIII. Ann. Rep. U. S. Geol. Survey, Part III., Plate XC.*

1. Simple fissure vein on one fault plane, with quartz filling, which alone is ore. Wall-rock altered, but barren. 2. Complex fissure with four fault planes. Rich ore fills the long narrow openings and impregnates adjacent, altered wall-rock. 3. Simple, narrow, fissure vein, filled with ore which also impregnates altered wall-rock. 4. Complex fissure vein, with two fault planes. Intermediate rock and outer walls altered, the former also sheeted. 5. Irregularly shattered zone between two fault planes. Intermediate rock excessively altered. Quartz fills seams and cracks. 6. Quartz vein of rich ore along under side of altered porphyry dike and with branches into hanging. Altered dike forms low-grade ore.

2.10.21. Alturas County contains one very important silver-lead district, the Wood River, which has been earlier referred to (under Example 32*a*). Owyhee County forms the southwestern corner of the State. Apparently the same granite that is so prominent in Boise and Elmore reappears from beneath the intervening Tertiary deposits, and comes up near Silver City. Still further southwest quartz-porphyry and metamorphic rocks are found with dikes of basalt. Gold-quartz and high-grade silver ores are present. The Poorman Lode is famous for ruby silver ores. W. P. Blake mentions seeing a piece from this mine at the Paris Exposition which weighed about 200 pounds.[1] It was awarded a gold medal. The crystal from which it was broken weighed 500 pounds.[2] In Cassia, Logan, Oneida and other counties in the southern part, placers are being or have been worked, and in Bear Lake County, in the southeast corner, salt and sulphur deposits are recorded.[3] The gold of the Snake River sands is extremely fine, and difficult to save.

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[1] *Amer. Jour. Sci.*, ii., XLV., 97.

[2] Raymond's *Reports on Mineral Resources West of the Rocky Mountains*, 1868, p. 523.

[3] G. F. Becker, *Tenth Census*, Vol. XIII., p. 59. T. Egleston, "The Treatment of Fine Gold in the Sands of the Snake River, Idaho," *Trans. Amer. Inst. Min. Eng.*, XVIII., 597. Raymond's *Reports on Mineral Resources West of the Rocky Mountains*. *Rep. Dir. of the Mint*, 1882, p. 227.

CHAPTER XI.

SILVER AND GOLD, CONTINUED.—THE REGION OF THE GREAT BASIN, IN UTAH, ARIZONA, AND NEVADA.

UTAH.

2.11.01. *Geology.*—The eastern half of Utah, terminating with the western front of the Wasatch, is in the Colorado Plateau, but the western is within the limits of the Great Basin. The plateau portion consists largely of Mesozoic strata, quite horizontal and more or less carved by erosion. The east and west arch of the Uintah Mountains, in the northern part, has upheaved them, so that where the Green River has cut a channel across, the Paleozoic is exposed in great strength. The Wasatch range rises with a gradual ascent from the east, and then terminates with a great fault line, having a steep westerly front. This line of weakness was developed in the Archean and has been a scene of movement even to recent times. It is a very important structural feature. West of the Wasatch, which is a fine example of block-tilting in mountain-making, the mountains belong to the Basin ranges, which are more typically developed in Nevada. The Wasatch section was shown by the Fortieth Parallel Survey to involve 12,000 to 14,000 feet of the Upper Archean, and nearly 30,000 feet of the Paleozoic. In southern Utah the Triassic rocks are important and contain some rich mines.[1]

[1] G. F. Becker, *Tenth Census*, XIII., 38. Whitman Cross, "The Laccolitic Mountain Groups of Colorado, Utah and Arizona," *XIV. Ann. Rep. U. S. Geol. Survey*, Part II., 165. C. E. Dutton, Report on the High Plateaus of Utah, Washington, 1880. S. F. Emmons, "Origin of Green River," *Science*, VI., 19, 1897. Sir. A. Geikie, "Archean Rocks of the Wasatch Mountains," *Amer. Jour. Sci.*, iii., XIX., 363. G. K. Gilbert, "Lake Bonneville," *Monograph I., U. S. Geol. Survey*, and *II. Ann. Rep.*, 169-200

2.11.02. The greater number of the Utah mines are for lead-silver ores, and have been mentioned under "Lead-silver." The northwestern county, Box Elder, is in the alkaline desert region of the Great Basin. The mining districts occur in the central part of the State, in the Wasatch and Oquirrh mountains, and are also found in the extreme southwest.

2.11.03. Ontario Mine. Nearly east of Salt Lake City, in Summit County, is the Ontario mine, a vein from four to twenty-three feet wide (averaging eight feet), in quartzite, but extremely persistent, being opened continuously for 6,000 feet. In the lower working a porphyry dike has come in as one of the walls. It is extensively altered by fumarole action to clay. The best parts of the mine have quartzite walls. The ores consist of galena, gray copper, silver glance, blende, etc. The Ontario vein extends through a number of claims and at least one other important vein is known, the Daly West, which however, has one wall, limestone. Its product and the latter developments on the Ontario have changed the camp to a lead-silver producer.[1]

2.11.04. The lead-silver veins of Bingham Cañon, in Salt Lake County, have already been mentioned. Reference may

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"The Ancient Outlet of the Great Salt Lake," *Amer. Jour. Sci.*, iii., XV., 256; XIX., 341; see also A. C. Peale, *Ibid.*, XV., 439. "The Henry Mountains," Washington, 1877. R. C. Hills, "Types of Past Eruptions in the Rocky Mountains," *Proc. Colo. Sci. Soc.*, IV., 14. International Geological Congress, Washington meeting, 1891, Guide Book to the Rocky Mountains. J. D. Irving, "The Stratigraphical Relations of the Browns' Park Beds, Utah," *Trans. N. Y. Acad. Sci.*, XV., 252. Hague, King, and Emmons, *Fortieth Parallel Survey*, Vols. I. and II. O. C. Marsh, "On the Geology of the Eastern Uintah Mountains," *Amer. Jour. Sci.*, iii., I., 191. H. Montgomery, "Volcanic Dust in Utah and Colorado," *Science*, I., 656, 1895. B. Silliman, "Geological and Mineralogical Notes on Some of the Mining Districts of Utah Territory," *Amer. Jour. Sci.*, iii., III., 195. G. O. Smith, "Igneous Phenomena in the Tintic Mountains, Utah," *Science*, VII., 502, 1898. J. Walther, "The North American Deserts," *Nat. Geog. Magazine*, IV., 163. Wheeler, Gilbert, Lockwood and others, on Western Utah, *Wheeler's Survey, Rep. Prog.*, 1869–71–72. *Idem*, Final Reports, III.

[1] T. J. Almy, "History of the Ontario Mine, Park City, Utah," *Trans. Amer. Inst. Min. Eng.*, XVI., 35. "The Ontario Mine," *Eng. and Min. Jour.*, May 28, 1881, p. 365. D. B. Huntley, *Tenth Census*, Vol. XIII., p. 438. H. L. J. Warren, "The Daly West Mine, Park City, Utah," *Eng and Min. Jour.*, October, 14, 1899.

again be made to the great bed-veins of gold quartz associated with them. Ophir Cañon and Dry Cañon, in Tooele County, and the Tintic district, in Juab County, have also been described. In addition to the smelting ores, others have been treated by milling. Quite recently interest has been directed to the mines of the Camp Floyd district, of which Mercur is the chief town. Rich deposits of gold ores, formerly refractory, have yielded to the cyanide process, and have given a new and large lease of life to a district that was abandoned years ago, after having had a short career as a silver producer. Mercur is situated in the southern end of the Oquirrh Mountains, in a valley known as Lewiston Cañon. A thick series of Carboniferous limestones and very subordinate shales has

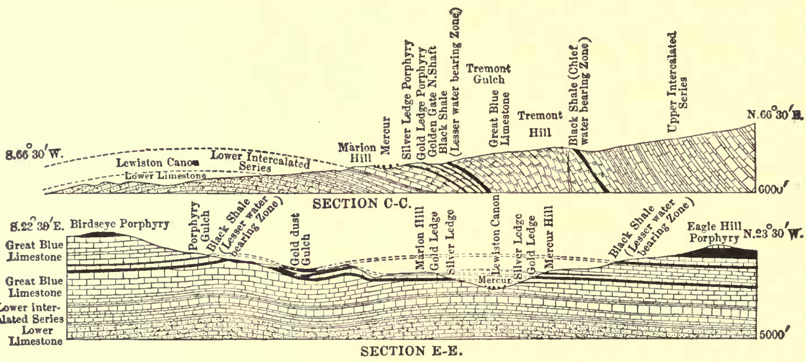

FIG. 128.—*Geological cross-sections at Mercur, Utah, reduced from colored ones by J. E. Spurr; XVI. Ann. Rep. Dir. U. S. Geol. Survey, Plate XXVII. The sections cut each other at right angles.*

been folded into a low anticline, as shown in Fig. 128, whose axial crest is also folded, so that the beds constitute a low dome or swell. One great stratum of limestone has been intruded by an interstratified sheet of quartz porphyry, locally called the Eagle Hill porphyry, which at the most productive mines has split into three thin sheets, each 150 feet or less from its neighbor. At some time after the intrusion, ore-bearing circulations percolated along the lowest sheet and impregnated the limestone for a zone, usually 10 to 20 feet thick, but reaching even 50 feet or more, with silver-bearing minerals in a gangue of cherty quartz. Where mined the silver was present in thin films of the chloride coating fragments of the chert and limestone. Associated metallic minerals are few. Stibnite is known, and pyrite has been detected with the microscope. Carbonates of copper have been noted. As gangue minerals cal-

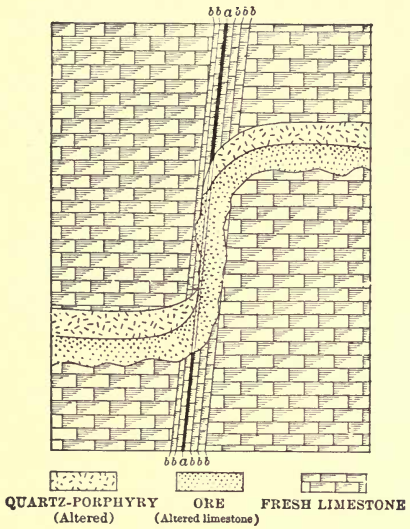

FIG. 129.—*Diagram showing relations of ore to fault in Tunnel No. 3, Marion Mine, Mercur, Utah. Scale* 40 *feet to the inch. After J. E. Spurr, XVI. Ann. Rep. U. S. Geol. Survey,* 420.

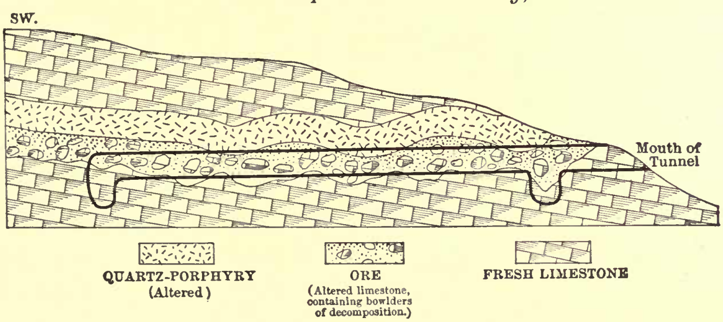

FIG. 130.—*Section along the Geyser mine tunnel, Mercur, Utah. After J. E. Spurr, XVI. Ann. Rep. U. S. Geol. Survey,* 422.

cite and barite are next to chert in abundance. Spurr favors heated waters as the vehicles of the ore. Long after the silver ores had been deposited the gold series were formed, probably as tellurides, along the contact of the next overlying sheet of porphyry. They are now found where this sheet is cut by a series of small northeast fissures in the limestone, which fissures are thought with great reason by Spurr to have been the conduits through which the ores were introduced. The gold in the oxidized ores is in some condition that is readily soluble in potassium cyanide, but it is uncertain what that state is. Realgar and occasionally cinnabar are associated with it. In the unoxidized ores pyrites are abundant, but the gold is but slightly attacked by the cyanide. It is thought to have been deposited as a telluride. The ores average about ten dollars per ton. The region is poorly supplied with water, and all the springs are carefully utilized. R. C. Hills,[1] in the paper cited below, explained the ores as introduced through a series of fissures which, now filled with calcite, penetrate to the chutes. J. E. Spurr,[2] however, regards the open fissures along which the chutes extend, as the conduits, and favors a vaporous or fumarolic method of introduction. A laccolite of igneous rock at some unknown point below is suggested as the source of the vapors.[3]

Considerable interest has been directed of late to the mines of the Deep Creek district, on the extreme western border of Utah, in the Ibapah range. Limestones regarded by Blake as Carboniferous, and other sedimentary rocks, have been broken through by great outflows of granite, andesite, hypersthene-andesite, etc. The ore bodies appear to be contact deposits in limestone near igneous rocks, and carry much free gold.[4]

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[1] R. C. Hills, "Ore Deposits of Camp Floyd District, Tooele Co., Utah," *Proc. Colo. Sci. Soc.*, August 6, 1894. Rec.

[2] J. C. Spurr, "Economic Geology of the Mercur Mining District, Utah," with an Introduction by S. F. Emmons. *XVI. Ann. Rep. Dir. U. S. Geol. Survey*, II., 349. Rec.

[3] Other papers on Mercur are the following: R. C. Gemmell, "The Camp Floyd Mining District and the Mercur Mine, Utah," *Eng. and Min. Jour.*, LXIII., 403, 1897. A. Lakes, "The Oquirrh Mountains or the Mercur Mining District, Utah," *Colliery Engineer*, XVI., 243, 1896. W. H. Moeller, "The Mercur Gold Deposit in the Camp Floyd District, Utah," *Eng. and Min. Jour.*, LVII., 51, 1894. D. Maguire, "Gold Mines of Mercur," *Mines and Minerals*, XIX., 81, 130, 1898. J. W. Neill, "Camp Floyd District, Utah," *Eng. and Min. Jour.*, LXI., 85, 1896.

[4] W. P. Blake, "Age of the Limestone Strata at Deep Creek, Utah, and the Occurrence of Gold," etc., *Amer Geol.*, January, 1892, p. 47. *Eng. and Min. Jour.*, February 23, 1892, p. 253. S. F. Emmons, *Fortieth Parallel*

FIG. 131.—*Open cut, showing the pay-streak, at Mercur, Utah. From a photograph by P. K. Hudson*, 1898

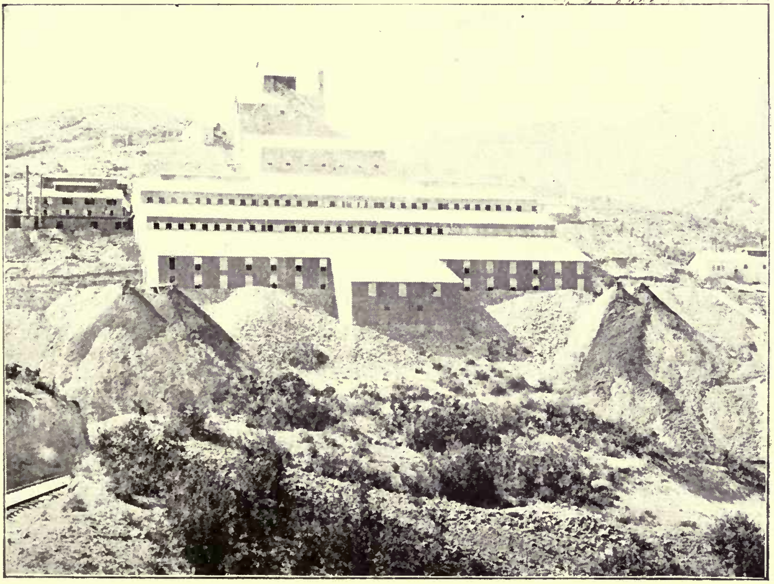

FIG. 132.—*The Golden Gate cyanide mill, Mercur district, Utah. From a photograph by L. E. Riter, Jr.*, 1898.

In Beaver County the interesting deposits of the Horn Silver, the Carbonate, and the Cave ore bodies have been mentioned under Examples 30*g*, 33*a*, and 32*b*. The iron ore bodies of Iron County will be found under Example 14. In Piute County, near the town of Marysvale, around Mount Baldy, are a number of mines with lead-silver or milling ores in quartz porphyry (copper belt), or between limestone and quartzite (Deer Trail, Green-eyed Monster, etc.). Selenide of mercury is found in the Lucky Boy.[1]

2.11.05. Example 41. Silver Reef, Utah. Native silver, cerargerite and argentite, impregnating Triassic sandstones, and often replacing organic remains. These deposits were earlier referred to under Example 21, p. 80. They were discovered in 1877. At Silver Reef there are two silver-bearing strata or reefs, with beds of shale between. Above the water-

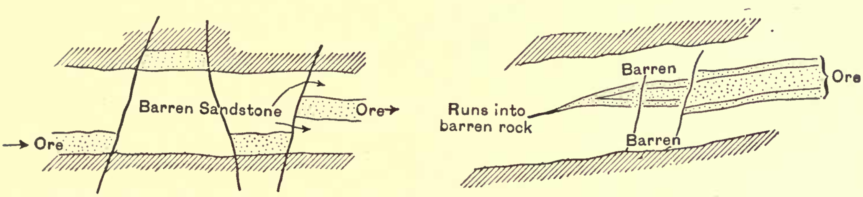

FIG. 133.—*Two sections of the argentiferous sandstone of Silver Reef, Utah. After C. M. Rolker, Trans. Amer. Inst. Min. Eng., IX., p. 21.*

line the ore is horn silver; below it is argentite. At times it replaces plant remains; at other times no visible presence of ore can be noted, although the rock may afford $30 to the ton. The silver always occurs along certain ore channels, distributed through parts of the sandstone. The origin of the deposits has given occasion to a vigorous discussion. J. S. Newberry held that the silver was deposited in and with the sandstone from the Triassic sea, although it may have been concentrated since in the ore channels. F. M. F. Cazin holds that the organic remains were deposited in and with the sandstone, and that these were the immediate precipitating agents of the ores. R. P. Rothwell explained them much as does Rolker, below.

Survey, Vol. II., p. 475. J. F. Kemp, "Petrographical Notes on a Suite of Rocks Collected by E. E. Olcott," *Trans. N. Y. Acad. Sci.*, XI., 127, 1892.

[1] G. J. Brush, "On the Onofrite," etc, *Amer. Jour. Sci.*, iii., XXI., 312.

C. M. Rolker, who was for some years in charge of several of the mines has also written about them, and is probably nearest to the truth. Rolker argues that the impregnation was subsequent to the formation of the sandstone, and was caused by the igneous outbreaks in the neighborhood, and probably runs along old lines of partial weakening or crushing that afterward healed up. Eruptive rocks are known in the neighborhood of the ores both in Utah and in the Nacemiento copper district of New Mexico. From what we know of ore deposits in general this seems most probable.[1]

ARIZONA.

2.11.06. *Geology.*—Arizona lies partly in the plateau region, and partly in the Great Basin. The Basin ranges converge with the Rocky Mountains, which, however, are chiefly in New Mexico. The uplands of the ranges are well watered and covered with timber, but the low-lying portion of the Great Basin is an arid desert, and in southwestern Arizona is the hottest part of the United States. Cretaceous and Jura-Trias largely form the plateau region. Running southeast to northwest is the great development of Carboniferous limestone so often referred to under "Copper," and underlying this are found Archean granites, gneisses, etc. A great series of ore deposits is ranged along this contact. In the southwest are mountains of granites and metamorphic rocks. The Territory also contains vast flows of igneous rocks, and in the plateau country between the converging ranges some 20,000 or 25,000 square miles are covered by them. The Grand Cañon of the Colorado has laid bare a magnificent geological section of many thousand feet, from the Archean to the Tertiary.[2]

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[1] F. M. F. Cazin, "The Origin of the Copper and Silver Ores in Triassic Sandrock," *Eng. and Min. Jour.*, December 11, 1880, p. 381; April 30, 1881, p. 300. "The Silver Sandstone Formation of Silver Reef," *Ibid.*, May 22, 1880, p. 351; January 10, 17, 24, 1880, pp. 25, 48, 79 (Rothwell). A. W. Jackson, "Silver in Sedimentary Sandstone," *Rep. Dir. of Mint*, 1882, p. 384, reprinted from *Cal. Acad. Sci.* J. S. Newberry, "Report on the Properties of the Stormont Silver Mining Company," etc., *Eng. and Min. Jour.*, October 23, 1880, p. 269. "The Silver Reef Mines," *Ibid.* January 1, 1881, p. 4. C. M. Rolker, "The Silver Sandstone District of Utah," *Trans. Amer. Inst. Min. Eng.*, IX., 21.

[2] "Central Arizona," *Eng. and Min. Jour.*, April 23, 1881, p. 285. "Colorado River of the West," review of Ives Expedition, *Amer. Jour. Sci.*, ii

2.11.07. Apache County is in the northeastern corner. In the southern part of the county gold and silver ores, in veins in limestone, associated with copper ores, are reported, and some small placers.

2.11.08. Yavapai County. Gold and silver ores, in quartz veins, in granite and metamorphic rocks. The Black range copper district has already been referred to under Example 20*e*.

Mohave County. Silver sulphides, arsenides, etc., and alteration products in veins in granite, at times showing a gneissoid structure. Only the richest can now be worked.

Yuma County. Quartz veins, with silver ores and lead minerals in metamorphosed rocks (gneiss, slate, etc.), or in granite.

Maricopa County contains both Paleozoic and Archean exposures. The ore deposits lie mostly along the contact of the two, in granite or highly metamorphosed strata. They are usually quartz veins, with silver ores and copper, lead, and zinc minerals. The Globe district, extending into Pinal County, is the principal one. Mention has already been made of it under "Copper," Example 20*c*.

Pinal County adjoins Maricopa on the south and contains a number of important mines. They produce mostly silver ores, with lead and copper associates, and some blende. The gangue minerals are quartz, calcite, etc., occasionally manganese compounds, and sometimes, in the granites, barite. Limestone, slate, sandstone, and quartzite, as well as granite, diabase and diorite, occur as wall rock.

2.11.09. Silver King Mine. A central mass or chimney of quartz, with innumerable radiating veinlets of the same, carrying rich silver ores and native silver, in a great dike of feld-

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XXXIII., 387. G. F. Becker, *Tenth Census*, Vol. XIII., p. 44. C. E. Dutton, "The Physical Geology of the Grand Cañon District," abstract of *Monograph II., Sec. Ann. Rep. Dir. U. S. Geol. Survey*, 49–161; see also the Monograph. Patrick Hamilton, *The Resources of Arizona*, A. L. Bancroft & Co., San Francisco, 1884. B. Silliman, "Report on Mining Districts of Arizona, near the Rio Colorado," *Eng. and Min. Jour.*. August 11, 1877, p. 111; taken from *Amer. Jour. Sci.*, ii., XLI., 289. C. D. Wolcott, "Permian and Other Paleozoic Groups of the Kanab Valley, Arizona," *Amer. Jour. Sci.*, iii., XX., 221. "Pre-Carboniferous Strata in the Grand Cañon of the Colorado, Arizona," *Amer. Jour. Sci.*, December, 1883, 437. *Wheeler Survey*, Vol. III., and Supplement.

spar porphyry, with associated granite, syenite (Blake), porphyry, gneiss, and slates, all of Archean age. The veinlets ramify through the strongly altered porphyry, and form a stockwork, which furnished the principal ores. In the region are also Paleozoic strata, whose upper limestone beds are referred by Blake to the Carboniferous. The minerals at the mine were native silver, stromeyerite, argentite, sphalerite, galenite, tetrahedrite, bornite, chalcopyrite, pyrite, quartz, calcite, siderite, and, as an abundant gangue, barite.

Graham County contains the Clifton copper district, referred to under Example 20*a*.

Cochise County is the southeastern county, and contains the Tombstone district, once the most productive of the precious metals in the Territory.

2.11.10. Tombstone. A great porphyry dike up to 70 feet thick, faulted and altered, and carrying above the water line in numerous vertical joints, or partings, quartz with free gold, horn silver, and a little pyrite, galenite, and lead carbonate. Curiously enough, in the porphyry itself and far from the quartz veins, flakes and scales of free gold have been found, evidently introduced in solution. Ore also occurs along the side of the dike. There are also other fissures parallel with this principal dike, and still another series crossing these and the axis of the great anticline of the district. Connected with these fissure veins are bedded deposits in the limestone, along the bedding planes or dropping from one to another, appearing to have originated by replacement. Blake offers two explanations of the first-mentioned dike deposit—either that the dike itself held the precious metals, or that they came from the pyrite of the adjoining strata. Several other mining districts of less note occur in the county. The important copper deposits of the Bisbee region have already been mentioned under Example 20*f*. The most productive mine of the territory for the last year or two has been the Pearce at the town of the same name, but operated by the Commonwealth Co. It is a quartz vein as yet productive of oxidized ores containing silver and gold.

2.11.11. Pima County is the central county of the southern tier, and has Tucson as its principal city. There are numbers of mines of the precious metals, and a few less important copper deposits.

Yuma County, in the southwestern corner, has some mines along the Colorado River, on quartz veins in metamorphosed rocks, containing silver and lead minerals.[1] The Fortuna mine is at present the chief producer.

NEVADA.

2.11.12. *Geology.*—Nevada lies almost entirely in the Great Basin, only the western portion being in the Sierras. The surface is thus largely formed by the dried basins of former great lakes, principally Lakes Lahontan and Bonneville. A large number of ranges extend north and south through the State, known collectively as the Basin ranges. They have been formed by block tilting on a grand scale, and present enormously disturbed strata. The geological sections exposed are of surpassing interest (cf. Example 36), and show Archean and Paleozoic in great thickness. In these mountains are found the mining districts, while between them lie the alkaline plains.[2]

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[1] G. F. Becker, *Tenth Census*, Vol. XIII., p. 44. G. H. Birnie, "Castle Dome District," *Wheeler's Survey*, 1876, p. 6. W. P. Blake, "The Geology of Tombstone, Arizona," *Amer. Inst. Min. Eng.*, X., 334; *Eng. and Min. Jour.*, June 24, 1882, p. 328; *The Silver King Mine*, a short monograph, New Haven, March, 1883. Rec. See also *Eng. and Min. Jour.*, April 28, 1883, p. 238. J. F. Blandy, "The Mining Region around Prescott, Ariz.," *Trans. Amer. Inst. Min. Eng.*, XI., 286; *Eng. and Min. Jour.*, July 21, 1883. "On Tombstone, Arizona," *Ibid.*, May 7, 1881, p. 316; March 18, 1882, p. 145. "Silver in Arizona," General Review, *Eng. and Min. Jour.*, September 21 and 25, 1880, pp. 172, 203. "Central Arizona," *Ibid.*, April 23, 1881, p. 285. O. Loew, "Hualapais District," *Wheeler's Survey*, 1876, p. 55. B. Silliman, "Report on the Mining District of Arizona near the Rio Colorado," *Amer. Jour. Sci.*, ii., XLI., 289; see also *Eng. and Min. Jour.*, August 11, 1877, p. 111. Raymond's Reports and those of the Director of the Mint contain notes on the Arizona mines.

[2] J. Blake, "The Great Basin," *Proc. Cal. Acad. Sci.*, IV., 275; *Amer. Jour. Sci.*, iii., VI., 59. W. P. Blake, "On the Geology and Mines of Nevada" (Washoe Silver Region), *Quar. Jour. Geol. Sci.*, Vol. XX., p. 317. H. G. Clark, "Aurora, Nevada: A Little of its History, Past and Present," *School of Mines Quarterly*, III., 133. G. K. Gilbert, "A Theory of the Earthquakes of the Great Basin, with a Practical Application," *Amer. Jour. Sci.*, iii., XXVII., 49. I. C. Russell, "Geology and History of Lake Lahontan, a Quaternary Lake of Northwestern Nevada," *Monograph XI., U. S. Geol. Survey;* also, *Third Ann. Rep. Dir. U. S. Geol. Survey*, 195. C. D. Wolcott, "Paleontology of the Eureka District," *Monograph*

2.11.13. Lincoln County is in the southeastern corner, and contains a number of small mining districts. The ores are in general silver-lead ores in limestone, or veins with sulphuret ores in quartzite and granite. Pioche is one of the principal towns, near which is found the once famous and now reopened Raymond & Ely mine. A strong fissure cuts Cambrian quartzite and overlying limestone, where the latter has not been eroded, and is occupied by a great porphyry dike. Along the contact between the porphyry and the wall rock the chutes of ore have been found. Mr. Ernest Wiltsee, at the Montreal meeting of the American Institute of Mining Engineers, February, 1893, described and figured the Half Moon mine, on this same great fissure, where the quartzite still retained a limestone cap. The ore-bearing solutions, on reaching a shaly streak containing a limestone layer, departed from the fissure and followed under the limestone, so as to form a lateral enlargement, much like those described and figured from Newman Hill, Colorado, under 2.09.10. The Pahranagat and Tem Pahute districts, still further south, have had some prominence, but the whole region is so far from the lines of transportation that the conditions are hard ones.[1]

2.11.14. Ney County, next west, has an important mining center, in its northern portion, around the town of Belmont. Quartzites and slates rest on granites in the order named, and in them are veins with quartz gangue and silver chlorides, affording very rich ores. Southeast of Belmont is Tybo.[2]

2.11.15. White Pine County lies to the northeast, and contains the White Pine district. The principal town is Hamilton, about 110 miles south of Elko, on the Central Pacific. The Humboldt range is prolonged southward in some broken hills, consisting chiefly of folded Devonian limestone. At Hamilton these are bent into a prominent anticline, and this has a strong fissure crossing the axis. The geological section is Devonian

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VIII., U. S. Geol. Survey. Gilbert, Wheeler, Lockwood, and others, "Eastern Nevada: Notes on its Economic Geology," *Wheeler's Survey, Rep. Prog.*, 1869, 71, 72; also Vol. III. and Supplement. For further literature, see under Example 36.

[1] E. P. Howell, *Wheeler's Survey*, III., 257. G. M. Wheeler, Report, *Wheeler's Survey*, 1869, p. 14.

[2] S. F. Emmons, *Survey of the Fortieth Parallel*, Vol. III., p. 393. G. K. Gilbert, "On Belmont and Neighborhood," *Wheeler's Survey*, III., 36.

limestone, thin calcareous shale, thin siliceous limestone, argillaceous shale, probably Carboniferous sandstone, and Carboniferous limestone. The ore bodies occur, according to Arnold Hague, in four forms, all in the Devonian limestone: (1) in fissures crossing the anticlinal axis; (2) in contact deposits between the limestones and shales; (3) in beds or chambers in the limestone parallel to the stratification; (4) in irregular vertical and oblique seams across the bedding. The ore is chiefly chloride of silver in quartz gangue. It is thought by Mr. Hague to have probably come up through the main cross fissure, and, meeting the impervious shale, to have spread through the limestone in this way.[1]

Egan Cañon is in the northern part of the county, and shows a geological section of granite, quartzite, and slate in the order named. In slates, and perhaps extending into the quartzite, is a quartz vein five to eight feet wide, carrying gold and silver ores.

Eureka County is the next county west of White Pine. The deposits at Eureka have already been described under "Lead-silver." (Example 36.)

2.11.16. Lander County lies next west to Eureka. The Toyabe range runs through it from north to south, and in its southern portion, in Ney County, contains the Belmont deposits. (See above, 2.11.14.) At Austin, which is 80 or 90 miles south of the Central Pacific Railroad, now connected with it by a branch, are the mines of the Reese River district, named from the principal stream near by. From Mount Prometheus, which consists of biotite granite or granitite, and which is pierced by a great dike of rhyolite, a western granite spur runs out, known as Lander Hill. The oro bodies are in this hill, and are narrow fissure veins with a general northwest and southeast trend, carrying rich ruby silver ores, with gray copper, galena, and blende, in a quartz gangue with associated rhodochrosite and calcite. They are also often faulted. At times they show excellent banded structure. Antimony has recently been found in this region.[2] (See under "Antimony.")

[1] J. E. Clayton, "The geological structure and mode of occurrence of the silver ores in the White Pine district," *Cal. Acad. Sci.*, IV., 89. A. Hague, *Fortieth Parallel Survey*, Vol. III., p. 409.

[2] S. F. Emmons. *Fortieth Parallel Survey*, Vol. III., p. 349

2.11.17. Elko County lies north of White Pine and Eureka counties, and contains the Tuscarora mining district. The deposits are high-grade silver ores in veins, in a decomposed hornblende andesite.[1]

Humboldt County is the middle county of the northern tier, and contains a number of mining disrticts, which produce both silver and gold from quartz veins in the Mesozoic slate. Small amounts of the precious metals come also from Washoe County, in the northwest corner of the State.[2]

Churchill County adjoins Lander on the west, and possesses a few silver mines.

Esmeralda County, in the southwest, has a considerable number of rich silver and gold mines, which produce high-grade ores from veins, with a quartz gangue in metamorphic rocks, slates, schists. etc. (See also under "Nickel.")

2.11.18. Storey and Lyon are two small counties in the western central portion of the State, but the former contains the most important and interesting ore deposit in Nevada, if indeed it is not the largest and richest single vein yet discovered.

2.11.19. Comstock Lode. A great fissure vein, four miles long, forked into two branches above, along a line of faulting in eruptive rocks of the Tertiary age, and chiefly andesites. In the central part of the vein the displacement has been about 3,000 feet, shading out, however, at the ends. The ores are high-grade silver and gold ores in quartz, and occur in great bodies, called "bonanzas," along the east vein. Over $325,-000,000 in gold and silver has been extracted, in the ratio of two of the former to three of the latter. The vein lies on the easterly slope of a northeasterly spur of the Sierras. West of it is Mount Davidson. The outcroppings lie on the flank of the latter, about 6,500 feet above the sea and 1,500 below the summit. The general strike of the vein is east of south, and it dips east.

Views regarding the geology of the Comstock have changed in the course of years, as they have been influenced by the successive writings of Von Richthofen, King, Church, Becker, and Hague and Iddings, the points in especial controversy being the determinations of the rock species.

[1] G. F. Becker, *Tenth Consus,* Vol. XIII., p. 34. [2] *Ibid.*, p. 33.

2.11.20. It may be remarked that the whole scheme of the classification of the volcanic (effusive) rocks rests largely on Von Richthofen's early studies, and that perhaps the most important generalization of late years is due to the work of Hague and Iddings on the same. Von Richthofen (1865) described the ore body as filling a fissure on the contact of a so-called syenite, and an eruptive rock that he called "propylite." The ore and gangue are thought to have been brought up from below by solfataric action, in which fluorine, chlorine, and

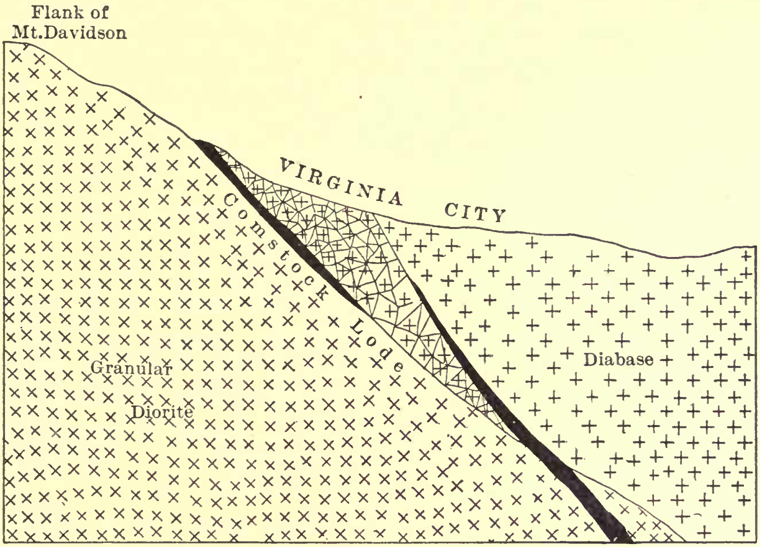

FIG. 134.—*Section of the Comstock Lode on the line of the Sutro tunnel. After G. F. Becker, Monograph III., U. S. Geol. Survey. The colors of the original are here indicated by line-work.*

sulphur were the principal dissolving agents. Clarence King (1867-68, published in 1870) brings out forcibly the fact that the foot-wall of the vein approximates closely the natural continuation of Mount Davidson, and contends that the vein filled a fissure between the syenite of which Mount Davidson consists, and the late Tertiary eruptive rocks poured out against its flanks. He traced the geological succession of these and explained the filling of the vein by solfataric action, attendant on a thin dike of andesite, which forced its way into the contact. J. A. Church

(1877) thought that the diorite (called syenite above) of Mount Davidson had been extruded originally in thin, horizontal sheets, which were folded in east and west folds. This was to account for the sheeting of the rocks of the lode as now seen. On the diorite was poured out next the propylite, likewise in successive horizontal sheets. Then they were all tilted along north and south axes, and eruptions of andesite penetrated between their sheets in very large amount. Further movements forced the convexities of the first-formed folds against the andesites, and crowded their substance sidewise, to some extent, into the synclinals. This movement slightly parted the beds, affording watercourses through which rose siliceous waters. These dissolved away the neighboring beds, leaving extensive quartz bodies in their places. They also removed the andesite caps. No ore was formed as yet. Now followed great trachyte eruptions on the east, which loaded the hanging wall of the lode so heavily as to cause a downward movement of it on the foot, making a new series of openings, and into these poured the ore-bearing solutions which brought the precious metals. No one who has intelligently followed this explanation will doubt that Mr. Church has shown great ingenuity, and yet it is natural to prefer to avoid so long and involved an hypothesis, if a simpler course will lead to the same results. At the time of Mr. Church's visit the workings were becoming very deep, and the great heat, which has been since such an obstacle, was manifesting itself. Flooded drifts, it was thought, had been observed to grow hotter, and from this the hypothesis of kaolinization was conceived. It was that the kaolinization of the feldspar in the deeply buried rock occasioned the heat of the lode.

2.11.21. G. F. Becker (1879-82) comments on the excessive alteration which the rocks have undergone, as it figures largely in his hypothesis of origin. He then traces the results of faulting, and shows that under conditions like those present the surface would tend to assume a logarithmic curve, which coincides surprisingly well with the present outline of the country. After describing the lode itself, the origin of its metalliferous contents is traced as follows. Waters under hydrostatic pressure from the heights to the west are supposed to have percolated toward the lode, passing through deeply buried regions of heat. They were probably diverted from rising directly through the lode by an impervious clay seam, and were thus forced to traverse the diabase hanging, relieving it in passage of the metals, which were afterward deposited in the higher portions of the lode. The metals themselves were probably largely derived from the augite of the rock. Mr. Becker had as an associate Dr. Carl Barus, who studied the heat phenomena (especially the hypothesis of kaolinization) and the electrical manifestations of the lode. The result of Dr. Barus's careful experiments threw great doubt on kaolinization as a source of heat. The electrical experiments were not satisfactory. They were carried on also at Eureka, Nev., but no very definite results were reached.

2.11.22. The correct determination of the eruptive rocks neighboring to the Comstock has been of great importance, not alone because of their scientific interest, but as bearing on the fact as to whether the lode itself was a contact fissure between two different rocks, or whether it was simply a fissure vein. It is worthy of note that in connection with it Von Richthofen developed one of the first important attempts to classify the volcanic rocks, and that Hague and Iddings have finally urged that the peculiar crystalline textures of all eruptive rocks depend primarily on the rate of cooling and pressure (*i.e.*, depth below the surface) under which they have solidified, destroying thus the time element in classification. This is, to be sure, an old idea, but it gains its best confirmation from the Comstock. Von Richthofen, in his report to the Sutro Tunnel Company, and in his later memoir on "The Natural System of the Volcanic Rocks" (*Cal. Acad. Sci.*, 1867; also *Zeitschrift d. d. geol. Gesell.*, 1868, 663), distinguished in the Washoe district syenite, metamorphic rocks, quartz-porphyry, propylite, sanidine-trachyte, and very subordinate andesite. Mr. King referred much of the propylite of Von Richthofen to andesite, but retained the propylite as a distinct species, although remarking the close affinities of the two. The quartz-porphyry he called quartz-propylite. In other respects no changes are introduced. Zirkel (*Fortieth Parallel Survey*, Vol. VI.) determined the syenite as granular diorite, and while accepting hornblende-propylite and quartz-propylite as separate species, called the greater part of the quartzose rock dacite. He introduced for the first time augite-andesite, rhyolite, and basalt. Mr. Church paid less attention to lithology, and used the terms of his predecessors somewhat loosely. Mr. Becker makes the following classifications: granular diorite, porphyritic diorite, micaceous diorite-porphyry, quartz-porphyry, earlier diabase, later diabase, earlier hornblende-andesite, augite-andesite, later hornblende-andesite, and basalt. In this it will be seen that several new varieties are introduced, but the main mass of Mount Davidson was still considered diorite, and the vein was thought to lie between this and some of the other species mentioned, especially diabase. In 1885, Arnold Hague and J. P. Iddings completed new microscopal studies upon the materials collected by Mr. Becker, and the results were published as *Bulletin 17 of the United States Geological Survey* ("On the Development of Crystallization in the Igneous Rocks of Washoe," etc.). These two writers had had more to do with the eruptive rocks of the Great Basin and the Pacific slope than any other geologists, and hence brought to the review an exceptional experience. Nowhere else in the world are such exposures and thorough sections afforded, alike in depth and in horizontal extent. They proved that the diabase and augite-andesite shade into each other, the differences in crystallization being due to depth; that the hornblende of the so-called diorite was largely secondary from original augite, being derived by paramorphic change (uralitization), and that the diorite was a structural variety of the diabase; that the porphyritic diorites shade into the earlier hornblende-andesites, and are structural varieties of them; that the mica-diorites and hornblende-andesites are related in the same way; that the assumed pre-Tertiary age of the quartz-porphyry was unwarranted, and that it was partly dacite and partly rhyolite, the two shading into each other; that the younger diabase, so-called, of the sub-surface dike, was identical with the rock elsewhere occurring on the surface and called basalt, and was really a basalt, owing to its holocrystalline character to its depth; and finally—the most important conclusion of all in this connection, although the other conclusions are among the most important advances made in late years—"that the Comstock Lode occupies a line of faulting in rock of the Tertiary age, and cannot be considered as a contact vein between two different rock masses."

The crystalline structure of the Washoe rocks has been subsequently treated by Mr. Becker. ("The Washoe Rocks," *Bull. Cal. Acad. Sci.*, Vol. II., p. 93, January, 1887; "Texture of Massive Rocks," *Amer. Jour. Sci.*, ii., Vol. XXXIII., p. 50, 1887.) The various structures—granular, porphyritic, and glassy—are referred more to differences in composition and fluidity than to circumstances of solidification.[1]

[1] G. F. Becker, "Geology of the Comstock Lode and the Washoe District," *Monograph III., U. S. Geol. Survey.* Rec. See also *Eng. and Min. Jour.*, March 1, 1884, p. 162; *II. Ann. Rep. Dir. U. S Geol. Survey.* Rec. J. A. Church, *The Comstock Lode: Its Formation and History.* New York: John Wiley & Sons. Reviewed in *Eng. and Min. Jour.*, February 21, 1880 p. 397. See also shorter papers in the *Eng. and Min. Jour.*, December 28, 1878, p. 456; July 19, 1879, p. 35; December 12, 1885, p. 397; January, 23, 1886, p. 52. "On the Changes in the Comstock Vein," *Eng. and Min. Jour.*, December 18, 1886, p. 434; "The Discovery of the Comstock Lode," *Ibid.*, December 5 and 19, 1891, and other papers in 1892 by Dan De Quille. Hague and Iddings, "On the Development of Crystallization in the Igneous Rocks of Washoe, Nevada," etc., *Bull. 17, U. S. Geol. Survey.* See also *Bull. 6, Cal. Acad. Sci.*, and *Eng. and Min. Jour.*, December 11, 1886, p. 415. Charles Howard Shinn, "The Story of the Mine," *Hist.*

CHAPTER XII.

THE PACIFIC SLOPE: WASHINGTON, OREGON, AND CALIFORNIA.

WASHINGTON.

2.12.01. *Geology.*—Little is available in the way of systematic descriptions of the geology of Washington, and an attractive field remains to be developed. The ranges of the Rocky Mountains extend across the panhandle of Idaho and show in northeastern Washington, affording considerable amounts of ores. They are prevailingly granite and gneiss, which have escaped being covered by the enormous volcanic outbreaks of Tertiary and later time. West of the granites a great plateau country of somewhat diversified surface is met. It seems to have been an ancient lake basin, but is now covered by igneous rocks and deposits of volcanic tuff. Still farther west the Cascade chain forms the central divide of the State. The rocks are granites, flanked by Paleozoic, Mesozoic, and metamorphic strata, much like the Sierras of California. They were upheaved in large part before the Cretaceous, and since then other movements have occurred. There are vast developments of igneous rocks, forming, as at Mount Rainier, some of the highest American peaks. West of the Cascade range is a great valley formerly marking a drainage system, but now covered partly by glacial drift and partly by the waters of Puget Sound. The glacial deposits are enormous, and render the problem of working out the geology very difficult. Some glaciers remain on the heights even to the present day. West of the Puget Sound Basin is the northerly extension of the Coast range, locally called the Olympics, and largely Cretaceous and Tertiary strata.[1]

[1] G. F. Becker, *Tenth Census*, Vol. XIII., p. 27. G. A. Bethune, *First Ann. Rep. State Geol.*, 1891. A. Bowman, "Mining Developments on the

2.12.02. Good descriptions of the ore deposits of Washington are greatly needed. The First Annual Report of the State Geologist has little of scientific value, and the other accounts are more or less obsolete. There are gold placers in Yakima, Stevens, and Kittitas counties, largely worked by Chinese. But in Okanogan, Snohomish and Stevens counties, in the northeast, the developments of deep mining for silver ores, although recent, are considerable. The Monte Cristo veins afford great quantities of refractory and rather low grade ores, from very prominent veins. The chief country rock is granite, but numerous dikes of more basic varieties are present. The veins are largely in metamorphic rocks and contain the usual sulphides in quartz gangue.[1]

OREGON.

2.12.03. *Geology.* — Northeastern and northern central Oregon are formed by a prolongation southward of the igneous plateaus of Washington. Slates and granite appear in Baker County on the east, in the Blue Mountains, and the geology seems to resemble the Sierras. All southeastern Oregon belongs in the Great Basin, which comes north from Nevada, but is better watered than the southern portion. It is traversed by several subordinate ranges of the block-tilted basin type. Of these the Stein Mountains are the most prominent. The general surface is formed by Quaternary lake deposits and

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Northwest Pacific Coast and their wider Bearing," *Trans. Amer. Inst. Min. Eng.*, XV., 707. J. MacFarlane, *Geol. Railway Guide*, second edition, p. 262; notes by Pumpelly, Willis, and others. Rec. J. S. Newberry, "Geology and Botany of the Northern Pacific Railroad," *Trans. N. Y. Acad. Sci.*, III., 1884, p. 253. C. A. White, "Puget Group of Washington," *Amer. Jour. Sci.*, iii., XXXVI., 443. B. Willis, "Our Grandest Mountain and Deepest Forest," *School of Mines Quarterly*, VIII., 152. "Report on the Coal Fields of Washington Territory," *Tenth Census*, Vol. XV., p. 759. "Some Coal Fields of Puget Sound," *XVIII. Ann. Rep. Dir. U. S. Geol. Survey*, Part III., 393. "Changes of River Courses in Washington Territory due to Glaciation," *Bull. 40, U. S. Geol. Survey.* "Drift Phenomena of Puget Sound," *Bull. Geol. Soc. Amer.*, IX., III., 1898.

[1] G. A. Bethune, *First Ann. Rep. State Geol.*, 1891. C. N. Fenner. "The Monte Cristo District, Snohomish County," *School of Mines Quarterly*, November, 1892. "The Mines of Kittitas County," *Eng. and Min. Jour.*, December 24, 1892, p. 608. F. L. Nason, "The Auriferous Gravels of the Upper Columbia River," *Eng. and Min. Jour.*, March 21, 1896.

great outbreaks of igneous rocks. West of the basin and the plateau the Cascade range traverses the State, and is cut by the Columbia River on the north and the Klamath on the south. The range consists of granite and metamorphic rocks, etc., the latter chiefly Mesozoic. In northern Oregon a broad valley intervenes between the Cascade and the Coast ranges, but in the southern part the two ranges run together, and their distinction has been only partly worked out. (See *Bull. 33, U. S. Geol. Survey.*) In the Coast range Cretaceous and Tertiary strata predominate.[1]

2.12.04. Oregon is an important producer of gold both from placers and from veins. Baker County, on the east, presents the characteristic placers and gold quartz of the California Sierras, and is the most productive section of the State. Grant and Josephine counties also have placers, and smaller amounts come from a few others. In the extreme southeast, near the California line, is Curry County, containing:

2.12.05. Example 44*a*. Port Orford. Auriferous beach sands at the foot of gravel cliffs, and shifting with the winds and tides. At Port Orford the ocean has access to great sea cliffs of gravel which it breaks down by the force of the waves. A sorting action ensues, performed by the undertow and the littoral current. The heavier gold dust is concentrated and is gathered up by the miners at low tide. Some submarine work has also been attempted. The product is not great, and the

[1] G. F. Becker, *Tenth Census*, Vol. XIII., p. 27. T. Condon, "On Some Points Connected with the Igneous Eruptions along the Cascade Mountains of Oregon," *Amer. Jour. Sci.*, iii., XVIII., 406. J. S. Diller, "Notes on the Geology of Northern California," *Bull. 33, U. S. Geol. Survey.* "A Geological Reconnaissance in Northwestern Oregon," *XVII. Ann. Rep. U. S. Geol. Survey*, Part I., 447, with notes on the Economic Geology. J. C. Fremont, "Observations on the Rocky Mountains and Oregon," *Amer. Jour. Sci.*, ii., III., 192. George Gibbs, "Notes on the Geology of the Country East of the Cascade Mountains, Oregon," *Amer. Jour. Sci.*, ii., XX., 275. J. Leconte, "On the Great Lava Flood of the West and on the Structure and Age of the Cascade Mountains," *Amer. Jour. Sci.*, iii., VIII., 167, 259. C. King, *Fortieth Parallel Survey*, Vol. I. J. MacFarlane, *Geol. Railway Guide*, p. 316. J. S. Newberry, *Pacific R. R. Reports*, Vol. VI., pp. 1–73. I. C. Russell, "A Geological Reconnaissance in Southern Oregon," *IV. Ann. Rep. Dir. U. S. Geol. Survey*, pp. 435–462. G. O. Smith, "The Rocks of Mt. Rainier," *Idem*, 416. "Glaciers of Mt. Rainier," *XVIII. Ann. Rep. U. S. Geol. Survey*, II., 349.

deposit is chiefly interesting in its scientific bearing. It runs along into California as well. Auriferous sands occur at Yakutat Bay, Alaska.[1] The gold of the Potsdam sandstones of the Black Hills has been explained in a similar way, but later observations have modified the hypothesis. The magnetite sands which were referred to under 2.03.13 furnish something of a parallel.[2]

CALIFORNIA.

2.12.06. *Geology.*—The topography and geology of northern California have been but recently made clear. Diller considers that the southern end of the Cascade range is Mount Shasta; that the Sierras proper terminate near the north fork of the Feather River, but the line is continued about fifty miles farther north, in the Lassens Peak volcanic ridge, and that all else west and south of Mount Shasta belong to the Coast range. Central California, as is well known, has the Sierras on the east, the great Sacramento Valley in the middle, with the Coast range on the west. The arid regions of the Great Basin just touch the northeastern corner, but on the southern extremity they swing around and form a large part of the State. The Great Basin portion is formed by Quaternary lake deposits. The Sierras consist of central granite and gneiss, with great developments of slates and eruptives on their flanks. The excessive metamorphism has largely destroyed the fossils, but enough have been found to prove that while in large part Jurassic and Carboniferous, Triassic and Silurian representatives are also present. The western slopes have the mantles of gravel, which have furnished so much gold, and with these are large outflows of basalt. The upheaval of the Sierras occurred

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[1] J. Stanley-Browne, *Nat. Geogr. Mag.*, Vol. III., 196–198, 1891.

[2] G. F. Becker, *Tenth Census*, Vol. XIII., p. 27, general account of Oregon. W. P. Blake, "Gold and Platinum from Cape Blanco (Port Orford)," *Amer. Jour. Sci.*, ii., XVIII., 156. "Remarks on the Extent of the Gold Regions of California and Oregon," etc., *Amer. Jour. Sci.*, ii., XX., 72. A. W. Chase, "The Auriferous Gravel Deposits of Gold Bluffs, California," *Cal. Acad. Sci.*, 1874; *Amer. Jour. Sci.*, iii., VIII., 367. "Dredging for Gold," *Eng. and Min. Jour.*, June 23, 1883, p. 360. B. Silliman, "Cherokee Gold Washings," *Amer. Jour. Sci.*, iii., VI., 132. W. P. Watts, "Sands in Santa Cruz County, California," *Rep. Cal. State Mineralogist*, 1890, p. 622.

before the middle Cretaceous time. The Coast range contains large areas of sandstones, cherts, and lavas, probably of Jurassic age, as well as Cretaceous and Tertiary strata. They were upheaved in post-Miocene time. Great outbreaks of andesite also occurred, and later basalts. The principal product of California is gold, but there are districts which have furnished considerable silver, and which are first described in order to lead up to gold. The copper and iron resources have already been mentioned, and the mercury, antimony, and chromium deposits remain for description after the precious metals.[1]

[1] G. F. Becker, "Notes on the Early Cretaceous of California," *Amer. Jour. Sci.*, iii., II., 201. "Antiquities from under Tuolumne Table Mountain, California," *Bull. Geol. Soc. Amer.*, II., 189. "Cretaceous Metamorphic Rocks of California," *Amer. Jour. Sci.*, iii., XXXI., 348. "Structure of a Portion of the Sierra Nevada of California," *Bull. Geol. Soc. Amer.*, II., 50. "Notes on the Stratigraphy of California," *Bull. 19, U. S. Geol. Survey.* W. P. Blake, "Notes on California," *Amer. Jour. Sci.*, ii., XVIII., 441. W. H. Brewer epitomizes Whitney's report, *Amer. Jour. Sci.*, ii., XLI., 231; also 351. J. D. Dana, "Notes on Upper California," *Amer. Jour. Sci.*, ii., VII., 376. J. S. Diller, "Geology of the Lassen Peak District," *Eighth Ann. Rep. Dir. U. S. Geol. Survey*, pp. 401, 435. "On the Cretaceous Rocks of Northern California," *Amer. Jour. Sci.*, iii., XL., 476. "On the Geology of Northern California," *Proc. Phil. Soc. of Wash.*, January 16, 1886; Abstract, *Amer. Jour. Sci.*, iii., XXXIII., 152. "Geology of the Taylorville Region, Plumas County," *Bull. Geol. Soc. Amer.*, III., 369. G. K. Gilbert, "The Recency of Certain Volcanoes of the Western United States," *Amer. Assoc. Adv. Sci.*, XXIII., 29. A. Hyatt, "Jura and Trias of Taylorville, California," *Bull. Geol. Soc. Amer.*, III., 395. William Irelan, State Mineralogist, *Ann. Rep.*, 1886, and following, especially 1890, geology by counties. J. Leconte, "Post-Tertiary Elevation of the Sierra Nevadas, shown by the River Beds," *Amer. Jour. Sci.*, iii., XXXII., 167. "Old River Beds of California," *Ibid.*, iii., XIX., 190; iii., XXXVIII., 261. "Extinct Volcanoes about Lake Mono, and their Relations to the Glacial Drift," *Ibid.*, iii., XVIII., 35. Jules Marcou, "Report on the Geology of a Portion of Southern California," *Wheeler's Survey, Ann. Rep.*, 1876, App., p. 158. J. E. Mills, "Stratigraphy and Succession of the Rocks of the Sierra Nevada of California," *Bull. Geol. Soc. Amer.*, III., 413. E. Reyer, *Theoretische Geologie*, p. 537, 1888. I. C. Russell, "The Quaternary History of Mono Valley, California," *Eighth Ann. Rep. Dir. U. S. Geol. Survey*, pp. 267–400. H. W. Turner, "The Geology of Mount Diablo, with the Chemistry of the Rocks by W. H. Melville," *Bull. Geol. Soc Amer.*, II., 383. "Further Contributions to the Geology of the Sierra Nevada," *XVIII. Ann. Rep. Dir. U. S. Geol. Survey*, Part I., p. 521. Rec. "The Granitic Rocks of the Sierra Nevada," *Jour. Geol.*, VII., 141. Rec. J. A. Veatch, "Notes on a Visit to the Mud Volcanoes of the Colorado Desert," etc., *Amer. Jour. Sci.*, ii.,

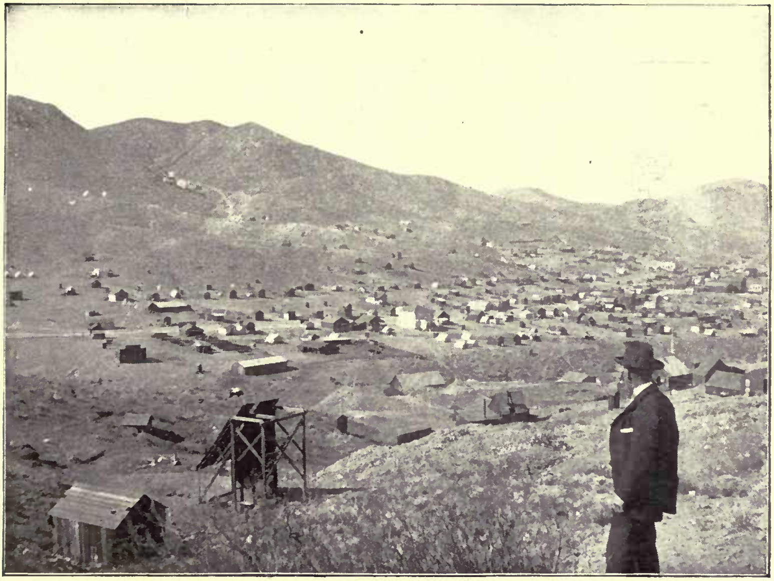

FIG. 136.—*View of Randsburg, Calif., looking southwest. Schists underlie the town, but the hills are eruptive. From a photograph by H. A. Titcomb, E. M.*

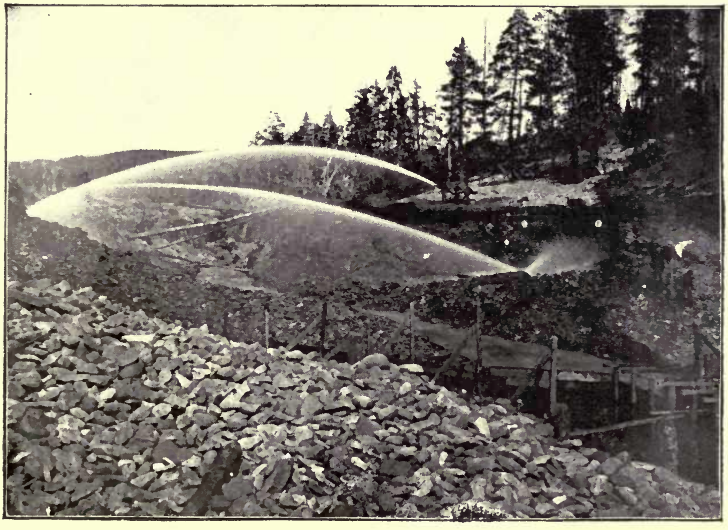

FIG. 137.—*The Stevens Hydraulic placer mine, Auro City, Colorado. From a photograph.*

FIG. 138.—*View in the Malakoff Hydraulic placer mine, North Bloomfield, California. From a photograph.*

FIG. 139.—*View in the Malakoff Hydraulic placer mine, North Bloomfield, California. From a photograph.*

2.12.07. Calico District. Deposits of silver chloride in fissure veins, and in small fractures and pockets in liparites, tuffs and sandstones, probably of the Pliocene series. They occur in Southwestern California, in that portion of the State belonging rather to the Great Basin than to the Pacific slope. An immense outbreak of liparite has formed a series of elevations, and the attendant tuffs are extensively developed. The ore is thought by Lindgren to have come in heated solution from below and to have filled the fissures and overflowed, forming the surface deposits in the tuffs. (Cf. Silver Cliff, Colorado.)

2.12.08. Likewise in the desert region, a gold camp has sprung up at Randsburg, in Kern County. Mica schists form the country rock of a series of hills that rise above an abandoned

XXVI., 288. J. D. Whitney and others, reports of the California Geological Survey, issued at Cambridge, Mass. L. G. Yates, "Notes on the Geology and Scenery of the Islands forming the Southern Line of the Santa Barbara Channel," *Amer. Geol.*, V., 43. The United States Geological Survey has prepared a number of folios on the geology of the gold belt, which are invaluable to all who are interested in the region. Each embraces a geological description and maps, which severally show the topography, geology, and mineral resources. The following have been issued and can be obtained at 25 cents each by addressing the Director of the U. S. Geological Survey, Washington, D.C. (the Nevada City Folio is 50 cents): Placerville, Sacramento. Jackson, Lassen Peak, Marysville, Smartsville, Nevada City, Pyramid Peak, Downieville, Truckee, Sonora and Big Tree. Others are in preparation.

FIG. 135.—*Geological section of the Calico district, California. After W. Lindgren, Trans. Amer. Inst. Min. Eng.*, XV., 719.

lake basin. The schists are seamed by dikes of porphyritic rock, which may have come from the volcanic center of Red Mountain or from other volcanic eminences not far away. The rock from the central and south peaks of Red Mountain, when examined in thin sections from specimens kindly sent the writer by H. A. Titcomb, E.M., proved to be hornblende-andesite, but the dikes from the vicinity of the mines were too decomposed for recognition. The gold ores occur in quartz veins, which usually are in association with the porphyry dikes, the country rock being the mica schist. The region suffers for lack of water, but as it is now connected by rail with the Santa Fé system, a number of mines and mills are in successful operation. The accompanying photograph (Fig. 136) illustrates the country.[1] The remoteness of other camps militates against their development.

2.12.09. On the eastern border of California and lying along the eastern slopes of the Sierras are Inyo and Mono counties, two that have been quite serious producers of silver (with subordinate gold) in past years. Deserted or greatly dwindled mining camps are frequently met throughout the mountains. The region lies within the confines of the Great Basin, and is somewhat poorly supplied with water. In Inyo County, granite, schists and crystalline limestone are very prominent in the general geology, and the ores are prevailingly of the lead-silver variety, and in limestone walls. The Cerro Gordo and Panamint districts were heavy producers in their day.[2] Mono

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[1] F. M. Endlich, "Mining in the Mohave Desert of California," *Eng. and Min. Jour.*, August 29, 1896, 147. H. G. Hanks, "On the Calico District," *Fourth Rep. Cal. State Mineralogist*, 1884, 366. Wm. Irelan, "On the Calico District," *Eighth Rep. Cal. State Mineralogist*, 1888, 490. W. Lindgren, "The Silver Mines of Calico District, California," *Trans. Amer. Inst. Min. Eng.*, XV., 717. F. L. Nason, "The Goler Gold Diggings," *Eng. and Min. Jour.*, March 9, 1895, 223. W. A. Skidmore, "On Calico District," *Rep. Director of the Mint*, 1884, 539. Rec. Other Reports of the Director of the Mint and Raymond's earlier reports may be advantageously consulted. In the *Min. and Sci. Press*, April 1, 1899, will be found a sketch of the Randsburg district and of the Yellow Aster Mine. The notes in the text on Randsburg were based on specimens and data kindly furnished by the writer's friend, H. A. Titcomb.

[2] H. DeGroot, "Report on Inyo County," *Tenth Rep. Cal. State Mineralogist*, 1890, 209. W. A. Goodyear, "Report on Inyo County," *Eighth Rep. Cal. State Mineralogist*, 1888, 224–309. Rec. H. G. Hanks, "Silver in

County lies next north of Inyo, and is remarkable for the vast development of volcanic rocks that it contains. While there are not a few mining districts in the county of no inconsiderable moment, details of which will be found in the references cited below, yet the pre-eminent one is Bodie. At Bodie a quite complex series of veins cut hornblende-andesite, over which, on the surface, is volcanic breccia. Various other eruptives occur in the neighborhood. The faults in which the veins are found have been formed at several different periods, but the tracing of their exact relations will require very careful work. The gangue is chiefly quartz, through which are distributed silver minerals with more or less gold.[1] Nearly all the other deep mines for the precious metals in California yield little else than gold, and although a few, such as those at Ophir, afford considerable silver, they will be mentioned with the distinctively gold-quartz veins.

2.12.10. Example 44. Auriferous Gravels. (1) River gravels, or placers in the beds of running streams. These have been often referred to in other States, but the type is placed in California, as they are there best known. They were the first gravels washed in 1849, and although substantially exhausted by 1860, were very productive. Eastward from the great Sacramento Valley the surface rises with a quite gentle gradient to the summit of the Sierras. The country consists chiefly of metamorphic rocks, which have yielded a very few well-determined fossils of both Carboniferous and Jurassic ages; but the identity of the strata in all the area is difficult to make out, because where the fossils were originally present they are almost entirely destroyed by metamorphism. Down

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California," *Fourth Rep. Cal. State Mineralogist*, 1884, 361. W. A. Skidmore, "Gold and Silver Mining in California, Past, Present and Future," *Rep. of Director of the Mint*, 1884, 538.

[1] H. DeGroot, "Report on Mono County," *Tenth Rep. Cal. State Mineralogist*, 1890, 336. H. W. Fairbanks, "Mineral Deposits of Eastern California," *Amer. Geol.*, March, 1896, 144. "Notes on the Geology of Eastern California," *Idem*, February, 1896, 63; describes Mono and Inyo Counties. C. D. Walcott, "Lower Cambrian Rocks in Eastern California," *Amer. Jour. Sci.*, February, 1895, 141. "The Appalachian Type of Folding in the White Mountain Range of Inyo County, California," *Idem*, March, 1895, 169. H. A. Whiting, "Report on Mono County," *Eighth Rep. Cal. State Mineralogist*, 352–402. "On Bodie," 382–402. Rec.

the slopes of the range the modern streams have flowed and cut deep cañons in which gravels have gathered. Out in the more open country the gravels have also accumulated and have furnished some productive bars. The gold has been derived principally from the quartz veins of the slates, which are later described, and has been mechanically concentrated in the streams. Before coming to its final rest it may have lodged in the high or deep gravels, of which mention will next be made.

It is accompanied by magnetite as a general thing, by zircon, garnet, and rarely by other heavy metals, such as platinum and iridosmine. The greatest amount is usually near the bedrock, and when this is at all porous the gold may work into it to a small distance from the top. The gold is usually in flattened pellets of all sizes, from the finest dust to nuggets of considerable weight, which show evidence of being water worn. The interesting phenomena connected with the possible circulation of the precious metal in solution through the gravels are discussed under the deep gravels. Important deposits of the same general character as these have also been dug over, near Santa Fé, N. M.; in California Gulch, near Leadville, Colo.; at Fairplay, Colo.; in San Miguel County, Colorado; in the Sweetwater district, Wyoming; near Butte, Mont.; in Last Chance and Prickly Pear gulches, near Helena, Mont.; in the Black Hills; in southern Idaho, especially along the Snake River; and at various points in Washington and Oregon. Placers of this type have also been found on the slopes of the Green Mountains and in the Southern States, but they never have proved of serious importance.

2.12.11. (2) High or Deep Gravels. With the exhaustion of the river gravels the gold seekers of California were driven to prospect on the higher slopes, where auriferous gravels much less accessible had long been noted. Increasing observation and development have shown that these are the relics of former and very extensive drainage systems, which were more or less parallel with the present streams, but of greater volume. The beds lie in deep gulches in the slates, and are capped in most cases by basaltic lava flows or by consolidated volcanic tuffs, called cement. They extend some 250 miles along the Sierras and up to 7000 feet above the sea. They have at times great thickness, reaching 600 feet at Columbia Hill, but drop elsewhere to 1 or 2 feet. They vary from a maximum width in workable material of 1,000 feet to a minimum of 150. The inclosing slates on the sides of the old river valley are called "the rims," and on them are sometimes found other gravels. In some districts channels, belonging to two or three periods of flow, have been traced. They tend to follow the softer strata, breaking at times across the harder rocks. The channel filling consists of gravel, sand, and clays, volcanic tuffs, and firm basalt. With these are great quantities of silicified trees, and even standing trunks project through some beds. The gravel is oftenest formed of white quartz pebbles, but may contain all the metamorphic rocks of the neighborhood, and even boulders brought from a great distance. The gravel at times is cemented together by siliceous and calcareous matter, and it

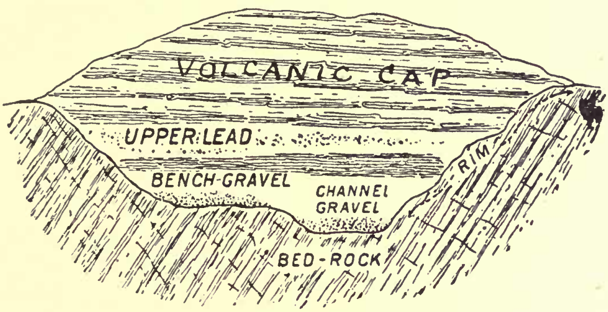

FIG. 140.—*Generalized section of a deep gravel bed, with technical terms. After R. E. Browne, Rep. Cal. State Mineralogist,* 1890, *p.* 437.

then requires blasting; but loose gravel also occurs. The clays are locally called "pipe clays," and are often interbedded with sand layers. They are blue when unoxidized, giving rise to the term "blue lead," but red oxidized clays are not infrequent. The clays contain many leaf impressions of species thought by Lesquereux to be late Tertiary. (See further under 2.12.13.) The gravels also contain bones of extinct vertebrates, and have afforded some authentic human remains and stone implements of good workmanship. The volcanic tuffs have been strong factors in modifying the original drainage lines. They have flowed into the ancient valleys in a state of mud and have then consolidated.

2.12.12. The richest gravels are those nearest the bed rock.

In these the distribution of the gold is governed more or less by the character of the ancient channels. It favors the insides of bends and the tops of steeper runs. The gradients of the old channels were fairly high, often running 100 to 200 feet per mile. Gold has also been found by assay in pyrite that has been formed in the gravels since their deposition, and from this it is evident that the precious metal does circulate in solution with sulphate of iron, but on this slender foundation some quite unwarranted chemical hypotheses for the origin of nuggets have been based. Substantially all the gold has been derived by the mechanical degradation of the quartz veins in the slates on other wall-rock.

2.12.13. The depths to which the modern streams have cut

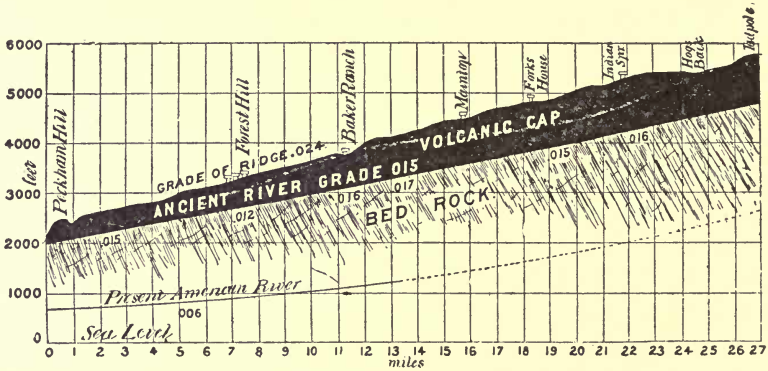

FIG. 141.—*Section of Forest Hill Divide, Placer County, California, to illustrate the relations of old and modern lines of drainage. After R. E. Browne, Rep. Cal. State Mineralogist*, 1890, *p.* 444.

out their channels below the old drainage lines have received considerable attention. Whitney concluded that no disturbance had taken place since the old gravels were laid down, but Le Conte has inferred that there has been a tilting or elevation of the higher parts of the range, all moving as a block. Becker has recently described in the high portions a great series of small north and south faults with uniform downthrow on the western side or upthrow on the eastern. (See paper below, cited from Geological Society of America.) This is supposed to have been of varied intensity in different portions and to have been limited to the strip just west of the summit. It is attributed to the Pliocene and is thought to have increased the gradient of the streams where the present deep cañons occur, but to have had no effect near the plains, where the old and new channels are nearly on the same level. Later work has cast much doubt on these views.

2.12.14. After the formation of the deep gravels and after the volcanic flows, glaciation took place in great extent over the mountain sides, but it was doubtless later in time than the glacial period of the East. References to the similar great development of the ice in Washington have already been made. Many hypotheses were early advanced to explain the deep gravels. They have been referred to the ocean, to ocean currents, and to glaciers; but it is now well established that they are river gravels, formed when the rainfall was probably in excess of what it is to-day, and when the attitude of the land toward the ocean probably was different.[1]

[1] G. F. Becker, "Notes on the Stratigraphy of California," *Bull. 19, U. S. Geol. Survey.* "Structure of the Sierra Nevadas," *Geol. Soc. Amer.*, II., 43. W. P. Blake, "The Various Forms in which Gold Occurs," *Rep. Director of the Mint*, 1884, p. 573. A. J. Bowie, Jr., "Hydraulic Mining in California," *Trans. Amer. Inst. Min. Eng.*, VI., 27. R. E. Browne, "The Ancient River Beds of the Forest Hill Divide," *Rep. Cal. State Mineralogist*, 1890, p. 435. Rec. "California Placer Gold," *Eng. and Min. Jour.*, February 2, 1895, 101. T. Egleston, "Formation of Gold Nuggets and Placer Deposits," *Trans. Amer. Inst. Min. Eng.*, IX., 63. "Working Placer Deposits in the United States," *School of Mines Quarterly*, VII., p. 101. J. H. Hammond, "Auriferous Gravels of California." *Rep. Director of the Mint*, 1881, p. 616. Rec. *Rep. Cal. State Mineralogist*, 1889, p. 105. H. G. Hanks, "Placer Gold," *Rep. Director of the Mint*, 1882, p. 728. H. G. Hanks, William Irelan and J. J. Crawford, *Rep. Cal. State Mineralogist*, Annual. T. S. Hunt, "On a Recent Formation of Quartz, and on Silicification in California," *Eng. and Min. Jour.*, May 29, 1880, 369. J. Leconte, "The Old River Beds of California," *Amer. Jour. Sci.*, iii., XIX., 80, p. 176. J. J. McGillivray, "The Old River Beds of the Sierra Nevada of California," *Rep. Director of the Mint*, 1881, p. 630. R. I. Murchison, "Siluria," etc.; contains a sketch of the distribution of gold over the earth. F. L. Nason, "The Goler Gold Diggings," *Eng. and Min. Jour.*, March 9, 1895, 223. J. S. Newberry, "On the Genesis and Distribution of Gold," *School of Mines Quarterly*, Vol. III.; *Eng. and Min. Jour.*, December 24 and 31, 1881. J. A. Phillips, "Notes on the Chemical Geology of the California Gold Fields," *Philos. Mag.*, Vol. XXXVI., p. 321; *Proc. Roy. Soc.*, XVI., 294; *Amer. Jour. Sci.*, ii., XLVII., 134. F. L. Ransome, "The Great Valley of California: A Criticism of Isostasy," *Bull. Dept. of Geol., Univ. of Cal.*, I., 370–428, 1896. B. Silliman, "On the Deep Placers of the South and Middle Yuba, Nevada County, California," *Amer. Jour. Sci.*, ii., XL., 1. J. D. Whitney, "Auriferous Gravels of the Sierras," Cambridge, 1880. "Climatic Changes in Later Geological Times," Cambridge. See also references on succeeding pages relating to California.

2.12.15. The U. S. Geological Survey has been directing its attention in recent years to the geology of the gold belt in the Sierras in connection with the issue of atlas sheets, based on topographic and geologic surveys. Several of these are practically complete, and they and the auxiliary papers which have resulted from the work have served to throw a flood of light upon the obscure problems of the geology of the Sierras. At the same time, as cited under subsequent paragraphs, other local workers have been active. The geological relations of the gravels as well as the solid strata have been made clear in greater detail than ever before. Waldemar Lindgren has discussed the geological history of the American and Yuba rivers in his valuable paper entitled, "Two Neocene Rivers of California" (*Bull. Geol. Soc. of America*, IV., 257, 1893.) The conclusion is that the old divide in general coincided with the present one, but that the slope of the Sierra has been considerably increased since the time when the Neocene (*i.e.*, Miocene and Pliocene) ante-volcanic rivers flowed over its surface. "It finally appears probable . . . that the surface of the Sierra Nevada has been deformed during this uplift, and that the most noticeable deformation has been caused by a subsidence of the portion adjoining the great valley, relatively to the middle part of the range." A careful review of the age of the auriferous gravels in general by Lindgren, and of the fossil plants from Independence Hill, by Knowlton, has led to the conclusion that the deep gravels, which themselves lack fossils, date, in instances, probably as far back as the Eocene, but not earlier. Some bench gravels certainly were strongly developed in the Miocene and gravels of one sort or another have been formed from that time to the present.[1]

Lindgren has even brought to light the existence of an auriferous conglomerate in the upturned Mariposa beds of Jurassic age, near Mine Hill, Calaveras County. The crushed conglomerate gave good colors, but no black sand, from which it was inferred with great reason that the gold came from veins already existing in pre-Jurassic time in the earlier strata and before the intrusion of the basic igneous rocks of the region.[2]

[1] W. Lindgren, "Age of the Auriferous Gravels of the Sierra Nevada," with a Report on the Flora of Independence Hill, by F. H. Knowlton, *Jour. Geol.*, IV., 881, 1896.

[2] W. Lindgren, "Auriferous Conglomerate of Jurassic Age in the Sierra Nevada," *Amer. Jour. Sci.*, October, 1894, 275.

H. W. Fairbanks has controverted the above interpretation and regards the presence of the gold as due to later mineralization.[1]

Fairbanks also takes issue with the interpretation by R. L. Dunn of an auriferous conglomerate in the Klamath Mountains, as a river gravel of pre-Chico age, regarding it rather as shore conglomerate in the Chico itself.[2]

J. S. Diller has discussed the early physiography but for a wider range of country than any of the papers hitherto cited.[3] Mr. Diller shows that the western side of the present Sierras formed in the Eocene or Tejon times a gently-sloping base-level of erosion, with quiet streams and extensive superficial deposits of a residual character. The Sierras were from 4,000 to 7,000 feet below their present altitude. With the Miocene came a period of upheaval, of increased gradients and rapid denudation of the soft surface materials. The old auriferous gravels were thus formed in the stream channels while the lighter materials were transported out to sea. The course of development is graphically traced out by Diller in accordance with our modern knowledge of stream-erosion and transportation. For southern California, A. C. Lawson has described a somewhat similar development in later geological time,[4] but as the region is not one of auriferous gravels, it is only cited here as of interesting correlative character. H. W. Turner has lately reviewed the whole stratigraphy of the region south of the fortieth parallel, has correlated the new formational names adopted in the survey atlas sheets, has added many valuable notes on the petrography of the igneous rocks, and has outlined the stratigraphical relations of the gravels.[5] Mr. Turner distinguishes two series of Neocene river gravels (p. 241). (1) The older gravels composed

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[1] H. W. Fairbanks, "Auriferous Conglomerate in California," *Eng. and Min. Jour.*, April 27, 1895, 389.

[2] R. L. Dunn, *Twelfth Ann. Rep. Cal. State Mineralogist*, 1894, 459.

[3] J. S. Diller, "Revolution in the Topography of the Pacific Coast since the Auriferous Gravel Period," *Jour. Geol.*, II., 32, 1894.

[4] A. C. Lawson, "The Post-Pliocene Diastrophism of the Coast of Southern California," *Bull. Dept of Geol., Univ. of Cal.*, I., 115, December, 1893.

[5] H. W. Turner, "Geological Notes on the Sierra Nevada," *Amer. Geol.*, XIII., pp. 228, 297, 1894.

chiefly of white quartz pebbles and frequently capped by rhyolitic flows. These may be characterized in a broad way as the gravels formed before the volcanic period. (2) A later series, containing volcanic pebbles chiefly of andesite and later in age than the rhyolitic flows. These may be called the gravels of the volcanic period. Such gravels are often capped by andesite-tuffs. Included fossil leaves indicate that the older gravels are Miocene or Eocene; the later, Pliocene. The Pliocene river gravels merge into shore gravels of the same age in Amador and Calaveras counties. The pebbles in the shore gravels are quartzite, mica-schist, quartz-porphyrite, granitoid rocks, andesite, and rhyolite, the last named being at times very abundant and characteristic. They appear to have been deposited along the shores of the great gulf which filled the central valley of California in these times. They now range as a general thing 500 to 700 feet above the sea. Later than the Pliocene gravels are the Pleistocene, both shore and river deposits. The former occur in the depressions between the Neocene and older hills and at a lower altitude, by one to several hundred feet. They seem to consist of the harder pebbles of the Pliocene gravels, the softer ones having been destroyed by abrasion. The Pleistocene river gravels lie usually less than 100 feet above the present streams, and also in remnants of the channels left behind by old changes of course. They and the shore deposits of this time are often highly auriferous. Several lake-bottoms of this period have been recognized where, for some reason, such as the damming of a stream by a volcanic flow, or a probable mountain upheaval, the waters were set back. These lakes have left benches which mark their old shore lines. Finally, we have the recent stream gravels and alluvium. These papers show that the geological relations are more complex than was earlier known, but in their practical bearings the gravels can perhaps hardly be better grouped than into the River gravels or placers, in the beds of running streams, and the High or Deep gravels, according to the old nomenclature.

2.12.16. In résumé of the above review it should be first appreciated that stream gravels are the least favorable of all sediments to the preservation of organic remains. Not only are few animals with hard parts resident of swiftly flowing currents, but such shells or bones as might reach them would be liable to destruction from the trituration of the boulders. The stratigraphical relations of the gravels must therefore be worked out in great part, by other forms of evidence. It should also be appreciated that the old channel-fillings remain to us to-day only as fragments of their former extent, and that they are largely buried under lava flows and tuffs. The gravels therefore appear in narrow outcrops and set up narrow valleys, which are cut off from their neighbors, north and south by high divides. While they were being deposited, moreover, in past geological time, more extensive contemporaneous formations were being laid down in the then submerged valley of California, and with the latter it is important to correlate them. The kinds of evidence that are available are the following: The lithological character of the pebbles; the relations of the non-fossiliferous gravels to others in whose interbedded clays or tuffs, fossil plants occur; the physiographic conditions under which the gravels were laid down, and which must have been uniform over a great part of the State and have left correlative records, if they can be found; and finally the relations of the gravels to the volcanic outbreaks, whose lithological succession may be worked out.

In the following tabular statement the endeavor has been made to utilize the classification of the gravels into periods, which was prepared by Ross E. Browne (*10th Ann. Rep. Calif. State Mineralogist*, 437) and add thereto other determinations by the geologists of the U. S. Survey, or by California geologists.

Jurassic.	Auriferous gravel, now a conglomerate.[1]
Cretaceous.	Pre-Chico auriferous river gravel in the Klamath Valley, Siskiyou County.[2] (They may be beach gravels of the Chico itself.)[2]
Eocene.	Auriferous gravels doubtful.
Miocene.	Deep gravels with quartz pebbles of Browne's First Period,[3] which was

[1] W. Lindgren, "An Auriferous Conglomerate of Jurassic Age from the Sierra Nevada," *Amer. Jour. Sci.*, October, 1894, 275; see also H. W. Fairbanks, *Eng. and Min. Jour.*, April 27, 1895, 389.

[2] R. L. Dunn, "Auriferous Conglomerate in California," *Twelfth Ann. Rep. Cal. State Mineralogist*, 1894, 459; see also H. W. Fairbanks, as under preceding reference.

[3] Ross E. Browne, "The Ancient River Beds of the Forest Hill Divide," *Tenth Ann. Rep. Cal. State Mineralogist*, 1890, 437–440.

	closed by Pliocene andesite eruptions. The chief auriferous gravels belong in this period. Bench gravels. Some rhyolite eruptions occurred during it.[1] (Turner's "Intermediate Period,"[1] pebbles of pre-Cretaceous sedimentary and igneous rocks; presumably later than the first period, but of uncertain taxonomic relations with the second period.)[2]
Miocene Pliocene.	Second Period of Browne[3] gravels formed in shifting channels during or between successive volcanic eruptions and mud flows, both of andesitic nature. Pebbles mostly volcanic.
Pliocene to Present.	Third Period of Browne,[3] dating from last important lava and mud-flow; beginning and completion of present stream valleys. River gravels.

2.12.17. Example 45. Gold Quartz Veins. Veins of gold-bearing quartz, often described as segregated veins, in slates or metamorphosed igneous rocks, and more or less parallel with the schistosity. Less commonly the walls are massive, igneous rocks. The quartz contains auriferous pyrite, free gold, arsenopyrite, chalcopyrite, tetrahedrite, galena, and blende, but pyrites is far the most abundant. Tellurides have been occasionally detected in small amounts.[4] The veins approximate at times a lenticular shape, which is less marked in California than in some other regions, and which shows analogies of shape with pyrites lenses (Example 16) and magnetite lenses

[1] H. W. Turner, "Auriferous Gravels of the Sierra Nevada," *Amer. Geol.*, June, 1895, 372.

[2] Lindgren and Knowlton, "Age of the Auriferous Gravels of the Sierra Nevada," *Jour. Geol.*, IV., 881, 1896; see especially table, p. 906.

[3] Ross E. Browne, "The Ancient River Beds of the Forest Hill Divide," *Tenth Ann. Rep. Cal. State Mineralogist*, 1890, 437–440.

Each of the above papers has important complementary relations to the others.

[4] For a review and bibliography of the Tellurides, see J. F. Kemp, *The Mineral Industry*, Vol. VI., p. 295.

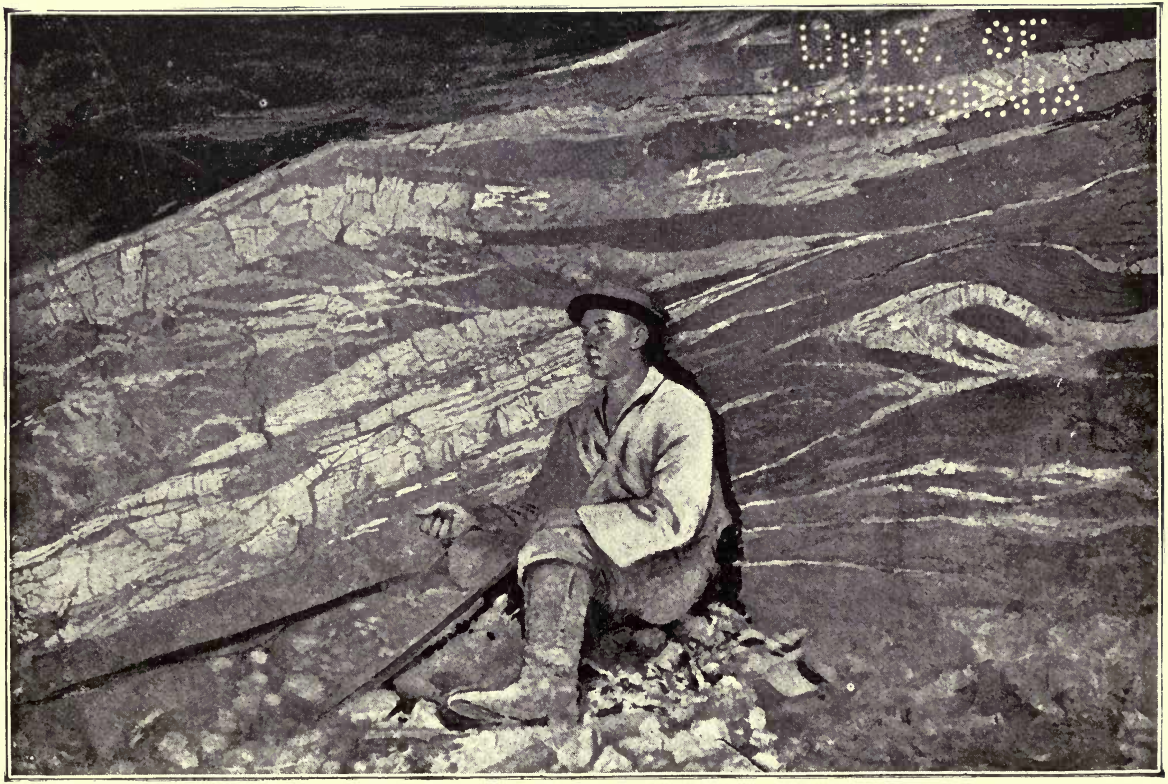
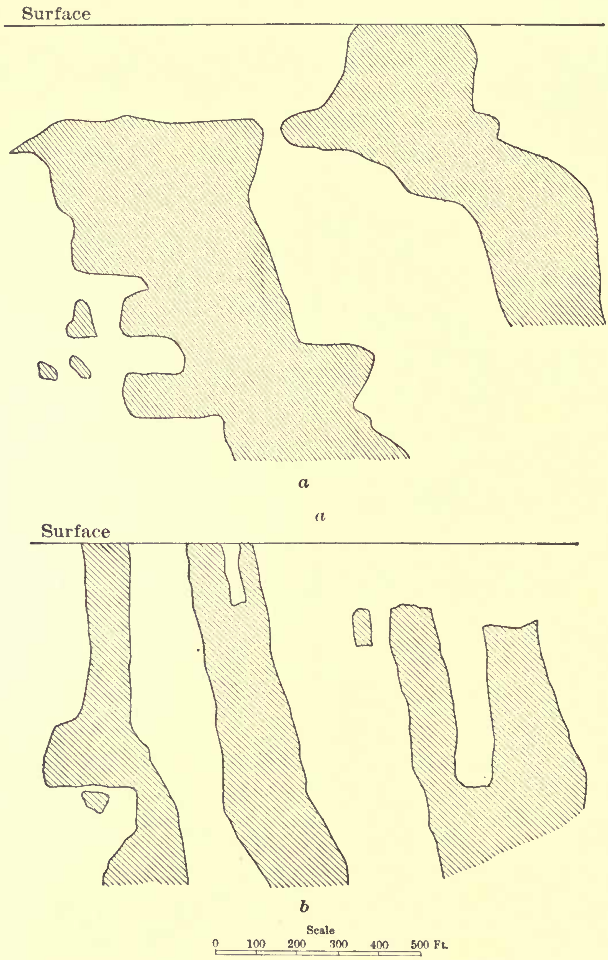


FIG. 142.—*North Star vein, Grass Valley, Calif., showing quartz-vein in brecciated and altered diabase After W. Lindgren, XVII. Ann. Rep. U. S. Geol. Survey, Part II., Plate XIV.*

(Example 12). In such cases the fissure-vein character is somewhat obscure. In California the veins occupy undoubted fissures in the slates. The largest and best known is the so-called Mother Lode, which is a lineal succession of innumerable larger and smaller quartz veins that run parallel with the strike, and rarely cut the steep dip of the slates at an angle of 10°. It was doubtless formed by faulting in steeply dipping strata. The wall rocks of the California veins embrace many types of igneous rocks, as well as sedimentary slates, for all these enter into the western slopes of the Sierras. The frequent serpentine is probably a metamorphosed igneous rock, while the diabase and diorite form great dikes. Considerable calcite, dolomite, and ankerite occur with the quartz, and very often it is penetrated by seams of a green, chloritic silicate, which was provisionally called mariposite, but which has been shown by Turner to be a potassium mica, colored green by chromium. The quartz veins vary somewhat in appearance, being at times milk white and massive (locally called "hungry," from its general barrenness), at times greasy and darker, and again manifesting other differences, which are difficult to describe, although more or less evident in specimens. The richer quartz in many mines is somewhat banded, and is called ribbon quartz. The quartz has been studied in thin sections, especially in rich specimens, by W. M. Courtis, who shows that fluid or gaseous inclusions of what is probably carbonic acid are abundant. In rich specimens the cavities tend to be more numerous than in poor, but more data are needed to form the basis of any reliable deductions. Some quartz shows evidence of dynamic disturbances. The walls of the veins are themselves at times impregnated with the precious metal and the attendant sulphides. The rich portions of the veins occur in chutes which run diagonally down on the dip.

2.12.18. The great Mother Lode is the largest group of veins in California. It extends 112 miles in a general northwest direction. Beginning in Mariposa County, in the south, it crosses Tuolumne, Calaveras, Amador, and El Dorado counties in succession. It is not strictly continuous nor is it one single lode, but rather a succession of related ones, which branch, pinch out, run off in stringers, and are thus complex in their general grouping. Over 500 patented locations have been made on it. Whitney suggested that it may have originated from the silicification of beds of dolomite, but others regard it, with greater reason, as a great series of veins along a



FIGS. 143 *and* 144.—*Ore shoots of Nevada City and Grass Valley mines, Cal. After W. Lindgren, XVII. Ann. Rep. U. S. Geol. Survey, Part II., Plate XVIII., slightly reduced.*

fissured strip. The veins are often left in strong relief by the erosion of the wall rock, and thus are called ledges, or reefs. Some discussion has arisen over the condition of the gold in the pyrite, but in most cases it is the native metal mechanically mixed, and not an isomorphous sulphide. It has been detected in the metallic state, in a thin section of a pyrite crystal from Douglass Island, Alaska, as later set forth (2.13.13,) and the fact that it remains as the metal when the pyrite is dissolved in nitric acid makes this undoubtedly the general condition. The association of gold with bismuth, which has been shown by R. Pearce to occur in the sulphurets of Gilpin County, Colorado (referred to on p. 306), and the difficulty experienced in amalgamating some ores, indicate the possibility of

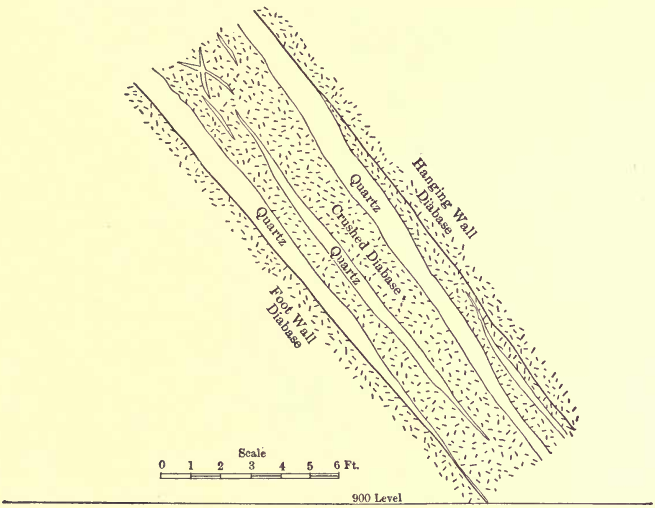


FIG. 145.—*Section of the Pittsburg vein, ninth level, Nevada City district, Cal. XVII. Ann. Rep. U. S. Geol. Survey, Part II., p.* 204, *reduced one half.*

other combinations. When crystallized, gold has shown, in one specimen and another, nearly all the holohedral forms of the isometric system, but the octahedron and rhombic dodecahedron are commonest.

2.12.19. The veins are younger than the igneous rocks with which they are associated. Granite and grano-diorite are especially frequent, but diorite, gabbro, diabase, porphyrite and serpentine, presumably derived from some basic intrusion, are also met. Although Von Richthofen stated that the veins seldom occur far from granite, this has been shown by Lindgren to be unjustified. The greater number are in slates, and the richest in a particular series of slates, but they also cut all manner of igneous rocks and have no constancy of direction. No

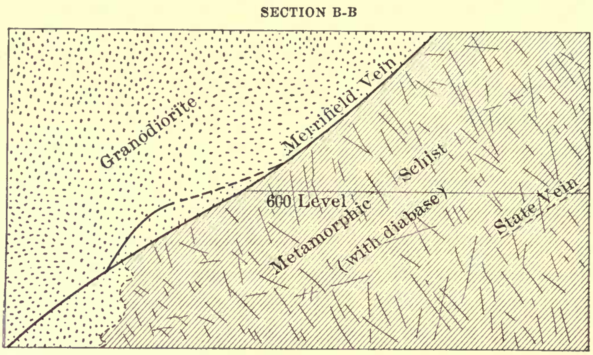


FIG. 146.—*Geological section at the Merrifield vein; Providence claim, Nevada City district, Cal. After W. Lindgren, XVII. Ann. Rep. U. S. Geol. Survey, Part II., Plate XXI., slightly reduced.*

sharp line divides them from silver-gold veins, which occasionally occur in the distinctive gold-belt nor from the veins earlier

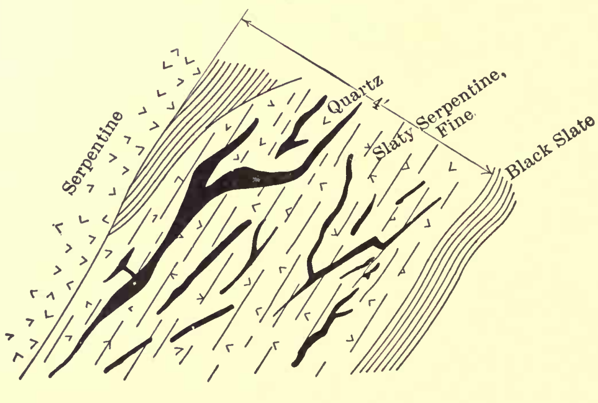


FIG. 147.—*Cross-section of vein in St. John mine, fifth level, Nevada City district, Cal. After W. Lindgren, XVII. Ann. Rep. U. S. Geol. Survey, Part II., p.* 223.

described in eastern California (2.12.07), but still the gold-quartz type is in characteristic examples sufficiently pronounced to justify its special treatment. The close relationships that prevail between pegmatite dikes or veins, at one extreme and quartz veins at the other, in many parts of the world, and the occasional auriferous character of true pegmatites, may be suggestive as throwing light on their nature and origin, especially in regions of intrusive granite.

While igneous dikes often form one wall and slate the other, the source of the ore has been placed by our best observers in deep-seated regions, whence the uprising solutions have brought it. Lateral secretion finds slight support and the character of the walls has exercised small influence, yet the presence of igneous rocks is in the large way favorable, because indicating

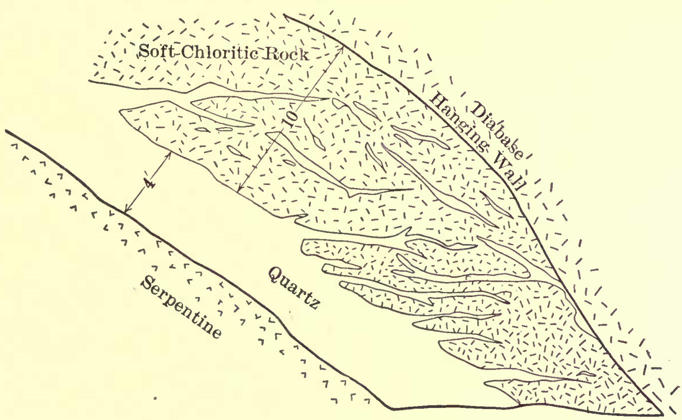


FIG. 148.—*Cross-section of the Maryland vein, in slopes above the* 1500-*foot level, Grass Valley district, Cal. After W. Lindgren, XVII. Ann. Rep. U. S. Geol. Survey, Part II., p.* 226, *slightly reduced.*

thermal conditions at depths, which have stimulated mineral-bearing circulations.

Fairbanks has thought that evidence of the replacement of the wall rocks could be noted, but Lindgren controverts this view and refers them to the filling of actual cavities. As a rule, they are not much broader than two or three feet, although a network of small veins and even solid quartz may extend over a much greater width, and the gold may to a considerable degree impregnate the wall-rock. In the case of a considerable width of pure quartz, say 20 or 30 feet, an original cavity of this size is thought improbable by Fairbanks, who cites such veins as strong indications of replacement. That some gold-bearing ore bodies, which depart from the typical quartz vein, have been deposited by replacement is also maintained by H. W. Turner[1] who mentions the Diadem lode, southwest of Meadow Valley, Plumas County, which appears to be a bed of limestone or dolomite chiefly replaced by gold-bearing quartz and chalcedony, but in such a way that fossil foraminifera are still identifiable in the ore. Turner also mentions a number of albitic dikes, of which one at the Shaw mine is described in the next paragraph, and which are impregnated with gold-bearing pyrites

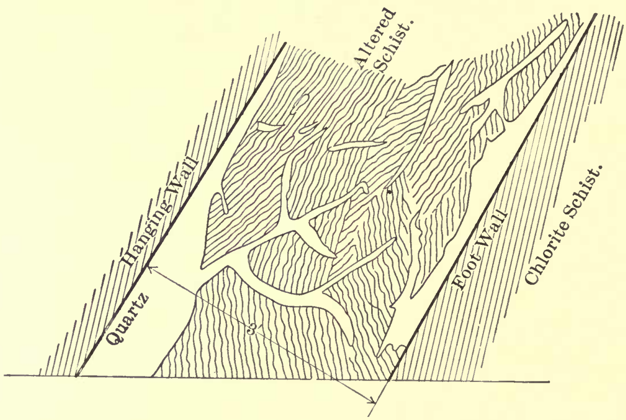


FIG. 149.—*Cross-section of the Brunswick vein, on the* 700-*foot level, Grass Valley district, Cal. After W. Lindgren, XVII. Ann. Rep. U. S. Geol. Survey, Part II., p.* 230.

of low grade. The latter has partly entered cracks and partly impregnated the rock itself. In connection with replacement, however, Lindgren has acutely remarked that siliceous replacements exhibit either a very fine-grained aggregate of minute quartz crystals or else chalcedony, both quite different from the coarsely crystalline quartz of the typical veins.

2.12.20. In rare instances the gold is associated with some other gangue than quartz. Thus in Vol. XIII., p. 24, of the *Tenth Census*, G. F. Becker records gold in calcite, in the Mad Ox mine of Shasta County, where the hanging wall is a

[1] H. W. Turner, "Replacement Ore Deposits in the Sierras," *Jour. Geol.*, May–June, 1899, 389.

siliceous limestone. J. S. Diller has cited a similar case from Minersville, Trinity County. The gold occurred in veinlets of calcite in a dark, carbonaceous shale (*Amer. Jour. Sci.*, February, 1890, p. 160). Waldemar Lindgren[1] has described an instance in which gold with some silver occurred in seams of barite, which were themselves in a kaolinized zone in diabase and diabase-porphyrite. In the kaolin 0.34% $BaSO_4$ was determined by analysis. It may have been derived from the feldspar of the original diabase. W. F. Hillebrand[2] has lately shown the wide distribution of both barium and strontium. Lindgren[3] has also written of most remarkable veins at Meadow Lake in Nevada County, that contain auriferous sulphides and arsenides in a gangue of tourmaline, quartz and epidote in granitic and diabasic rocks. This aggregate suggests fumarolic action. Similar associations of gold with tourmaline have been met in the Zoutpansberg District, South Africa, and in Brazil, as earlier noted. Through the kindness of Mr. Leo von Rosenberg, the writer has had an opportunty to examine a suite of ores from the Shaw mine, El Dorado County, which have been donated to the School of Mines, Columbia University. The same had been previously studied by H. W. Turner, of the U. S. Geol. Survey, by whom the determinations were originally made. The mine is based on a dike of porphyrite, sixty or seventy feet thick and charged with pyrites. It is auriferous throughout, but richest next the walls. The gold in the native form occurs in veinlets of albite, which ramify through the porphyrite. An analysis by Mr. Hillebrand established the identity of the albite.[4] T. A.

[1] W. Lindgren, "The Gold Deposit at Pine Hill, California," *Amer. Jour. Sci.*, August, 1892, p. 91.

[2] W. F. Hillebrand, "The Widespread Occurrence of Barium and Strontium in Rocks," *Jour. Amer. Chem. Soc.*, February, 1894, p. 81.

[3] W. Lindgren, "The Auriferous Veins at Meadow Lake, California," *Amer. Jour. Sci.*, September, 1893, 201.

[4] Since the above was written Mr. Turner has published the results of his examination of this ore, as well as many additional important notes on the associates of the gold. (H. W. Turner, "Notes on the Gold Ores of California," *Amer. Jour. Sci.*, June, 1894, p. 467.) Mr. Turner also cites gold in quartz in rhyolite, and gold with cinnabar. For a cross section of the mine, see E. E. Olcott, *Trans. Amer. Inst. Min. Eng.*, XXIV., 883. Other notes appear in a paper by C. A. Aaron, *Eng. and Min. Jour.*, November 19, 1892, and in a paper in the *Amer. Geol.*; XVII., 380, 1896

Rickard[1] has called attention to the especial abundance of gold at the intersection of small quartz veins in Tuolumne and Calaveras counties, California, and to the occurrence of a particularly rich pocket in the Rathgeb mine, San Andreas, where a small vein was faulted a few inches, and where the gold was associated with pitch-blende or uraninite and uranium ochre.[2] W. H. Storms describes the Alvord mine in San Bernardino County where the gold occurs with a siliceous limonite in chutes in a belt of limestone.[3] Storms in the citations given below records a great variety of wall rocks in which the veins occur, as well as interesting mineralogical details.

2.12.21. The formation of much the greater number of the veins followed the intrusion of the grano-diorite, which occurred at the close of the Jurassic or in early Cretaceous time. Some, however, may have existed before this, as is shown by Lindgren's interpretation of the Jurassic, auriferous conglomerate, earlier cited, and a great series of veins certainly followed the Tertiary igneous outbreaks in the high Sierras. It seems quite indisputable, as advocated by Lindgren, that the gold and its associated minerals, including the quartz gangue came up in heated alkaline solution, and that the vein formation was attended by extended carbonatization of the walls. The deposition of the silica had slight chemical effect on the wall rock in other respects, for the change of the latter to carbonates is the chief alteration visible. The enormous introduction of silica is one of the most extraordinary features of the geology of the Sierras, and indicates a remarkable activity of circulating waters.

The igneous intrusions doubtless promoted, if they did not cause, the circulations.[4] While the gold is often entangled in

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[1] T. A. Rickard, "Certain Dissimilar Occurrences of Gold-bearing Quartz," *Proc. Colo. Sci. Soc.*, September, 1893, pp. 6–9.

[2] Henry Lewis has given a very complete review of the associates and occurrence of gold in the *Mineralogical Mag.*, X., 241, London, 1893.

[3] W. H. Storms, "The Wall Rocks of California Gold Mines," *Eng. and Min. Jour.*, February 23, 1895, 172.

[4] F. Alger, "Crystallized Gold from California," *Amer. Jour. Sci.*, ii., X., 101. M. Attwood, "On the Wall Rocks of California Gold Quartz and the Source of the Gold," *Rep. Cal. State Mineralogist*, 1888, p. 771 (thought to be due to igneous injection in diabase). W. P. Blake, "On the Parallelism between the Deposits of Auriferous Drift of the Appalachian

pyrite, and while it appears to have been associated with this iron compound in its precipitation, yet it also seems to have certainly been precipitated in the native state in many instances 2.12 22. The chemical reactions involved in the introduc-

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Gold Field and those of California," *Amer. Jour. Sci.*, ii., XXVI., 128. "Remarks on the Extent of the Gold Region of California and Oregon," etc., *Ibid.*, ii., XX., 72. "The Carboniferous Age of a Portion of the Gold-bearing Rocks of California," *Ibid.*, ii., XLV., 264. W. H. Brewer, reply to above, *Ibid.*, ii., XLV., 397. A. Bowman, "Geology of the Sierra Nevada in relation to Vein Mining," *Min. Resources West of the Rocky Mountains,* 1875, p. 441. W. H. Brewer, "On the Age of the Gold-bearing Rocks of the Pacific Coast," *Amer. Jour. Sci.*, ii., XLII., 114. F. G. Corning, "The Gold Quartz Mines of Grass Valley, California," *Eng. and Min. Jour.*, December 11, 1886, p. 418. W. M. Courtis, "Gold Quartz," *Trans. Amer. Inst. Min. Eng.*, XVIII., 639. H. W. Fairbanks, "Geology of the Mother Lode," *Tenth Ann. Rep. Cal. Min.;* also in briefer form in *Amer. Geol.*, April, 1891, p. 201. Rec. "On the Pre-Cretaceous Rocks of the California Coast Ranges," *Amer. Geol.*, March, 1892; February, 1893. "The Relation between Ore Deposits and their enclosing Walls," *Eng. and Min. Jour.*, March 4, 1893, 200. J. H. Hammond, "Mining of Gold Ores in California," *Tenth Ann. Rep. State Min.*, p 852. . Rec. P. Laur, "Du Gisement et de l'Exploration de l'Or en Californie," *Ann. des Mines*, Vol. III., 1863, p. 412. W. Lindgren, "The Gold Deposit at Pine Hill, California," *Amer. Jour. Sci.*, August, 1894, 92. "The Auriferous Veins of Meadow Lake, California." *Idem,* September, 1893, 201. "Characteristic Features of California Gold Quartz Veins," *Bull. Geol. Soc. of Amer.*, VI., 221, 1895. Rec. "The Gold-Silver Veins of Ophir, California," *Ann. Rep. Dir. U. S. Geol. Survey,* 249, 1895. Rec. G. W. Maynard, "Remarks on Gold Specimens from California," *Trans. Amer. Inst. Min. Eng.*, VI., 451. J. S. Newberry, "On the Genesis and Distribution of Gold," *School of Mines Quarterly,* III., p. 16. E. E. Olcott, "On the Shaw Mine, Eldorado Co.," with a cross section, *Trans. Amer. Inst. Min. Eng.*, XXIV., 883, 1894. A. Remond, "Mining Statistics," *No. 1, Cal. Geol. Survey* (tabular statement of quartz mining and mills between the Merced and Stanislaus Rivers). J. A. Phillips, "Mining and Metallurgy of Gold and Silver," also treatise on Ore Deposits, p. 254. Rec. C. M. Rolker, "The Late Operations in the Mariposa Estate," *Trans. Amer. Inst. Min. Eng.*, VI., 145. B. Silliman, "Notice of a Peculiar Mode of Occurrence of Gold and Silver in the Foothills of the Sierra Nevada, California," *Amer. Jour. Sci.*, ii., XLV., 92; *Cal. Acad. Sci.*, Vol. III., p. 353. W. H. Storms, "The Wall Rocks of California Gold Mines," *Eng. and Min. Jour.*, February 23, 1895, 172. H. M. Turner, review of recent papers by H. W. Fairbanks and others on California geology, in *Amer. Geol.*, June, 1893. Rec. J. D. Whitney, *Cal. Geol. Survey,* Geology, Vol. I., p. 212. J. S. Wilson, "On the Gold Regions of California," *Quar. Jour. Geol. Soc.*, Vol X., p. 308, 1854.

tion and precipitation of gold in its characteristic veins have been the subject of consideration and investigation by many observers, especially in Australia. The almost invariable association of the gold with silica; its very frequent entanglement in iron pyrites, and the possibility of its chemical combination with iron pyrites through the medium of silver or bismuth or tellurium, are all important factors to be considered. The existence of silicate of gold was early shown by Bischoff, who did not fail to appreciate the possibility of its having played an important part in the filling of veins.[1]

The solubility of gold in solutions of ferric sulphate is well-established, although the amount taken up is small. If such auriferous solutions were to be exposed to a reducing action, auriferous pyrites would be a natural result. Experiments by Richard Pearce[2] have indicated that when pure gold is fused with pyrites it still remains as globules through the resulting matte, but if alloyed with silver, bismuth or tellurium, it apparently combines with the pyrites, or, at all events, becomes invisibly disseminated in it The demonstrated presence of bismuth and tellurium in some auriferous pyrites as mined and the peculiar metallurgical behavior of such ores give good reason, as Mr. Pearce has pointed out, for suspecting that the bismuth and tellurium have exerted a strong influence in the original precipitation of the gold. Again, the wide distribution of haloid salts in Nature and the notable solubility of the haloid compounds of gold, gives this group of elements no small theoretical importance. Taken in connection with alkaline salts, especially carbonates and sulphides, the former of which is an active solvent of silica, considerable light may be thrown on the chemistry of vein-formation. Thomas Egleston[3] has recorded interesting experiments upon the solubility of gold in ammoniacal compounds, and as these are

[1] Gustav Bischoff, "Lehrbuch der Chemischen und physikalischen Geol ogie," Edition 1854, II., 2654–2657; Edition 1866, III., 843–846. The passage is omitted in the English translation published by the Cavendish Society.

[2] Richard Pearce, "The Association of Gold with other Metals in the West," *Trans. Amer. Inst. Min. Eng.*, XVIII., 447, 1890. *Idem*, XXII., 738.

[3] T. Egleston, "The Formation of Gold Nuggets and Placer Deposits," *Trans. Amer. Inst. Min. Eng.*, IX., 633, especially 639, 1881.

thought by G. F. Becker to have been factors in the production of the cinnabar deposits of California (see 2.15.03), the reactions may be suggestive. Of the haloid elements, iodine has been given particular prominence by several observers, notably T. A. Rickard.[1] Where a reducing action is required, organic matter in the wall rocks is the most available precipitating agent. William Nicholas had laid stress upon its importance.[2] Below is given a list of the other principal papers bearing on this subject,[6] but attention may also be directed to the general literature of California gold deposits on a previous page. Considerable difference of opinion prevails as to whether the gold has come from a fine dissemination in the marine sediments, which received it from the ocean, during their deposition, or whether from igneous rocks, from which it has been dissolved. Gold has certainly been demonstrated to exist in appreciable quantities in sea-water[3] and also to have been produced by crystallization directly from an igneous magma.[4]

As bearing upon this last-named point an extraordinarily thorough and patient investigation has been carried through by Mr. John R. Don, of Otago, New Zealand, the object of which was to demonstrate by actual chemical analysis and assay, the source of the gold in certain Australian reefs. Vein matter, country rocks, sea-water, in fact, all the possible and available sources of gold, were subjected to quantitative analysis. The results were so largely negative, that the author feels compelled to go back to the

[1] T. A. Rickard, "Origin of the Gold-bearing Quartz of the Bendigo Reefs," *Trans. Amer. Inst. Min. Eng.*, XXII., 289, 1893, and discussion, p. 738.

[2] William Nicholas, "The Origin of Gold in Certain Victorian Reefs," *Eng. and Min. Jour.*, December 15, 1883.

[3] A. Liversidge, "On the Amount of Gold and Silver in Sea Water," *Proc. Roy. Soc. New South Wales*, October 2, 1895. See also *Chemical News*, September and October, 1896, 147, 160, 166; Muenster, *Jour. Soc. Chem. Industry*, April 30, 1892, XI., 351. E. Sonstadt, "On the Presence of Gold in Sea Water," *Idem*, October 4, 1872, p. 159.

[4] W. P. Blake, "Gold in Granite and Plutonic Rocks," *Trans. Amer. Inst. Min. Eng.*, September, 1896. G. P. Merrill, "Gold in Granite," *Amer. Jour. Sci.*, April, 1896, 309. W. Moericke, "Notes on Chilean Ore Deposits," *Tschermak's Mineralogische und Petrographische Mitth.*, XII. 195.

deep-seated sources and to refer the gold to a home in some rock, not available for assay. Too much commendation can scarcely be given to the thoroughness and care with which the investigation was carried out. The quantitative data have placed mining geologists the world over under a great debt.[1]

2.12.23. The stratigraphy of the auriferous strata in the Sierras was briefly referred to above as involving Paleozoic and Mesozoic strata. It would be impossible and undesirable to give in this place any complete bibliography of the subject, but in the papers of Diller,[2] J. P. Smith[3] and Turner,[4] cited below, quite full references are to be found to earlier work. In the atlas sheets of the U. S. Geol. Survey local names are given to the various formations, which are classified on the physical basis as outlined in the introduction (1.01.01), but as regards geological time, strata have been identified as follows: Pre-Silurian crystalline schists; Silurian quartzite and slate, with included lenses of limestone; Devonian coralline limestone; probably both Lower and Upper Carboniferous argillite, quartzite, mica-schist, and metamorphosed tuffs; various Triassic and Jura-Trias sediments more or less metamorphosed; Jurassic slates; Cretaceous (Chico) sandstone; Tertiary and Quaternary sandstone, sands, gravels and clays. (See pp. 228-249 of first paper of H. W. Turner, cited below. Also Diller op. cit.)

In the auriferous belt, J. P. Smith has admitted the presence of Silurian, Carboniferous, Triassic and Jurassic strata, but rejects Cretaceous.

2.12.24. Our knowledge has also increased of late regarding the intrusions of granite and the relations of the various sedimentary formations to the old basement upon which they were laid down. The work of H. W. Fairbanks, often cited in the

[1] John R. Don, "The Genesis of certain Auriferous Lodes," *Trans. Amer. Inst. Min. Eng.*, XXVII., 564, 1897.

[2] J. S. Diller and Charles Schuchert, "Discovery of Devonian Rocks in California," *Amer Jour. Sci.*, June, 1894, 416.

[3] J. P. Smith, "Age of the Auriferous Slates of the Sierra Nevada," *Bull. Geol. Soc. Amer.*, V., 243, 1894.

[4] H. W. Turner, "Geological Notes on the Sierra Nevada," *Amer. Geol.*, April and May, 1894, 228–297. Further contributions to the "Geology of the Sierra Nevada," *XVII. Ann. Rep. Dir. U. S. Geol. Survey*, 521–740. "Granitic Rocks of the Sierra Nevada," *Jour. of Geol.*, March, 1899, 141

text, and that of the U. S. geologists, Becker, Diller, Turner and Lindgren, have been bringing out forcibly the intrusive nature and Mesozoic age of much of the granite of the Sierras and of the Coast range. Most recently among the Canadians G. M. Dawson has traced similar effects to the north, and A. C. Lawson,[1] from an extended survey of the western coast, and search in the literature of Mexico, Central and even South America, forcibly portrays the advance of the great granitic "batholites" (*i.e.*, plutonic masses) toward the surface, the fusing into their magmas of the overlying strata, and the metamorphic effects. All these cannot but be strong factors to be considered in connection with the ore bodies, and as time goes on this connection will probably be shown.

In regard to the other forms of igneous rocks involved in the gold belt and often greatly metamorphosed, we are advancing rapidly in knowledge. These were referred to earlier under 2 12.19, but in his review of the igneous rocks Mr. Turner[2] cites nearly the entire series of plutonic and effusive types. In many instances the more basic members have passed under the influence of dynamo-metamorphism, into amphibolites and talcose rocks, but in other cases the dikes and sheets are still little if at all changed. Great areas are formed of them or involve them, and lead to the inference that they have not been without their influence in promoting ore-bearing circulations.

Mr. Turner's recent review of the geology of the Sierras[3] is important, not alone in its bearings on local geology, but upon theoretical petrology as well. The folios of the U. S. Geological Survey now embrace a large portion of the gold belt, and are much the most available expositions of the geological structure. They are listed, so far as yet issued, in the footnote to paragraph 2.12.06.

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[1] A. C. Lawson, "The Cordilleran Mesozoic Revolution," *Journal of Geology*, I., 579, 1893.

[2] *Amer. Geol.*, May, 1894, pp. 297–316.

[3] *XVII. Ann. Rep. Dir. U. S. Geol. Survey.*

CHAPTER XIII.

GOLD ELSEWHERE IN THE UNITED STATES AND IN CANADA.

2.13.01. Example 45*a*. Southern Appalachians. Gold-quartz veins and veinlets and auriferous impregnations of the country rocks, which are almost invariably of metamorphic types, and which are of considerable variety. From these, placers have resulted, both by superficial decay and by erosion. The general geology of the southern Atlantic States has been outlined in the introduction. Reference may again be made to the Coastal Plain of Quaternary, Tertiary, and Mesozoic sedimentary strata, and to the crystalline and metamorphosed belt, lying west of it. In the latter are found the gold deposits. Increasing observation tends to show that the quartz veins are all fillings of fissures, which have been produced in the geological disturbances to which the region has been subjected. The smaller reticulations indicate crushings, more or less intimately related to the general production of schistosity, but the larger veins often cut the schistosity at a notable angle and clearly have been produced by fairly extended dislocations. All are deposited in what Posepny has called "spaces of discission." The wall rocks embrace both metamorphosed sediments and metamorphosed igneous rocks. The latter are both of volcanic and plutonic origin, and the altered volcanics may closely resemble slates. Foliation is everywhere developed. Dikes of diabase, little, if at all, metamorphosed, are present in some districts of North Carolina, and have certainly exercised a favorable influence on the ore deposition. In all parts of the gold territory the superficial decay has been pronounced, and the rocks are extensively decomposed to depths that may reach over 100 feet. Such material has been called by Becker, saprolite, meaning by the word a general term for decomposed rock, whatever has been its original character. Laterite has been earlier used in the same sense and has priority. The ores are oxidized in these decomposed walls and the whole mass may be hydraulicked, the free gold being caught, and the boulders of gold quartz being concentrated for milling. The laterite also works down hill from its original position, and has been called in this connection "frost-drift" by Kerr. Natural erosion has led to the formation of the usual type of placers, and these have been worked more or less in earlier years, and are still productive in a small way. Above the level of the ground-water the veins chiefly afford free milling ores, but below it, they pass into more rebellious sulphurets of the usual types. The mineralogy of the veins is similar to that of the usual run of gold-quartz veins, but in the aggregate presents considerable variety. Becker records a total of 59 minerals, of which 45 are original, and 14 secondary. The gold is at times found in the country rock along quartz veins, and sometimes in rock free from vein formations, but it is presumably of secondary introduction. The garnets of a mica-schist near Dahlonega, Ga., have been proved by Becker to be notably auriferous.[1]

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[1] The following papers refer to the gold deposits of the Southern Appalachians in general; subsequently papers are grouped by States. G. F. Becker's paper, cited below, contains a quite complete bibliography, pp. 70–73, chronologically arranged, down to 1894. Acknowledgments are here made to it, but additional papers are also given. W. H. Adams, "Gold Mining in the Appalachian Belt," *Eng. and Min. Jour.*, July 4, 1896, p. 7. W. R. Balch, "Mines, Miners and Mining Interests of the United States," 1882, p. 1102. G. F. Becker, "Reconnaissance of the Gold Fields of the Southern Appalachians," *XVI. Ann. Rep. Dir. U. S. Geol. Survey*, Part II., 1895. Rec. F. C. Hand, "Southern Gold Fields," *Eng. and Min. Jour.*, December 7, 1889, p. 495. W. C. Kerr, "On the Action of Frost in the Rearrangement of Superficial Earthy Material," *Amer. Jour. Sci.*, XXI., 1881, 345. O. M. Lieber, "A Contribution to the Geologic Chronology of the Southern Appalachians," *Proc. Amer. Assoc. Adv. Sci.*, XII., 1859, 227. P. H. Mell, "Auriferous Slate Deposits of the Southern Appalachians," *Trans. Amer. Inst. Min. Eng.*, IX., 399; *Eng. and Min. Jour.*, June 11, 1881, 397. H. B. C. Nitze, "Present Condition of Gold Mining in the Southern Appalachian States," *Idem*, XXV., 661. Discussion, 1021, 1025. Rec. A review by Robert Peele in the *School of Mines Quarterly*, January, 1896, 177, is a valuable discussion. See also forthcoming *Bulletin 17, N. C. Geol. Survey*. E. G. Spilsbury, "Notes on the General Treatment of the Southern Gold Ores and Experiments in Matting Iron

2.13.02. Becker has broadly divided the auriferous area into three great belts: the Georgian belt, extending from Montgomery, Ala., through Dahlonega, Ga., to the Boilston Mine in North Carolina; the South Mountain belt, embracing a group of mountains of this name in North Carolina; and the Carolinian belt, lying far to the east of the latter and ranging from South Carolina two-thirds across North Carolina. The Virginia deposits lie in the same line further north. So far as North Carolina is concerned this classification, as shown later, has been amplified by Nitze.

2.13.03. *Alabama.* The gold-bearing belt begins in Alabama on the southwest and covers in this State a triangular area some 90 miles on a side and situated about the middle of the eastern boundary. In all nine counties are embraced. The country rock consists of the Talladega series of slates, quartzites, conglomerates, and dolomites; and of a complex series of gneisses, diorites, green schists, granites and some basic dikes, besides other minor varieties of rocks of igneous affinities. The Talladega series contains a large proportion of the gold mines, but others are known in the gneisses, diorites and green schists. The veins are commonly parallel to the foliation.[1]

Sulphides," *Trans. Amer. Inst. Min. Eng.*, XV., 767. J. W. Taylor, "The Gold and Silver Mines East of the Rocky Mountains," *Amer. Jour. of Mining*, II., 390, 1867. J. D. Whitney, *Metallic Wealth of the United States*, 1854. Volume XIII. of the *Tenth Census*, on the Precious Metals, has valuable statistics, and the volume on the Mineral Industries of the *Eleventh Census* has later ones.

[1] The following references may be consulted on Alabama. Attention is also called to the general references in the preceding footnote, that refer to the Southern Appalachians. Anonymous, "Notes on the Alabama Gold Belt," *Eng. and Min. Jour.*, January 20, 1894, p. 57. W. M. Brewer, "The Arbacoochee Gold District, Ala.," *Idem*, August 17, 1895, 148 W. M. Brewer, "The Gold Regions of Georgia and Alabama," *Trans. Amer. Inst. Min. Eng.*, XXV., 569. "The Upper Gold Belt of Alabama," *Bulletin 5, Alabama Geol. Survey*, 1896, contains supplementary notes by E. A. Smith, and valuable petrographical descriptions by J. M. Clements and A. H. Brooks; a few also by C. W. Hawes. Rec. J. L. Campbell and W. H. Ruffner, "A Physical Survey from Atlanta, Ga., across Alabama and Mississippi to the Mississippi River, along the line of the Georgia Pacific R. R.," New York. 1883, 37. O. M. Lieber refers at length to Alabama placers in his paper on "Der Itacolumit, seine Begleiter und die Metallführung desselben: *Gangstudien*," III., especially pp. 406 and following. W. B. Phillips, "The Lower Gold Belt of Alabama," *Bulletin 3*,

Geographically the gold region is sometimes divided into the Lower Belt, comprising Coosa, Tallapoosa, Chambers and part of Chilton counties, and the Upper, in Cleburne, Clay, Randolph and part of Talladega counties.

2.13.04. *Georgia.* The metamorphic areas containing the gold of Alabama are continued across Georgia in a northeasterly line, with a general strike of the foliation between 30 and 50 degrees N. E. The dip is southeast. Gneiss and schists prevail, but igneous rocks are not unknown. Dahlonega is the chief mining center, and has important hydraulic works and stamp mills in operation.[1] The decomposed rock is hydrau-

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Alabama Geol. Survey, 1892. Rec. J. W. Spencer, "Economic Geological Survey in Georgia and Alabama, along the Macon and Birmingham Railroad, 1889" (cited by G. F. Becker). M. Tuomey, "First Biennial Report on the Geology of Alabama," 1847–1849, 1850. Second ditto, 1855, 1858.

[1] Attention is called to the general papers, earlier cited. Adelberg and Raymond, "Report on the Lewis Gold Mine," 1866. "Report on the O'Neil Property," 1866. W. P. Blake, "Report on the Gold Placers of Lnmpkin County, Ga.," etc. (small book published by J. F. Trow, New York, 1858). See, also, *Amer. Jour. Sci.*, ii., XXVI., 278; *Mining and Statistical Magazine,* X., 457, 476, 1858. "On Placer Gold Mines in Georgia," etc., *Proc. Amer. Assoc. Adv. Sci.*, 1859. "Notes and Recollections Concerning the Mineral Resources of Northern Georgia and Western North Carolina," *Trans. Amer. Inst. Min. Eng.*, XXV. 796, 1895. W. H. Brewer, "The Dahlonega Gold Mining District," *Eng. and Min. Jour.*, December 15, 1894, 559. "New Work in the Villa Rica District," *Idem,* June 20, 1897. H. Credner, "Beschreibung einer paragenetisch, interessanter Goldvorkommen in Georgia, Nord Amerika," *Neues Jahrbuch,* 1867, 443. "Geognostische Skizze der Goldfelder von Dahlonega, Georgia, Nord America," *Zeitschr. d. d. Geol. Gesells.*, XIX., 34, 1867. C. T. Jackson, "Minerals from Georgia," *Proc. Bost. Soc. Nat. Hist.*, VII., 22, 1861. J. B. Mackintosh, "The Gold Mining District of Dahlonega, Ga.," *Eng. and Min. Jour.*, XXVII., 258, 1879. P. H. Mell, "Papers on Gold Mining in Georgia," *Eng. and Min. Jour.*, October 6 and 13, 1877, pp. 238, 275; also, p. 528; August 10 and 17, 1878, pp. 97, 116. P. C. Morton, "Mineral Resources of Georgia," *Amer. Jour. Mining,* I., 265, 1866. J. Peck, "The Mining Region of Georgia, Western North Carolina and East Tennessee," *Amer. Jour. Sci.*, i., XXIII., 4, 1833. Wm. Phillips, "Essay on the Georgia Gold Mines," *Idem,* i., XXIV., 1. C. U. Shepard, "On Lazulite, Pyrophyllite, and Tetradymite in Georgia," *Idem,* ii., XXVII., 36, 1859. J. W. Spencer, see under Alabama. H. G. Torrey, "Tests of Dahlonega Gold Ores," *Eng. and Min. Jour.*, January 5, 1895, 2. "Yeates, McCallie and King; Gold Deposits of Georgia," *Geol. Survey of Georgia, Bulletin 4,* 1896.

licked, the quartz boulders are caught and are then run through stamps.

2.13.05. *South Carolina.* The mines in this State are on the southern extension of the Carolinian belt in Lancaster, Chesterfield and Union counties. The Haile is one of the best known, and affords an ore consisting of impregnated muscovite schist, that is an altered pre-Cambrian volcanic, according to Becker. The rich portions occur along intruded diabase dikes. The Brewer mine, a few miles away, has similar wall rock.[1]

2.13.06. *North Carolina.* The Georgian belt of Becker just reaches North Carolina, the South Mountain belt lies wholly within it, and the Carolinian belt passes through its eastern or eastern central portion. Nitze and Hanna divide the gold-bearing areas of the State into six belts, which are from east to west. (1) The eastern Carolina belt, in Warren, Halifax, Franklin and Nash counties. Quartz veinlets are found in diorite, chlorite schist and gneiss. (2) The Carolina slate belt, extending southwest across the State from Person to Union counties. The mines are mostly in Randolph, Davidson, Montgomery, Stanley and Union counties. The wall rocks are slates and volcanics. Diabase dikes exert a favorable influence. (3) The Carolina igneous belt, chiefly in Mecklenburg, Cabarrus, Rowan, Davidson and Guilford counties. The rocks are granite, diorite, gabbro and diabase, and are later than the slates. The gold-quartz veins often carry copper. (4) The King's Mountain belt, in Gaston, Lincoln, Catawba, Davie and Yadkin counties. The rocks are crystalline schists, gneisses, siliceous limestones and quartzites. The ores are sometimes impregnated streaks of country rock, and again are quartz veins. The King's Mountain mine has ores in siliceous lime-

[1] Attention is called to the general papers earlier cited. G. E. Ladshaw, "Spartanburg, South Carolina, Gold Fields," *Eng. and Min. Jour.*, July 16, 1892, 52. O. M. Lieber, "Reports of the Geological Survey of South Carolina," 1856, 1858, 1859, 1860. "Gold in South Carolina" is often referred to in Lieber's paper on "Itacolumit," etc., *Gangstudien*, III., 309, 405, ff. R. Mills, "Gold Occurrences in South Carolina," in *Statistics of South Carolina*, 1826, pp. 26, 671. E. G. Spilsbury, "Gold Mining in South Carolina," *Trans. Amer. Inst. Min. Eng.*, XII., 99, 1884. A. Thies and E. Metzger, "Geology of the Haile Mine," *Idem*, XIX., 595, 1890. A. Thies and W. B. Phillips, "The Thies Process, etc., at the Haile Mine," *Idem*, XIX., 601, 1890.

stone, and is a well-known one. (5) South Mountain belt, in Burke, McDowell and Rutherford counties. The rocks are mica and hornblende gneisses and schists, with pegmatites and some minor pyroxenic varieties. Quartz veins in true fissures are the rule. They can be classed into five sub-belts. (6) Gold deposits west of the Blue Ridge in Ashe, Jackson, Transylvania, Macon and Cherokee counties. The rocks are gneisses and schists wth quartz veins. The Bulletin by Nitze and Hanna, cited below, gives details from all the mines of the State.[1]

2.13.07. *Virginia, Maryland and the Northern States.*

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[1] Attention is called to the general citations earlier given. W. P. Blake, "Remarks on the Minerals and Ancient Mines of the Cherokee River Valley, N. C.," *Proc. Amer. Assoc. Adv. Sci.*, 1859. L. S. Burbank, "Surface Geology of North Carolina," *Proc. Bost. Soc. Nat. Hist.*, 1873, 151. H. M. Chance, "Auriferous Gravels of North Carolina," *Amer. Phil. Soc.*, 1881, 477. H. E. Colton, "Mining in North Carolina," *Eng. and. Min. Jour.*, 1871, 323. H. Credner, "Report of Explorations in the Gold Fields of Virginia and North Carolina," *Amer. Jour. of Mining*, 1868, 361, 377, 393, 407. W. B. Devereux, "Gold and Its Associated Minerals at King's Mountain, N. C.," *Eng. and Min. Jour.*, January 15, 1881, 39. M. W. Dickeson, "Report on the Brown and Edwards Properties," 1860. "Report on the Rhea Mine," 1860. A. Eaton, "The Gold of the Carolinas in Talcose Slate," *Amer. Jour. Sci.*, i., XVIII., 50, 1850. E. Emmons, "Geological Report upon the Midland Counties of North Carolina," 1896. F. A. Genth, "Contributions to American Mineralogy," *Amer. Jour. Sci.*, ii., XIX., 18, 1855 ; ii., XXVIII., 246, 1859. "Report on the Stewart Mine," 1856. See *Journal of the Franklin Institute*, November, December, 1871. "Mineral Resources of North Carolina," in *Kerr's Report*, 1875, Appendix C. "The Minerals and Mineral Localities of North Carolina," printed for the State Board of Agriculture, Raleigh, 1885. "The Minerals of North Carolina," *Bulletin 74, U. S. Geol. Survey*, 1891. J. H. Gibbon, "Letter on the Gold of North Carolina," *Amer. Jour. Sci.*, i., XLVIII., 398, 1844. F. C. Hand, "Southern Gold Fields," *Eng. and Min. Jour.*, December 7, 1889, 495. G. B. Hanna, "The Fineness of Native Gold in the Carolinas and Georgia," *Idem*, September 18, 1886, 201. See, also, under Kerr and under Nitze. O. J. Heinrich, "On Gold Hill, N. C.," *Trans. Amer. Inst. Min. Eng.*, II., 324, 1874. J. A. Holmes, "Forthcoming Bulletin 17, North Carolina Geological Survey, with a Geological Bibliography," in preparation, 1897. C. L. Hunter, "Notice of the Rarer Minerals and of New Localities in Western North Carolina," *Amer. Jour. Sci.*, ii., XV., 375, 1853. C. T. Jackson, "Report on the McCullock Copper and Gold Mining Co.," 1853. W. C. Kerr, "Geological Report on North Carolina," 1869 ; ditto, 1875. "Gold Gravels of North Carolina," *Trans. Amer. Inst. Min. Eng.*, VIII., 462. "Some Peculiarities in the Occurrence of Gold in North Carolina," *Idem*, X., 475, 1882. "On the Action of Frost in the Arrangement

The Carolinian belt of Becker extends into Virginia, and has been the basis of some mining. The usual type of quartz veinlets in schists is met. The belt runs through the State east of the Blue Ridge.[1] Several small mines have been developed in

of Superficial Earthy Material," *Amer. Jour. Sci.*, iii., XXI., 345, 1881. S. P. Leeds, "Reports on the Karricker, the Rhymer, and the Rudisill Mines," 1854. O. M. Lieber, "Ueber das Gold-vorkommen in Nord Carolina," *Gangstudien*, III., 253, 1860; also, 417. Jules Marcou, "On Gold in North Carolina," *Proc. Bost. Soc. Nat. Hist.*, IX., 47, 1862. A. Metzger, "The Gold Mines of North Carolina," *Eng. and Min. Jour.*, October, 24, 1891, 480. E. Mitchell, "On the Geology of the Gold Region of North Carolina," *Amer. Jour. Sci.*, i., XVI., 19, 1829. H. B. C. Nitze, "The Genesis of the Gold Ores in the Central Slate Belt of the Carolinas," *Eng. and Min. Jour.*, June 19, 1897. H. B. C. Nitze and G. B. Hanna, "Gold Deposits of North Carolina," *Bulletin 3, N. C. Geol. Survey*, 1897. Rec. H. B. C. Nitze and A. J. Wilkins, "Gold Mining in North Carolina and other Appalachian States," *Bulletin X., Idem* (in preparation), 1897; see, also, *Trans. Amer. Inst. Min. Eng.*, XXV., 661. D. Olmstead, "Gold Mines of North Carolina," *Amer. Jour. Sci.*, i., IX., 5, 1825. C. E. Rothe, "Remarks on the Gold Mines of North Carolina," *Idem*, i., XIII., 201, 1828. C. U. Shepard, "Report on the Gold Hill Mine," 1853. "Gold in North Carolina," *N. Y. Mining Magazine*, X., 271, 1858; XI., 136. F. L. Smith, "Notice of Some Facts Connected with the Gold of a Portion of North Carolina," *Amer. Jour. Sci.*, i., XXXII., 130, 1837. R. P. Stevens, "Gold in North Carolina," *Amer. Jour. Min.*, I., 313, 1866. R. C. Taylor, "Report on the Washington Silver Mine," 1845. P. T. Tyson, "Report on the Gold Deposits of the Mateo Mining Co.," 1856. Arthur Winslow, "Gold Mines in North Carolina," *Eng. and Min. Jour.*, XL., 218, 1885.

[1] Attention is called to the general references on the Southern States, earlier given. J. L. Campbell, "Geology and Mineral Resources of the James River Valley," p. 99, New York, G. P. Putnam's Sons, 1882. Abstract in *Eng. and Min. Jour.*, September 9, 1882, 135. T. G. Clemson, "The Gold Region of Virginia," *Trans. Geol. Soc. Penn.*, 309, 1835. H. Credner, "Report of Explorations in the Gold Fields of Virginia and North Carolina," *Amer. Jour. of Mining*, 1868, pp. 361, 377, 393, 407. "Geognostische Skizzen aus Virginia. Nord Amerika," *Zeitschr. d. d. Geol. Gesellsch*, 1866, 83. A. Del Rio, "Report on the Rappahannock Gold Mine, Virginia," 1824. E. W. Johnson, "On the Garnett Gold Mine, Virginia," 1852. W. R. Johnson, "Some Observations on the Gold Formations of Maryland, Virginia, and North Carolina," *Proc. Amer. Assoc. Adv. Sci.*, 1850, IV., 20. M. F. Maury, "Notice of Gold Veins of the United States Mine, near Fredericksburg, Va.," *Amer. Jour. Sci.*, i., XXXII., 325, 1837. J. H. Morton, "Gold Mines in Virginia," *Eng. and Min. Jour.*, XXV., 1878. T. Pollard, on Gold in Virginia, see Lock's "Gold: Its Occurrence and Extraction," 1882, 182. B. Silliman, "Remarks on Some of the Gold Mines and on Parts of the Gold Regions of Virginia," *Amer. Jour. Sci.*, i., XXXII., 98, 183, 185, 1837.

Maryland, not far from Washington,[1] and a few indications of gold have been met in Pennsylvania,[2] New Jersey, New York,[3] and Massachusetts.[4] In the metamorphosed Cambrian and Silurian strata of Vermont[5] quite serious attention has been given to both veins and gravels. Gold-bearing mispickel is known in New Hampshire,[6] as well as in the usual quartz veins. Some attempts at washing gravels have been made in Maine[7] and in Rhode Island in the slates and gneisses around the great intrusions of granite, quartz veins are not infrequent. Traces of gold have been met.

2.13.08. Example 45*b*. In the fundamental complex (2.02.17) north of the iron region at Ishpeming, gold occurs at the Ropes mine in reticulations of pyritous quartz and country rock at the contact of a great intrusion of peridotite with greenstone schist. Other less developed locations are on quartz veins in the schists.[8]

2.13.09. *The Rainy River District.* This includes the country adjacent to Rainy Lake and the Lake of the Woods.

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[1] S. F. Emmons, "Notes on the Gold Deposits of Montgomery County, Md.," *Trans. Amer. Inst. Min. Eng.*, XVIII., 396, 1890. See also W. R Johnson, under Virginia above, and likewise, *Philos. Mag.*, XXXVI., 242, 1850, and *Amer. Jour. Sci.*, ii., IX., 126.

[2] Eckfeldt, "Discovery of Gold in Philadelphia Clay," (3 cents to cu. ft.), *Proc. Amer. Phil. Soc.*, VIII., 273 ; *Amer. Jour. Sci.*, ii., XXXII., 297. C. M. Wetherill, Note in *Philos. Mag.*, IV., 150, February, 1853, and in *Erdmann's Jour. für prakt. Chem.*, LVIII., 447 ; *Amer. Jour. Sci.*, ii., XIX., 290.

[3] J. G. Pohlê and John Torrey, "Gold in Rhinebeck, Dutchess County," *Amer. Jour. Sci.*, ii., XLVII., 139. See R. W. Raymond, "The New York Mining Law," *Trans. Amer. Inst. Min. Eng.*, XVI., 770.

[4] J. N. Blake, "Gold at Dedham, Mass.," *Amer. Jour. Sci.*, ii., II., 419.

[5] The subject is taken up in the Report of the *Geological Survey of Vermont*, Vol. II., 842, 1861, and a map showing the distribution of auriferous gravels is given in Plate I. O. P. Hubbard refers to Gold in Vermont in *Amer. Jour. Sci.*, ii., XV., 147.

[6] *Geology of New Hampshire*, III., Part V., p. 4, 1878. H. Wurtz, *Amer. Jour. of Mining*, September 12, 1868.

[7] M. E. Wadsworth, "On an Occurrence of Gold in Maine" (in a quartz vein), *Bull. Mus. Comp. Zoöl.*, VII., No. 3, p. 181, May, 1881. *Harvard Univ. Bull.*, June, 1881, p. 219. Gold gravels have occasioned some excitement on the Swift River. On silver in Maine, see above, 2.09.04.

[8] C. D. Lawton, *Rep. Mich. Com. of Mineral Statistics*, 1887, p. 167. "The New Michigan Gold Field," *Eng. and Min. Jour.*, September 22, 1888, p. 238. M. E. Wadsworth, *Ann. Rep. Mich. State Geologist*, issued January, 1892, p. 152.

For several years it has been known that gold prospects existed in the region lying along the national boundary, in and north of Minnesota. Some claims in the Rainy Lake region are in Minnesota, but the greater part of the productive or prospective country lies in Ontario. The geology of the regions around Rainy Lake has been mapped in detail by A. C. Lawson, but that around the Lake of the Woods has not yet received the same complete study. Near Rainy Lake the geology involves Laurentian granites and gneisses; mica schists and fine-grained micaceous gneiss of the Coutchiching; greenish and sericitic schist, conglomerate, graywackes, etc., of the Keewatin, and minor developments of eruptives, such as gabbros and diabase dikes. The ore deposits embrace segregated veins, fissure veins and fahlbands, according to H. V. Winchell and U. S. Grant, as cited below. The segregated veins are series of overlapping lenses of auriferous quartz, with pyrite, that, although of no great individual size, may yet form a somewhat extended deposit. They occur in the schists of the Coutchiching and Keewatin, and run parallel to the schistosity, apparently along lines of local faulting. The fissure veins are most pronounced in granite. They are individually larger than the first type, and when in foliated rocks, they cut the schistosity at a greater or less angle. The fahlbands are belts of foliated rock impregnated with sulphides. Sulphides of iron, copper, zinc, lead, cobalt and silver are known. The mines of Rainy Lake have not yet assumed great economic importance, but are of promise.[1]

2.13.10. The Lake of the Woods lies northwest from Rainy Lake and entirely within the limits of Ontario. The geological relations are much the same as those of the latter. Keewatin schists are infolded in Laurentian granite and gneiss, and all

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[1] A. P. Coleman, "Abstract of a Report to the Bureau of Mines of Ontario," *Eng. and Min Jour.*, December 22, 1894, 581. "Clastic Huronian Rocks of Western Ontario," *Bull. Geol. Soc. Amer.*, IX., 223, 1898. A. C. Lawson, "Report on the Geology of the Rainy Lake Region," *Geol. Survey of Canada, Ann. Rep.*, 1887, Part F. W. H. Merritt, "The Occurrence of Gold Ores in the Rainy River District, Ontario," *Trans. Amer. Inst. Min. Eng.*, XXVI., 853, 1896. W. W. Taylor, "Geology and Character of the Rainy Lake Gold District," *Eng. and Min. Jour.*, December 1, 1894, p. 509. H. V. Winchell and U. S. Grant, "Preliminary Report on the Rainy Lake Gold Region," *Geol. Survey of Minn.*, *XXIII. Ann. Rep.*. 35, 105, 1895.

are pierced by later granite. There is also a very considerable development of volcanic rocks, both tuffs and flows, now more or less schistose. Considerable alteration has taken place in all, and as emphasized by W. H. Merritt, secondary minerals have been developed. The veins are found in the schists, but favor the portions near the contact with the granite or gneiss. The gold is free and in the usual sulphides, and in some veins there is considerable molybdenite. Bismuthinite is also reported. Several mines have reached a productive stage, and there are many prospects.[1]

2.13.11. In the summer of 1897 indications of gold were also met in the region near Michipicoten River, which enters Lake Superior on its northeastern coast. Auriferous quartz veins, some of which have yielded good assays, have been located. The richest are near Wawa Lake.[2]

ALASKA AND THE CANADIAN NORTHWEST.

2.13.12. *Geology.*—Our knowledge of the geology of Alaska is still far from complete, when the entire territory is considered, but it has been greatly amplified within the last few years by the mining explorations, and the governmental expeditions sent out as a result of them. The observations thus far recorded deal chiefly with the coast, and with the drainage basin of the Yukon, or with the passes which penetrate to its upper waters. Mesozoic rocks extend north from Washington and Vancouver so as to appear in Queen Charlotte's Island, and at a few points in the Aleutian Islands. Tertiary beds occur over a wide area, and have been located at numerous points, both on the mainland and among the islands. Metamorphic rocks from both igneous and sedimentary originals, unaltered plutonic types and intruded dikes, and more recent effusive vol-

[1] E. Costé, "Report on the Gold Mines of the Lake of the Woods," *Geol. Survey Canada*, 1882–84, Rep. K. W. Douglass, "The Lake of the Woods District," *Eng. and Min. Jour.*, February 16, 1895, p. 152. W. H. Merritt, "The Occurrence of Gold Ores in the Rainy River District, Ontario," *Trans. Amer. Inst. Min. Eng.*, XXVI., 853, 1896. T. A. Rickard, "The Lake of the Woods Gold Field," *Idem*, July 3, 1897, p. 5. R. H. Williams, "The Lake of the Woods District," *Idem*, July 28, 1894, p. 75.

[2] J. T. Donald, "Canada's Newest Gold Field," *Eng. and Min. Jour.*, September 25, 1897, p. 369.

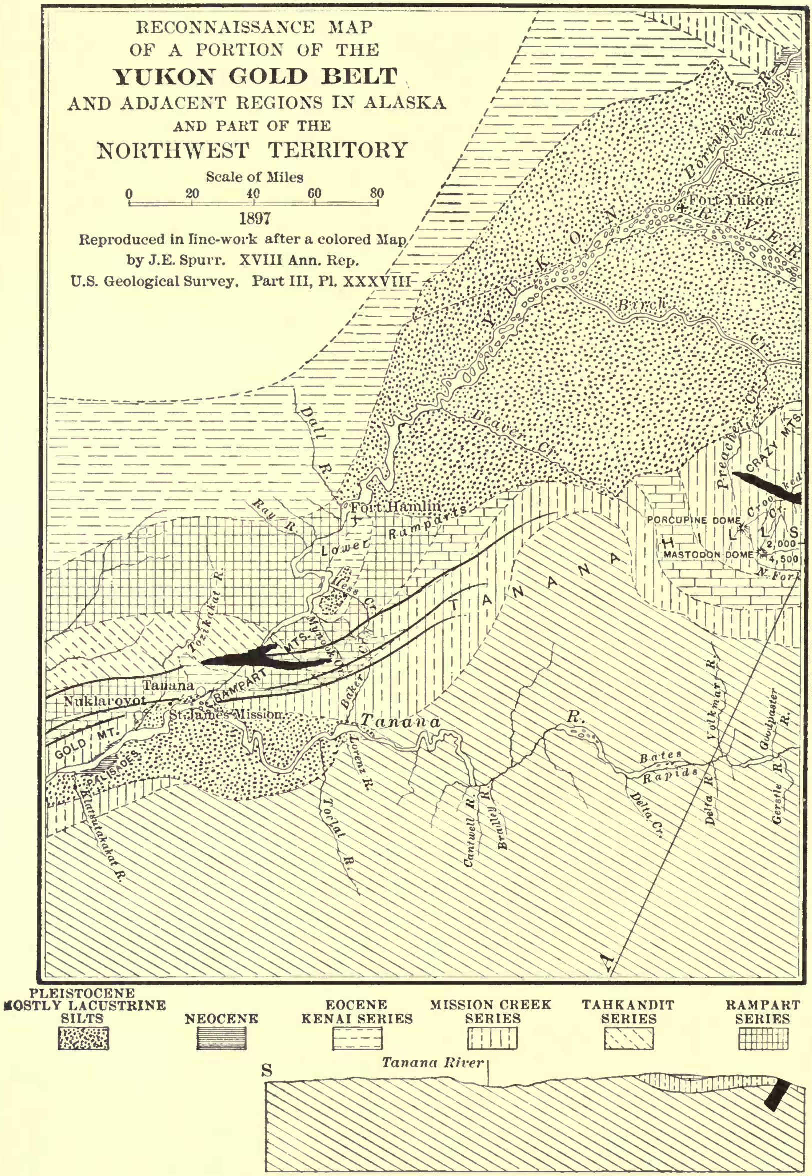

FIG. 150.—*Western half of Geological map of the Yukon Gold Belt and adjacent regions.* (*See* FIG. 151.)

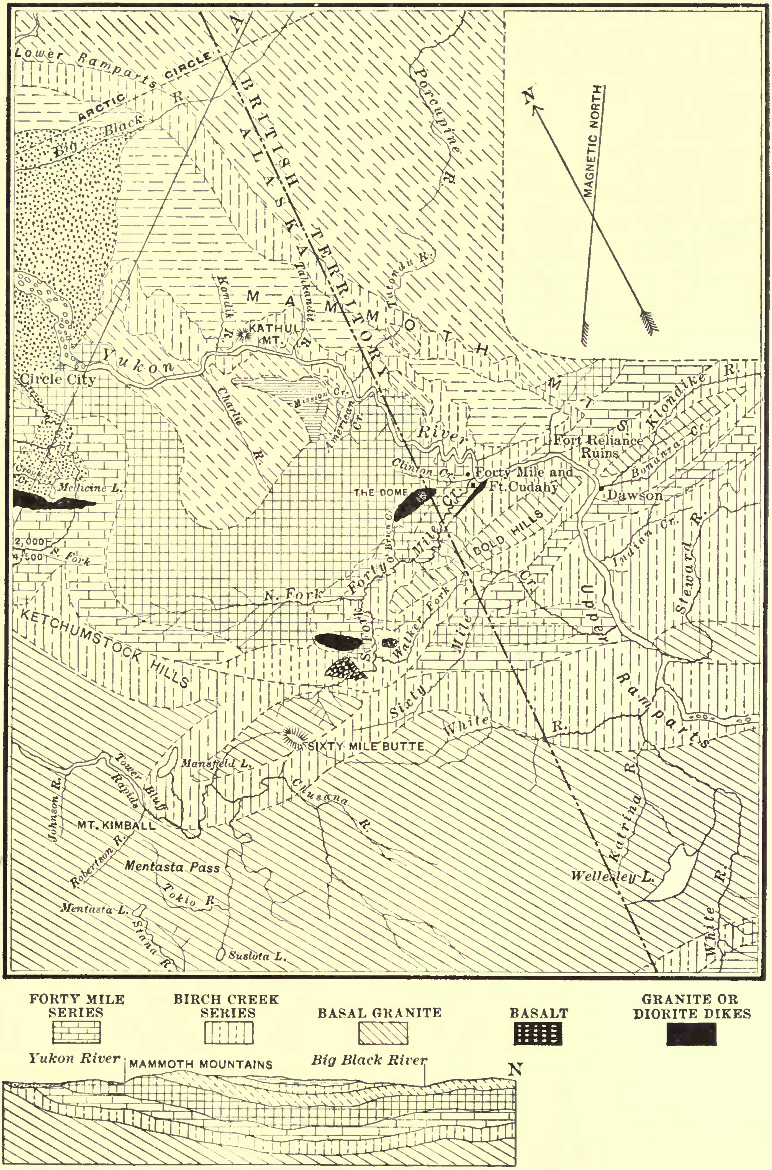

FIG. 151.—*Eastern half of Geological map of the Yukon Gold Belt, and adjacent regions, reproduced in line work and slightly reduced from a colored map by J. E. Spurr, XVIII. Ann. Rep. U. S. Geol. Survey, Part III., Plate XXXVIII., p. 252.*

canics, some from vents still active, are the chief components of the coastal exposures.

In the interior, in the Yukon basin, and especially in the area near the international boundary, the general stratigraphy has been more systematically studied, and may now be outlined, since the valuable paper of J. E. Spurr has become available. In order to make the geology of this important region clear, the colored reconnaissance map of Spurr is reproduced in Figs. 150 and 151, in line work on a somewhat smaller scale than the original, and in it the results of his explorations, as well as those of Dall, Hayes, Geo. Dawson, McConnell and others, are set forth.

The oldest formation is granite, of massive or more rarely gneissoid structure. It consists chiefly of quartz, orthoclase, microcline, plagioclase and biotite, with accessory muscovite, calcite, epidote, garnet, hematite, kaolinite, pyrite and chlorite. It is most extensively exposed south of the Yukon basin, but outcrops to the north in sufficient amount to show that the later formations rest upon it. It is considered Archean, and is called the Basal Granite. Immediately above it is a series of quartz-schists, estimated at 25,000 feet in thickness, and called the Birch Creek series. Many quartz veins occur in it, chiefly parallel with the schistosity. The Birch Creek series passes into the Forty-Mile series, which consists of micaceous and hornblendic schists with interbedded crystalline limestones. The Forty-Mile series likewise contains many quartz veins, and both it and the Birch Creek series are penetrated by many dikes of granite and diorite. In geologic succession the Rampart series follows, and exhibits a heavy cross-section and wide areal distribution of diabases, and associated tuffs, with some impure limestones and shales. The Rampart series is probably pre-Devonian, as is shown by the fossils in the next overlying series, and the Forty-Mile and Birch Creek series are still older, but all are uncertain in their taxonomic relations except for this approximate determination. Quartz veins are also present in the Rampart series. The Tahkandit series of white and gray limestones with alternations of carbonaceous shales and conglomerates follows next above. It is known from fossils to contain some Upper Carboniferous beds and probably also embraces others of Devonian age. Upon it rests the Mission

Creek series of black, calcareous and feldspathic shales and thin beds of impure limestone, and gray sandstone. They are known to be Lower Cretaceous. The Kenai series succeeds with its fresh-water sediments and coal seams of Eocene age. Neocene deposits follow and embrace the Nulato sandstones, the Twelve-mile beds of gravels and lignites, the Porcupine beds of sands, clays and conglomerates, and the Palisades conglomerates with the bones of huge, extinct vertebrates. The Yukon silts are Pleistocene and constitute a vast area of abandoned lake-bottoms along the middle Yukon. Eruptive basalt is also known, but in connection with the gold, the Basal granite, the Birch Creek, Forty-Mile and Rampart series and the recent gravels derived from them are of chief interest.

In its topographic character the interior is largely a great, dissected plateau so far as known, with rugged and uneven topography on a minor scale. The ranges of mountains are chiefly developed near the coast. The surface of the interior plateau and the talus slopes are covered by a heavy mantle of moss, called a tundra, whose roots, at a depth of a foot or two, are frozen in perpetual ice. This hides the geology, and makes exploration difficult and fraught with great hardship. Along the streams dense thickets of alder and spruce, and in the glaciated regions, the drift, all hide the rocks.[1]

[1] "Alaska as a Mining Territory," *Eng. and Min. Jour.*, June 27, 1885, p. 444. "Mineral and Agricultural Wealth of Alaska," *Eng. and Min. Jour.*, August 24, 1887, p. 134. G. F. Becker, "Reconnaissance of the Gold Fields of Southern Alaska, with some Notes on General Geology," *XVIII. Ann. Rep. U. S. Geol. Survey*, Part III., p. 7. Rec. T. A. Blake, "Report on the Geology of Alaska," *Ex. Doc.*, No. 177, Fortieth Congress, New Series, p. 314, Washington, 1868. W. P. Blake, "Geographical Notes upon Russian-America and the Stickeen River;" Report addressed to the Secretary of State, Washington, 1866. H. P. Cushing, "Notes on the Areal Geology of Glacier Bay, Alaska," *Trans. N. Y. Acad. of Sci.*, XV., 24. "Notes on the Muir Glacier Region and its Geology," *Amer. Geol.*, October, 1891, 207. W. H. Dall, "Explorations in Alaska," *Amer. Jour. Sci.*, ii., XLV., 96. Rec. "Notes on Alaska and the Vicinity of Bering Straits," *Ibid.*, iii., XXI. 104. "Notes on Alaska Tertiary Deposits, Geological Section of the Shumagin Islands," *Ibid.*, iii., XXIV., 67. "Alaska and its Resources," Washington, 1870. Rec. "Glaciation in Alaska," *Bull. Phil. Soc.*, Vol. VI., p. 33, Washington, 1884. G. M. Dawson, "Report on the Yukon District in 1887," *Geol. Survey of Canada*, 1887–88, Vol. III., Part B, pp. 14B, 17B, 154B–156B. H. W. Elliot, "Our Arctic Provinces,"

2.13.13. Example 38. (See above, 2.09.01.) Douglass Island. A dike of shattered albite-diorite (sodium-syenite) impregnated with gold-bearing pyrite. The largest and most productive of the mines along the coast of Alaska is the Alaska-Treadwell and its affiliated properties, on Douglass Island, about two miles southeast from the town of Juneau. The ore body is peculiar and interesting, and while the grade of the ore is low, the conditions for treating it cheaply, and on a large scale, are very favorable. The geological relations have recently been described by G. F. Becker, upon whose paper the following outline is based.

The country rock is a carbonaceous slate of uncertain but possible Triassic age. Its sedimentary bedding has been destroyed, but its cleavage strikes N. 50 E., and dips southeast. After the metamorphism to slate, it was penetrated by an irregular dike, which is 450 feet and less wide, and is considerably split up by horses of country rock. The dike rock is a peculiar one,

p. 163, New York, 1887. G. W. Garside, "Mineral Resources of Southeast Alaska," *Trans. Amer. Inst. Min. Eng.*, XXI., 815. E. J. Glave, "Pioneer Pack-horses in Alaska," *The Century*, September and October, 1892. C. W. Hayes, "An Expedition through the Yukon District," *Nat. Geog. Mag.*, IV., 117–162, 1892. Angelo Heilprin, "Alaska and the Klondike," New York, 1899. R. G. McConnell, "Glacial Features of Parts of the Yukon and Mackenzie Basins," *Geol. Soc. of Amer.*, I., p. 540. H. F. Reid, "Glacier Bay and its Glaciers," *XVI. Ann. Rep. Dir. U. S. Geol. Survey*, 1896, I., 421. I. C. Russell, "The Surface Geology of Alaska," *Geol. Soc. of Amer.*, I., p. 99. "An Expedition to Mt. St. Elias, Alaska," *Nat. Geogr. Mag.*, III., 53, 204, 1891. "Mt. St. Elias and its Glaciers," *Amer. Jour. Sci.*, March, 1892, 169. "Origin of the Gravel Deposits beneath the Muir Glacier, Alaska," *Amer. Geol.*, March, 1892, 180. J. E. Spurr and H. B Goodrich, "Geology of the Yukon Gold District," *XVIII. Ann. Rep. U. S. Geol. Survey*, Part III., 87. Rec. E. R. Skidmore, "Alaska," *Rep. Director of the Mint*, 1883, p. 17, and 1884, p. 17. J. Stanley-Brown, "Auriferous Sands at Yakutat Bay, Alaska," *Nat. Geogr. Mag.*, Vol. III., 196, 1891. J. J. Stevenson, "Some Notes on Southeastern Alaska and its People," *Scottish Geogr. Mag.*, February, 1893. J. B. Tyrrell, "Glacial Phenomena in the Canadian Yukon District," *Bull. Geol. Soc. Amer.*, X., 193, 1899. G. H. Williams, "Notes on Some Eruptive Rocks from Alaska," *Nat. Geogr. Mag.*, IV., 63.

NOTE.—*The Bulletin* of the Boston Public Library for September, 1897, p. 153, has a complete bibliography of the Yukon region up to that date. In 1899, the U. S. Geological Survey issued a pamphlet entitled, "Maps and Descriptions of Routes of Exploration in Alaska," together with a valuable series of maps.

and is, as a rule, now much altered, but in the freshest material available, it is almost entirely albite. It contains small amounts of augite, hornblende, biotite and a few plagioclases other than albite. Secondary quartz is abundant. After the intrusion of the diorite, a gabbro dike, with some tendencies toward diabase in its texture, penetrated along the northeast side of the diorite, being sometimes entirely in the slate. The gabbro is chiefly augite and plagioclase, and carries no value in gold that is practically serious. After the intrusion of the gabbro a narrow dike of analcite-basalt 4 to 6 feet wide cut all the other rocks. Before its intrusion, the others, and especially the albite-diorite, suffered severely from crushing, the latter being cracked by series of planes at right angles with each other, and inclined at 45° to the horizon. Along these cracks the mineralization has taken place, and quartz, calcite, gold-bearing pyrite, with rare chalcopyrite, mispickel, blende and galena entered. The analcite-basalt accompanied or closely followed the mineralization. During the latter the ferromagnesian silicates of the original albite-diorite were replaced by the pyrite.[1]

F. D. Adams has detected metallic gold in the midst of the pyrite in a thin section of the ore.

South from the Treadwell mine is an unworked claim, and then the Mexican, which is operated by the same parties as the Treadwell.

In connection with the petrography of the Treadwell ore, it is interesting to remark that numerous dikes of albitic rock occur in the Sierras of California, and are known to be gold-bearing in a number of instances.[2]

2.13.14. The other mines that have been developed along the coastal region are not numerous as yet. Some three miles east of Juneau there is, in the midst of the mountains, a small abandoned lake basin called Silver Bow basin, whose sands are

[1] F. D. Adams, "On the Microscopical Character of the Ore of the Treadwell Mine, Alaska," *Amer. Geol.*, August, 1889, p. 88. G. F. Becker, "Reconnaissance of the Gold Fields of Southern Alaska, with some Notes on the General Geology," *XVIII. Ann. Rep. Dir. U. S. Geol. Survey*, Part III., p. 1. Rec. G. M. Dawson, "Notes on the Ore Deposits of the Treadwell Mine, Alaska," *Amer. Geol.*, August, 1889, p. 84. *Min. and Sci. Press*, San Francisco, September 27, October 4, 1884.

[2] See H. W. Turner, "Replacement Ore Deposits in the Sierras," *Jour. of Geol.*, May–June, 1899, 389. Compare also paragraph 2.12.20.

gold-bearing to a degree that admits of profitable hydraulicking. In the surrounding mountains of schists there are a few veins that have received attention at the Bennet, the Lane and Hayward and the Taku mines. Over the divide to the south, in the drainage of Sheep Creek basin, are several other veins in schists. They carry silver-bearing sulphides, with minor gold values. The country rock is schist, carbonaceous and micaceous, with gabbro dikes.

2.13.15. At Sumdum Bay there are slates, which are penetrated by granitic dikes. They also contain lenses of quartz

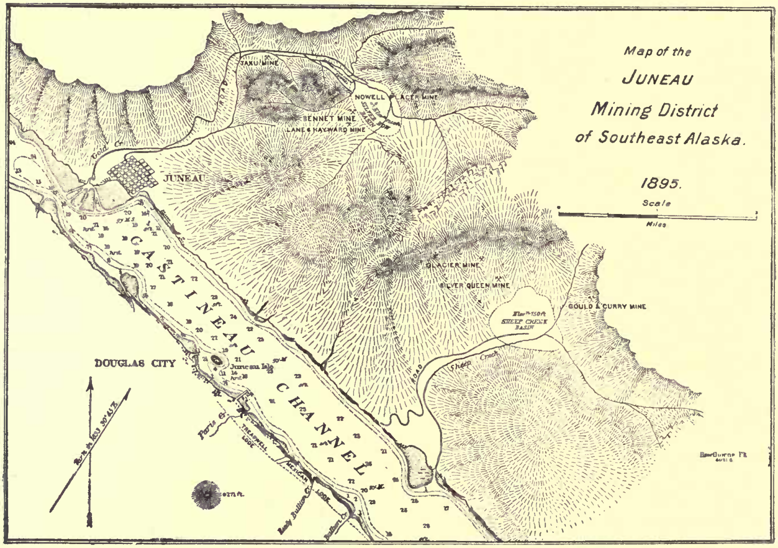

FIG. 152.—*Map of the Juneau mining district, southeast Alaska. After G. F. Becker, XVIII. Ann. Rep. Dir. U. S. Geol. Survey, Part III., Plate XVI., reduced.*

with sulphides carrying gold and silver. Near Berner's Bay the diorite has quartz veins with sulphides, and at Funter's Bay, in the Admiralty Islands, schists derived from diabase hold veins in cross-fissures. Pyrite and pyrrhotite occur in a gangue of quartz. Near Sitka veins with low grade ores have been found in a pyroclastic diorite, and on Kadiak Island there are some prospects, as well as gold-bearing beach sands. Next, however, after the mines on Douglass Island, the largest on the Alaskan coast is the Apollo mine on Unga

Island. The wall rock is andesite, probably post-Miocene. The ores are free gold, pyrite, galena, zincblende, chalcopyrite, and some native copper, in a large chute along a zone of fracture.

2.13.16. *The Yukon Basin.* The greatest interest, so far as the mineral resources of Alaska and the Northwest Territory of Canada are concerned, centers around the gold placers of the Yukon basin. So far as yet developed the richest lie in Canadian territory, and from these the chief production has thus far been obtained, but the older workings are on the American side, and some gold is annually obtained from them yet. The gold occurs in two different kinds of gravels. The ore lies on the bed-rock beneath the courses of the smaller streams and their tributary gulches, which latter are locally called "pups." Above the pay-streak lies a variable thickness of barren, frozen gravel, which is overlain by peaty muck. The pay-streak is exposed by thawing out a pit in the frozen gravel by means of fires and heated stones, so that it can be excavated and stacked up until the warm season affords water for panning, cradling, or more rarely, sluicing. Except that the ground is frozen the placers do not differ from those already fully outlined.

2.13.17. The second variety of gravels is the "bench" gravel, which occurs on the sides of the valleys above the present stream bottoms. They are regarded by Tyrrell as the terminal moraines of small glaciers, which came but a comparatively short distance down the hillsides and stopped.

2.13.18. The source of the gold appears to have been the quartz veins in the Birch Creek, Forty-Mile and Rampart series, as described under paragraph 2.13.12. The veins seem to have been individually small, for thus far no one has yet proved available for deep mining. A few have been proved to actually contain gold, and have thus given real as well as theoretical ground for the above inference. The veins chiefly run parallel with the foliation, although some fissure veins, that cross it, are known. Assays, so far as recorded, while they demonstrate the presence of gold, do not indicate great richness. (Citations of the literature will be found under 2.13.12.)

2.13.19. South of the headwaters of the Yukon, and after an interval of barren territory, so far as known, lies the Cassiar district, which is reached from the coast *via* Wrangell and the Stickeen River. From the coast inland schistose rocks, with a few limestones and extensive intrusions of granite form the oldest rocks, but there are many sheets of basalt of most interesting character, especially near the head of navigation on the Stickeen River. The chief gold discoveries have been made in the past in the drainage area of Dease Lake. The gold occurred in stream gravels, but the heavy glacial deposits have at times buried them under a great amount of later and barren débris. One of the routes to the Klondike passes through the region.[1]

2.13.20. In the drainage area of the Columbia River just north of the international boundary, and lying between it and the line of the Canadian Pacific railway, important developments in mining have been made in recent years. The region is mountainous and rugged. The Columbia and its tributary, the Kootenay, into which flows the Slocan, have their courses largely formed by long and relatively narrow lakes, which, being navigable, have greatly aided in the development of the mines. The Columbia passes through Upper and Lower Arrow Lake; the Slocan heads in Slocan Lake, lying to the east; and the Kootenay drains the waters of Kootenay Lake still further east. All these lie in long north and south valleys, and into them the smaller streams discharge from the mountains lying east and west. In the valleys, and on the mountain slopes along these creeks the veins have been located. The Slocan district extends from west of Lower Arrow Lake eastward beyond Slocan Lake; the Ainsworth district surrounds Kootenay Lake; the Nelson lies along the Kootenay River between Kootenay Lake and the Columbia River; while Trail Creek embraces both banks of the Columbia as it leaves Canada and crosses the international boundary.

Dr. Geo. M. Dawson[2] recognizes on Kootenay Lake and on Adams Lake (which latter is 150 miles northward of the former) the following series, beginning with the oldest (*Bull. Geol. Soc. Amer.* II., 168):

[1] G. M. Dawson, *Geol. Survey of Canada*, III., 1888, *Report B*. E. D. Self, "The Cassiar District," *Eng. and Min. Jour.*, February 18, 1899, 205.

[2] G. M. Dawson, "Report on a Portion of the West Kootenay District, British Columbia." *Rep. B. Can. Geol. Survey*, IV., 1888–89. Rec. "Note on the Geological Structure of the Selkirk Range," *Bull. Geol. Soc. Amer.*, II., 165, 1891.

1. The Shuswap series. Mica schists, gneisses and marbles. Archean.

2. The Nisconlith series. Black shaly or schistose argillite, with some limestone. Cambrian.

3. The Adams Lake series. Gray and greenish schists. Cambrian and Silurian.

Above these are limestones, argillites and schists.

W. A. Carlyle,[1] in the report cited below, mentions above the Nisconlith series in the Kootenay region.

3. The Kaslo schists, comprising a series of greenish, probably diabasic schists interbedded with some slates or dark argillites, and limestones.

4. The Slocan slates, a series of dark shales and slates, with limestones and calcareous quartzites. (*Bulletin Bureau of Mines*, p. 45.)

In addition to the stratified rocks there are vast intrusions of granite regarded as later, and also many, more basic rocks, such as porphyrite, diabase and gabbro, which are often intimately associated with the ore bodies.

2.13.21. In the Slocan district, W. A. Carlyle has recognized four kinds of veins, according to the variety of ores furnished, viz.: (1) Those with argentiferous galena, blende and some tetrahedrite in a gangue of quartz and siderite. They cut stratified rocks, dikes and granite in one place and another. Gold values are known but are not of great moment. These veins are the chief ones of the region. (2) Veins of argentiferous tetrahedrite, jamesonite and silver minerals in quartz gangue in granite and stratified rocks, but not numerous. (3) Veins in granite with quartz gangue, carrying argentite, native silver and gold. (4) Gold quartz veins in granite. (*Bulletin III.*, pp. 46-48.) In the Ainsworth district all the geological series are met, and any one may be the wall rock of a vein. The common gangue-minerals are quartz and calcite, and the ores are silver-bearing galena, with some blende; or pyrites; or silver minerals with more or less of the other sulphides, or of tetrahedrite with them. In the Nelson district the rocks and the ores

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[1] Wm. A. Carlyle, "Report on Slocan, Nelson and Ainsworth Mining Districts in West Kootenay, British Columbia," *Bull. III., Bureau of Mines*, Victoria, B. C., 1897. Annual reports, with maps, are issued by the *Provincial Mineralogist*, Victoria, B. C.

are somewhat different from those previously described, and tend to resemble the ones mined at Trail Creek. The country rocks are porphyrites, gabbros, diabases and slates, cut by numerous dikes. The ores are silver-bearing sulphides of copper, especially chalcopyrite, and the common associate of the latter in rocks of this character, pyrrhotite. Gold is very subordinate.[1] In the Trail Creek district igneous rocks are the chief varieties present. There is an older series, according to R. G. McConnell,[2] of porphyrites, diabases, gabbros, tuffs, and agglomerates, with occasional patches of limestone, which afford some fossils of probable Carboniferous affinities, and with some inclusions in the igneous rocks of black slate. Later than this igneous series, is granite, and through both, dikes of both acidic and basic rocks have been intruded. The chief economic interest centers about a small area of gabbro, near the town of Rossland, and about four miles long by one mile wide. From a gabbro of granitoid texture in the central mass, it passes gradually into a rim of augite- and uralite-porphyrites and diabase, which are seldom over a mile across, and which are brecciated. At or near the contact of the gabbro and the porphyritic border, are met the ore bodies. The ores consist of auriferous and slightly argentiferous pyrrhotite and chalcopyrite. They are not of high grade as a rule, the gold ranging from a trace to several ounces, and the silver from a trace to four or five ounces. A little nickel and still less cobalt can also be detected. Other minerals are not prominent; molybdenite, highly auriferous, and rarely galena and blende have been recorded. The oxidized zone extends but a few feet below the surface. It is still somewhat of a mooted point among observers, as to whether they are direct crystallizations from the cooling magma; or secondary segregations from the enclosing basic walls; or replacements along lines of fissuring; or true fissure veins. One mine and another seem to give support to each of these views.

The geological relations strongly suggest those of Sudbury, later described under nickel, and also those of many nickel

[1] The details of these districts are taken from the Bulletin of W. A. Carlyle, previously cited.

[2] R. G. McConnell, "Preliminary Abstract," issued in *Rossland Weekly Mining*, March 18. 1897, a local paper.

regions in Norway and elsewhere in the world. The question of their direct origin from a fused and cooling magma, is an important and interesting one, and examination should be carefully directed toward its solution. From observations made in connection with recent litigation over the War Eagle claim, W. Lindgren reached the conclusion that the ores had certainly been deposited by replacement.

2.13.22. Example 45*c*. *Nova Scotia.* The southeastern portion of Nova Scotia, exclusive of Cape Breton Island, is chiefly composed of a vast series of metamorphosed, fragmental deposits, which in places contain gold-bearing quartz veins of very interesting geological relations. As a rule, the veins conform to the bedding of the wall-rocks and therefore present structural problems, exactly like those of thin beds in a folded and, to some extent, faulted sedimentary series. The age of the sediments is thought by some to be Cambrian, by others pre-Cambrian or Algonkian, the absence of assured fossils making the question an open one. The metamorphic rocks are penetrated by numerous, great intrusions of granite, which constitute no inconsiderable part of the 6,000 or 7,000 square miles that the area embraces. The strata have been divided by geologists into two series. The upper, approximately 3,000 feet thick, consists of dark, pyritous slates, with some beds of quartzite, but with few veins. The lower series, roundly estimated at 8,000 feet, has a much larger proportion of coarse sediments and embraces slates, quartzites, sandstones, and even conglomerates. A Lower Carboniferous conglomerate is known to overlie the metamorphics, and to contain boulders of the gold-bearing quartz veins, so that the mineralization certainly was of earlier date. The slates, and even the quartzites, are quite richly provided with pyrites, and are known to carry gold even at a distance from the veins. There is reason to think that this gold was deposited with them originally, and even the pyrite may be of metamorphic production, from materials laid down in the sediments. The presence of the gold and pyrites in the slates has an important bearing on the methods of enrichment of the veins and the direction taken by the gold-bearing solutions.

Inasmuch as the larger veins lie parallel with the bedding and conform to the folds of the sediments, it is evident that the

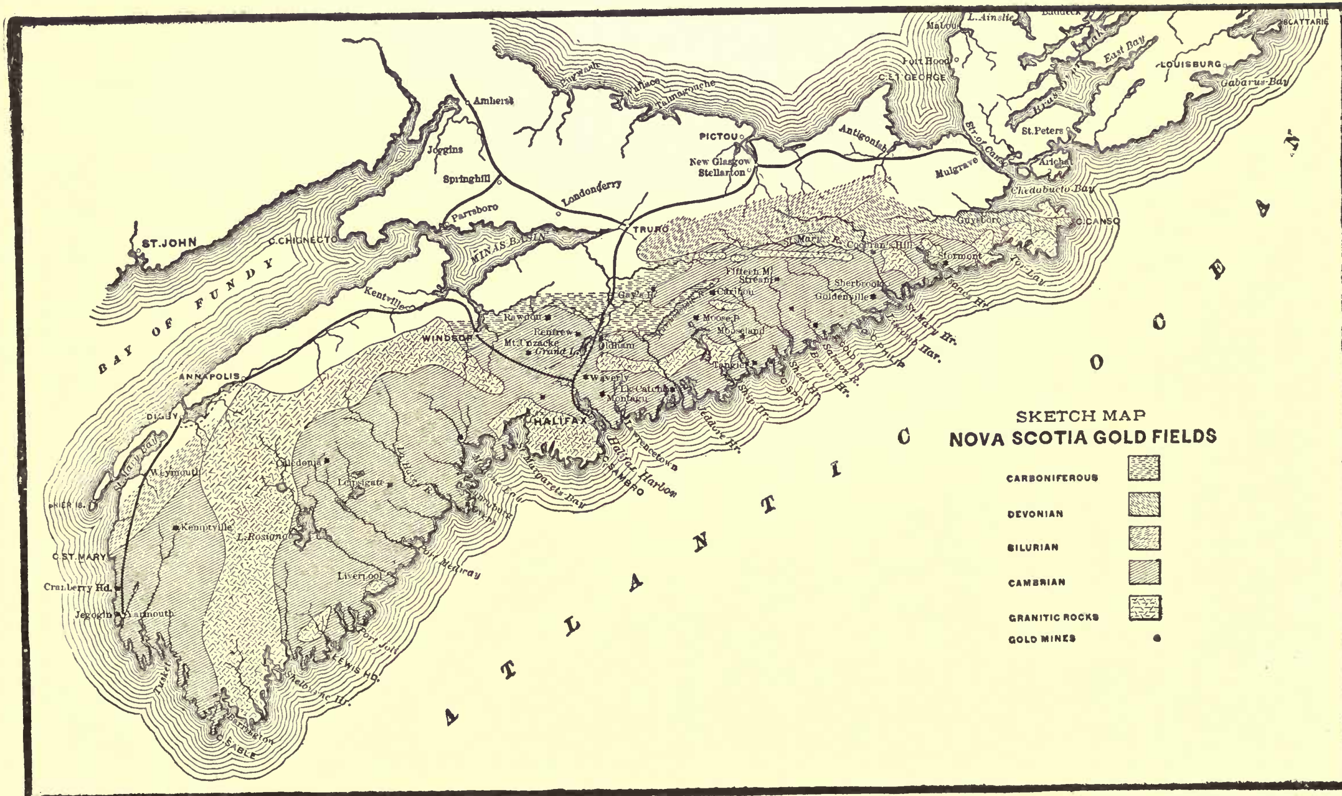

FIG. 153.—*After a map by E. Gilpin, Trans. Amer. Inst. Min. Eng., XIV., 688. (Reduced.) The strata colored Cambrian are considered pre-Cambrian by some.*

quartz was deposited in them before the folding took place. J. E. Woodman states that the original filling of the veins, presumably by uprising solutions, was not accompanied by the introduction of much gold. This came later, during the metamorphism, and probably was contributed by the pyritous wall-rock. The first and major folds were developed with axes running approximately east and west. In time a second compression nearly at right angles to the first, threw these folds into a north and south series, and caused many faults, mostly reversed. The corrugations produced in the first series of folds by these later ones, gave rise to the so-called "barrel quartz," and as the latter has the reputation of carrying good values in gold, there may have been some additional enrichment of it during the later disturbances. Probably the intrusion of the granite followed the second folding, but it is not certain that it may not have preceded the first upheavals. The second period of disturbance produced some fissures, which were filled at Cow Bay with gold quartz. In the subsequent history of the series, a pronounced northeastern cleavage was developed, and some small faulting. Erosion has been severe, and has planed off the domes produced by the cross-folding, and has largely determined the location and extent of the mining districts.

While the bedded character of the larger veins has been emphasized, it must be appreciated that they throw off stringers into the walls, called "angulars," and that parallel ones are connected by cross-veins. Still, except at Cow Bay, fissure veins of the ordinary type are not often met.

The ore minerals of the veins are free gold, gold-bearing pyrite, mispickel, and rarely galena and blende. The gangue is chiefly quartz, but calcite occurs sporadically. The veins average less than a foot in width, but may be several feet as an exception. They favor horizons where a soft rock, usually slate, lies near a hard one, usually quartzite.[1]

[1] In the following bibliography the citations given in the previous editions are greatly expanded by the aid of *Bulletin 127* of the U. S. Geological Survey and the very complete list in the paper of J. E. Woodman. W. J. Anderson, "Gold Fields of Nova Scotia," *Trans. Lit. and Hist. Soc.*, of Quebec, Part II., pp. 35–56, 1864. L. W. Bailey, "Preliminary Report on Southwestern Nova Scotia," *Geol. Survey Canada*, 1892–93, Report Q. G. F. Becker, "Gold Fields of the Southern Appalachians," *XVI. Ann*

2.13.23. Gold elsewhere in Canada. Auriferous gravels have been located at the headwaters of the Chaudière River, in eastern Quebec, and some quartz veins are found in the metamorphic rocks of the same region. They have been worked to

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Rep. U. S. Geol. Survey, III., 330. J. S. Campbell, "Report on the Gold Fields, Eastern Section," Halifax, 1862; "Report on the Gold Fields," Halifax, 1863. J. W. Dawson, "On Recent Discoveries of Gold in Nova Scotia," *Can. Nat. and Geol.*, VI., 417, 1861. The various editions of "Acadian Geology," of which the third, London, is the latest, 1878. E. R. Faribault, "Report on the Lower Cambrian Rocks of Guysborough and Halifax Counties," *Geol. Survey Canada*, 1886, Report P, 129. H. Fletcher, "Report on Various Counties in Nova Scotia," *Idem*, 1886, Report P, 1–129. E. Gilpin, "The Gold Fields of Nova Scotia," *Eng. and Min. Jour.*, XXXIV., 5, 17, 1882. "Results of Past Experience in Gold Mining in Nova Scotia," *Brit. Assoc. Adv. Sci.*, LIII., 711, 1885. "Nova Scotia Gold Mines," *Trans. Amer. Inst. Min. Eng.*, XIV., 674, 1886. Rec. "Notes on Nova Scotia Gold Fields," *Trans. Roy. Soc. Can.*, VII., 63, 1888. "The Evidence of a Nova Scotia Carboniferous Conglomerate," *Idem*, VIII., 117, 1890. "Ores of Nova Scotia," Halifax, 1898. W. Gossip, "The Rocks in the Vicinity of Halifax," *Proc. and Trans. Nova Scotian Inst. Nat. Sci.*, I., Part II., 44, 1864. "On the Barrel Quartz of Waverly," *Idem*, I., Part III., 141, 1865. P. S. Hamilton, "Auriferous Deposits of Nova Scotia," *Idem*, I., Part IV., 43, 1866. C. F. Hartt, "Pre-Carboniferous Gold," *Can. Nat.*, New Series, I., 459, 1864. A. Heathington, "Guide to the Gold Fields of Nova Scotia," 1868. H. Y. Hind, "Report on the Waverly Gold District," Halifax, 1869. "Gold Deposits of Nova Scotia," *Can. Nat.*, New Series, IV., 229, 1869. "Notes on the Structure of the Nova Scotia Gold Districts," *Proc. and Trans. Nova Scotian Inst. Nat. Sci.*, II., Part III., 102. "Preliminary Report on a Gneissoid Series Underlying the Gold-bearing Rocks," etc., Halifax, 1870. See also *Quar. Jour. Geol. Soc.*, XXVI., 468, 1870, and *Amer. Jour. Sci.*, XL., 347, 1870. "Report on the Sherbrook Gold District," etc., Halifax, 1870. "Report on the Mount Uniacke, Oldham, and Renfrew Gold Mining Districts," Halifax, 1872. D. Honeyman, "On the Geology of the Gold Fields of Nova Scotia," *Quar. Jour. Geol. Soc.*, XVIII., 342, 1862. "Geology of the Gay's River Gold Field," *Proc. and Trans. Nova Scotian Inst. Nat. Sci.*, II., 76, 1870. H. How, "Mineralogy of Nova Scotia," 1868, and again in official report, Halifax, 1869. J. Howe, "Report on the Gold Fields," Halifax, 1860. "Tangier Mines," report to the Provincial Secretary, Halifax, 1860. "Nova Scotia Gold Fields," Halifax, 1861. "Report on Gold Fields," 1871. T. S. Hunt, "Report on the Gold Regions of Nova Scotia," *Geol. Survey Can.*, 1868; *Can. Nat.*, February, 1868. W. E. Logan, *Geol. Survey of Can.*, 1863, and atlas, 1865. "Notes on the Gold of Eastern Canada," Montreal, 1864. J. Marcou and C. T. Jackson, "Note on Gold Slates of Nova Scotia," *Proc. Bost. Soc. Nat. Hist.*, IX., 47, 1862. O. C. Marsh, "The Gold of Nova Scotia," *Amer. Jour. Sci.*, XXXII., 395, 1861.

a small extent.[1] Auriferous mispickel has been developed in considerable quantity at Marmora (or Deloro), Hastings County, Ontario. It occurs with quartz in a vein of complex geological relations, and after proving refractory to older methods of treatment, has yielded to the cyanide process.[2] Regarding the mineral resources of the Hudson Bay territory, some further notes have been recorded by Dr. Robert Bell.[3]

2.13.24. The following table gives an idea of the relative importance of the several States. Full details of the United States and other countries are given in the Annual Reports of the Director of the Mint, the *Mineral Resources* of the United States Geological Survey, and the *Mineral Industry*, the annual statistical number of the *Engineering and Mining Journal*.

A. Michel and T. S. Hunt, "Report on the Gold Region of Canada," *Can. Geol. Survey*, 1866, 49–90. G. F. Monckton, "The Auriferous Series of Nova Scotia," *Proc. Geol. Assoc.*, XI., 454, 1891, London. H. F. Perley, "Gold in Nova Scotia," *Can. Nat.*, II., 198, 1865. H. Poole, "Report on Gold Fields, Western Section," Halifax, 186?. "The Gold Leads of Nova Scotia," *Quar. Jour. Geol. Soc.*, XXXVI., 307, 1880. W. H. Prest, "Deep Mining in Nova Scotia," *Proc. and Trans. Nova Scotian Inst. Nat. Sci.*, VIII., 420, 1895. A. R. C. Selwyn, "Gold Fields of Quebec and Nova Scotia," *Can. Geol. Survey*, 1870–71, pp. 252–289. B. Silliman, Jr., "On the so-called Barrel Quartz of Nova Scotia," *Amer. Jour. Sci.*, XXXVIII., 104, 1864. "Report on the Lake Loon Gold Mining Co.," 1864. "Report on the New York and Nova Scotia Gold Mining Co.," 1864. B. Symons, "The Gold Fields of Nova Scotia," *Trans. Min Assoc. and Inst. Cornwall*, III., 80, 1892. J. E. Woodman, "Studies in the Gold-bearing Slates of Nova Scotia," *Proc. Bost. Soc. of Nat. Hist.*, XXVIII., 375, 1899. Rec. There are also several official reports to provincial officers of Nova Scotia's Department of Mines.

[1] R. W. Ellis, "Report on the Mineral Resources of Quebec," *Geol. Survey of Can.*, New Series, 1888–89, Report K. *Trans. Amer. Inst. Min. Eng.*, XVIII, 316. A. Michel and T. S. Hunt, "Report on the Gold Regions of Canada," *Geol. Survey of Can.*, 1866, 49–90.

[2] "The Marmora Gold Mine," *Eng. and Min. Jour.*, October 23, 1880, p. 266. T. S. Hunt, "Report on the Gold Region of Hastings," *Geol. Survey of Can.*, Montreal, 1867. R. P. Rothwell, "The Gold-bearing Mispickel Vein of Marmora, Ontario," *Trans. Amer. Inst. Min. Eng.*, IX., p 409.

[3] R. Bell, "Mineral Resources of the Hudson Bay Territories," *Trans. Amer. Inst. Min Eng.*, XIV., 690, 1886. See also *Trans. Roy. Soc. Can.*, II., 241, 1885.

	1890.		1898.	
	Silver.	Gold.	Silver.	Gold.
Alaska	$9,697	$762,500	$147,500	$2,820,000
Arizona	1,292,929	1,000,000	1,622,500	2,800,000
California	1,163,636	12,500,000	442,500	14,900,000
Colorado	24,307,070	4,150,000	13,866,535	23,534,531
Georgia	517	100,000	....	....
Idaho	4,783,838	1,850,000	3,707,999	2,050,000
Michigan	71,111	90 000	....	....
Montana	20,363,636	3,300,000	8,743,011	5,247,913
Nevada	5,753,535	2,800,000	826,000	3,000,000
New Mexico	1,680,808	850.000	383,500	480,000
North Carolina	7,757	118,500	....	....
Oregon	96,969	1,100,000	75,712	1,216,669
South Carolina	517	100,000	....	....
South Dakota	129,292	3,200,000	354,000	5,720,000
Texas	387,878	....	354,000	....
Utah	10,343,434	680,000	3,876,451	2,372,442
Washington	90,505	204,000	206,500	600,000
Others	2,585	40,000	64,037	340,875
Total	70,485,714	32,845,000	34,670,245	65,082,430
Canada	518,000	1,149,776	2,616,110	13,790,000

The above figures for 1890 are from the *Report of the Director of the Mint* for that year. The figures for 1898 are from the *Mineral Industry*, VII., 1899. The totals illustrate the great falling off in the value of silver, although the number of ounces was actually greater in 1898 than in 1890. The immense increase in the output of gold is also brought out.

CHAPTER XIV.

THE LESSER METALS: ALUMINUM, ANTIMONY, ARSENIC, BISMUTH, CHROMIUM, MANGANESE.

ALUMINUM.

2.14.01. The importance of aluminum grows with improved and cheaper methods of production. Its sources are, or have been, alums, either natural or artificial, corundum, cryolite, kaolin and bauxite. The first of these is formed in nature by the decay of pyrite in shales and slates, and is little if at all used as an ore at present. The second is more valuable as an abrasive, and with the fall in the price of the metal has given way to other and cheaper ores. Still corundum (Al_2O_3) with 53.3 Al, is the richest natural mineral. Cryolite and bauxite are now the staple ores, but in the Grabau process kaolin is employed, although not as yet in any such amount as these other two. The fused cryolite plays the rôle of a bath in which the alumina is dissolved and reduced by electrolysis, so that really bauxite has come to be the principal source. Cryolite occurs as an immense bedded deposit in gneiss at Evigtok, on the Arksut Fjord, Greenland. It is mined as an open cut, and being near the water's edge, on a steep cliff, after hand-picking, it is loaded directly upon vessels, which moor to the cliff. The cryolite is associated with various related minerals, all rare and mostly limited to this locality, with sulphides of iron, copper and lead, and with siderite. The Pennsylvania Salt Co. of Natrona, Pa., receives by contract two-thirds of the output, the remaining third going to Denmark. The other localties of this mineral, at Miask, in the Urals, and near Pike's Peak, Colo., are small and commercially unimportant pockets.

Cryolite when pure contains 13.02 Al, and of itself is thus a very low grade ore.[1]

2.14.02. Bauxite (Al_2O_3, $3H_2O$) is now the main source of the metal. In the pure condition and of the composition given above it contains Al_2O_3, 65.55, or Al, 34.94, but various impurities are always with it, of which the commonest are silica, oxide of iron, oxide of manganese, carbonates of lime and magnesia, phosphoric acid, and, in the Southern States, small but constant amounts of titanic acid. The merchantable ore ranges from about 40 to over 60%, or even over 70% Al_2O_3, but any analysis over 65.55% Al_2O_3 indicates a mineral of different composition from Al_2O_3, $3H_2O$. There is no doubt that such exist, and in an interesting paper entitled "The Bauxites: A Study of a New Mineralogical Family," M. Francis Laur[2] has advocated that there is a whole series of hydrated compounds of alumina which are as complex, perhaps, as the anhydrous compounds of this metal. Bauxite is now known to occur in economic quantities in Georgia and Alabama, and in Arkansas. It has been mentioned, however, from numerous other points in States immediately north of the two former. The deposits in Georgia and Alabama[3] occur along a narrow belt in the Coosa Valley, extending some sixty miles from Adairsville, Ga., to Jack-

[1] On the geology of Greenland Cryolite see G. Hagermann, "On some Minerals associated with the Cryolite in Greenland," *Amer. Jour. Sci.*, ii., XLII., 93. C. Hart, "On the Cryolite Deposit," *Jour. of Analyt. and Applied Chem.*, October, 1892. G. Lunge, in the treatise entitled, "The Manufacture of Sulphuric Acid and Alkali." J. W. Taylor, "Cryolite of Evigtok," *Quar. Jour. Geol. Soc.*, XII., 140. See also *The Mineral Industry*, Vols. I. and II., and a pamphlet published by the Pennsylvania Salt Manufacturing Co.

[2] *Trans. Amer. Inst. Min. Eng.*, XXIV., 234, 1894.

[3] C. W. Hayes, "Geological Relations of the Southern Appalachian Bauxite Deposits," *Trans. Amer. Inst. Min. Eng.*, XXIV., 243; also 855, 861, 1894. Rec. *XVI. Ann. Rep. Dir. U. S. Geol. Survey*, 1894, III., 547. Rec. H. McCalley, "Alabama Bauxite," *Proc. Ala. Indust. and Sci. Soc.*, 1893. Reprinted in *Science*, November 25, 1892, p. 303; a later paper in the issue January 19, 1894, p. 29. "Bauxite," in *The Mineral Industry*, II., 57, 1894. *Idem*, V., 51. Rec. "Coosa Valley Region," *Ala. Geol. Survey*, 1897. Many details as per index. E. Nichols, "An Aluminum Ore: Bauxite," *Trans. Amer. Inst. Min. Eng.*, XVI., 905. R. L. Packard, "Aluminum," *Mineral Resources*, 1891, 147. J. W. Spencer, "Geology and Resources of Ten Counties in northwestern Georgia," p. 210, 1893. Rec.

sonville, Ala. The mineral itself is pisolitic or oölitic in structure, as a general thing, and the individual masses are often in concentric layers, and are held together either by non-oölitic bauxite or by silica. Less often the ore is more massive, and may be in fairly hard lumps or soft and earthy. The surface ore is often pitted and cellular. The general geological relations will be best understood by referring to Fig. 4, p. 22. The region is largely formed by Cambrian strata, of which the Connasauga shales are the upper member, and the Rome sandstone, or Weissner quartzite, is the lower. Above the Cambrian is found the Lower Silurian, Knox dolomite, rich in chert. These strata are broken by folds and faults of several series and formed at different periods. The great overthrust shown in Fig. 4 is of post-Carboniferous time, long

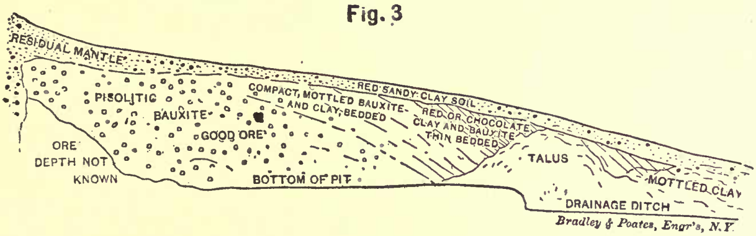

FIG. 154.—*Cross-section of a Bauxite deposit in Georgia. After C. Willard Hayes, Trans. Amer. Inst. Min. Eng., February*, 1894.

after the principal Appalachian upheaval. C. W. Hayes has shown that the ore bodies lie along certain of these fault lines, and the association gives us a possible clue to their method of deposition. They are very sharply limited to points lying between the 900 and 950 feet contours, and seem to have been occasioned by the attitude of the land toward the sea during the formation of the Tertiary peneplain in the region.

The ores are always found in the residual alteration products of the Knox dolomite, from which, however, they are quite sharply separable. The accompanying cross-section shows the relations. While more or less irregular in shape they have proved quite persistent, and many years' supply is now in sight. Mr. Hayes suggests that the crushing attendant on the faulting, developed great heat, and that atmospheric waters penetrating along these zones became charged with sulphuric acid, derived from decomposing pyrite. The acid would dissolve alumina from the Connasauga shales, possibly forming alums, with some alkali. Calcium carbonate would react on such solutions so as to precipitate hydrate of alumina, and this, rising as a flocculent precipitate in springs, gave rise to the oölitic and pisolitic deposits, which were afterward, in the decay of the Knox dolomite, involved in its residual products. The explanation is reasonable and has great claims to confidence. The same general hypothesis may be applied to the neighboring limonites. H. McCalley gives in *Science*, January 29, 1894, p. 30, the following working analyses from the War-whoop Bank. The analyses are based on samples from car-load lots, and represent 500 to 1,000 tons. The first column is the variety called "Hard White Ore"; the second, known as "War-whoop Ore," is the average of consumer's analyses.

	First.	*Second.*
Alumina	57.–62.	56.–62.
Ferric oxide	under 1.	2.5–3.0
Silica, about	2.50	5.00
Titanic acid	3.0– 4.0	3.0–4.0
Water, combined	29.0–30.0	about 30.0
Moisture, hygroscopic	2.0– 4.0	3.0–4.0

A little over half (53.3%) of the alumina is the metal itself.

2.14.03. The bauxite deposits of Arkansas are found within a few miles of Little Rock, and further west in Saline County, near the town of Bryant. They favor the contact of the intruded syenites (regarded as Cretaceous) and Paleozoic sediments, but they are themselves involved in most cases in Tertiary sandstones. The association with syenite is quite invariable. The bauxite is pisolitic and concretionary. The range in composition is considerable, some being high in iron, others in silica, while others are fairly pure. The variability even in the same opening is considerable, as indeed is always the case with deposits of this character. The deposits are individually somewhat irregular in shape and extent, but the quantity is large. J. C. Branner regards them as shore deposits, probably formed after the manner of oölitic concretions, which derived their hydrate of alumina from the syenite, through the medium of hot springs. A submergence of the still heated syenite beneath sea water is suggested as a possible explanation of the solution and deposition. Dr. Branner gives, in the reference from the *Journal of Geology*, cited below, a complete bibliography and review of the literature on bauxite and of the views regarding its origin.[1]

2.14.04. W. P. Blake has described deposits of alunogen and bauxite, on the upper Gila River, about 40 miles north of Silver City, New Mexico. The bauxite has resulted from the action of sulphuric acid, produced in the decay of pyrites, upon basalts. Alunogen and sulphate of iron are removed while bauxite remains as a residual deposit. The geological relations are therefore very like those of Glenariff, County Antrim, Ireland, and of the Vogelsberg, Germany.[2] The Gila River deposits are too remote for utilization under present conditions.

Bauxite is employed for many other purposes besides furnishing an ore of aluminum, as this is one of its later adaptations. Great quantities are used to produce alums, and as a refractory material it has long been appreciated.

2.14.05. In the earlier development of the aluminum industry corundum was somewhat sought as an ore. The varieties with vitreous luster and light colors are called sapphire, the duller and more smoky ones, corundum, while the impure kinds, which are mixed more or less with magnetite, hematite, spinel, etc., pass under the name of emery. The last named is of no importance in this connection. Some sapphire and corundum have been obtained in Chester County, Penn., but practically the only source of any moment in the United States is in a belt of a curious rock called dunite, which consists of grains of olivine, and which traverses western North Carolina

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[1] J. C. Branner, "Bauxite in Arkansas," *Amer. Geol.*, VII., 181, 1891. An extended report was announced for Vol. I., 1889, of Dr. Branner's Annual Reports as State Geologist of Arkansas, but it has not yet (1899) been issued. Preliminary reports appear in the *Arkansas Gazette* and *Arkansas Democrat*, Little Rock, January 8, 1891. Third Biennial Report, Bureau of Mines, Manufactures and Agriculture of the State of Arkansas, for 1893 and 1894, Little Rock, 1894, 119-125. Fourth Biennial Report, Little Rock, 1896, 105-110. "The Bauxite Deposits of Arkansas," *Jour. of Geol.*, V., 263, 1897. J. Francis Williams, *Ann. Rep. Geol. Survey Ark.*, 1880, II., 124.

[2] W. P. Blake, "Alunogen and Bauxite of New Mexico," *Trans. Amer. Inst. Min. Eng.*, XXIV., 571.

and Georgia. The corundum occurs along the contacts of the dunite and a hornblende gneiss with which it is associated. It lies in scattered lumps distributed through decomposed micaceous material, which is at times so soft as to be washed out in the hydraulic way. In some instances the mineral appears to have resulted from some reactionary effects of the two rocks, or of solutions emanating from them, on each other. The gneiss is aluminous, the dunite magnesian.[1] Again it seems to have crystallized directly from fusion and to have become concentrated near the walls, either from the operation of Soret's law, or from convection currents as described under 1.06.13.[2] J. H. Pratt has even been able to apply the results experimentally obtained by J. Morozewicz to the rocks which yield the corundum, and has made the following summary as the result of his observations and analyses, dealing in all cases with peridotites.

1. When the magma is a calcium-sodium-potassium silicate, no alumina held in solution will separate out as corundum, except when the ratio of the alumina to the other bases is more than 1:1, and the ratio of the silica is less than 6. (Molecular

[1] T. M. Chatard, *Mineral Resources, U. S. Geol. Survey*, 1883–84, 714. Rec. "The Gneiss-Dunite Contacts of Corundum Hill, N. C.," etc., *Bull. U. S. Geol. Survey*, XLII., 45, 1881. Rec. Short abstract in the *Eng. and Min. Jour.*, July 21, 1888, p. 46. J. P. Cooke, *Proc. Amer. Acad.*, IX., 48, 1874. F. A. Genth, "Corundum: Its Alterations and Associated Minerals," *Amer. Phil. Soc.*, September 19, 1873; July 17, 1874; *Amer. Jour. Sci.*, iii., VI., 461, 1873. T. S. Hunt, *Trans. Roy. Soc. Can.*, II., 1884. C. W. Jenks, *Quar. Jour. Geol. Soc.*, XXX., 303, 1874. A. A. Julien, *Proc. Bost. Soc. Nat. Hist.*, XXII., 131, 1893. W. C. Kerr, "Geology of North Carolina, Supplement," 64, 1875. F. P. King, "Preliminary Report on Corundum Deposits of Georgia," *Geol. Survey Georgia, Bulletin* 2, 1894. J. V. Lewis, "Corundum in the Appalachian Crystalline Belt," *Trans. Amer. Inst. Min. Eng.*, XXV., 832, 1895. Rec. R. W. Raymond, "Jenks' Corundum Mine, N. C.," *Trans. Amer. Inst. Min. Eng.*, VII., 83, 1878. C. U. Shepard, "On the Corundum Region of North Carolina and Georgia," *Amer. Jour. Sci.*, iii., IV., 109, 175, 1872. Rec. C. D. Smith, "Geology North Carolina, I., Appendix D.," 91, 1875; II., 43, 1881. J. L. Smith, "Notes on the Corundum of North Carolina, Georgia," etc., *Amer. Jour. Sci.*, iii., VI., 180, 1873. Rec. M. E. Wadsworth, *Mem. Mus. Comp. Zoöl.*, XI., Part I., p. 118, 1884.

[2] J. H. Pratt, "On the Origin of the Corundum Associated with the Peridolites in North Carolina," *Amer. Jour. Sci.*, July, 1898, p. 49.

ratios are meant, *i.e.*, the quotients obtained by dividing the percentage by the molecular weight in each case.)

2. If magnesia and iron are present in the above magma, corundum will not form unless there is more than enough alumina to unite with the magnesia and iron (that is, spinels will form in preference to corundum where possible).

3. When the magma is composed of a magnesium silicate without excess of magnesia, *all* the alumina held by such a magma will separate out as corundum.

4. Where there is an excess of magnesia in the magma just described, this will unite with a portion of the alumina to form spinel, and the rest of the alumina will separate out as corundum.

5. Where there is chromic oxide in a magma composed essentially of a magnesium silicate (as the peridotite rocks), and only a very little alumina and magnesia are present, these, uniting, separate out with chromic oxide to form the mineral chromite, and no corundum or spinel is formed.

6. When peridotite magmas contain, besides the alumina, oxides of the alkalies and alkali-earths, as soda, potash and lime, a portion of the alumina is used in uniting with these oxides and silica to form feldspar.

7. There is a strong tendency for the alumina to unite with the alkali and alkali-earth oxides, to produce double silicates like feldspars, whether such silicates form the chief minerals of the resulting rock, or are present only in relatively small amount. There is, however, but little tendency for the alumina to unite with magnesia, to form double silicates, when the magma is a magnesium silicate.[1]

2.14.06. The most important recent discovery of corundum in commercial quantities is that of the deposits associated with the belt of nepheline syenite that covers a large area in eastern Ontario, north of Kingston. The syenite, which is at times very coarsely crystalline and pegmatitic, contains crystals of corundum, often of large size and of considerable regularity of form. Blue sodalite also occurs in the rock in large masses. Experiments in concentration have been carried on at the School of Mines in Kingston under Professor Miller, and actual

[1] J. H. Pratt, "On the Separation of Alumina from Molten Magmas, and the Formation of Corundum," *Amer. Jour. Sci.*, September, 1892, 227

development is probable at an early date.[1] Corundum of gem grade has been mined at Yogo Gulch, Mont., and beautiful sapphires are obtained.[2] The commercial emery employed in America is largely imported from Smyrna, but it has no bearing on the production of aluminum. It is also mined at Chester, Mass., and near Peekskill, N. Y.[3] Corundum is reported in vast amount in India.[4]

ANTIMONY.

Senarmontite, Sb_2O_3; Sb. 83.56; O. 16.44.

Stibnite (Antimonite, Antimony Glance), Sb_2S_3; Sb. 71.8; S. 28.2.

2.14.07. Antimony occurs in composition with several silver ores, but almost its sole commercial source is stibnite. The oxide, senarmontite, is rarely abundant enough to be an ore. Stibnite was one of the minerals formerly cited as having originated in veins by volatilization from lower sources. But it has probably, in all cases, been derived from solutions of alkaline sulphides.

2.14.08. Example 47. Veins containing stibnite, usually in quartz gangue. California, Kern County. At San Emigdio a vein of workable size has been found. It has a quartz gangue and is in granite. The vein varies from a few inches to several feet across, and has afforded some metal. Several others are known in San Benito and Inyo counties.

[1] F. D. Adams, "Report on the Geology of a Portion of Central Ontario," *Geol. Survey Can.*, 1892–3, Report J, 5. "Occurrence of a Large Area of Nepheline Syenite in the Township of Dungannon, Ontario," *Amer. Jour. Sci.*, July, 1894, 10. (The corundum had not been discovered when these two papers were issued.) Archibald Blue, "Corundum in Ontario," *Amer. Inst. Min. Eng.*, Buffalo meeting, 1898. A. P. Coleman, "Corundiferous Nepheline-Syenite from Eastern Ontario," *Jour. Geol.*, VII., July–August, 1899, 437. B. J. Harrington, "Nepheline, Sodalite and Orthoclase from the Nepheline Syenite of Dungannon, Ont.," *Amer. Jour. Sci.*, July, 1894, 16. W. G. Miller, "Report of Ontario Bureau of Mines," VII., 207, 1898.

[2] L. V. Pirsson, "Corundum-bearing Rock from Yogo Gulch, Mont.," *Amer. Jour. Sci.*, December, 1897, 421.

[3] J. D. Dana, *Amer. Jour. Sci.*, September, 1880, 199. J. P. Kimball, *Amer. Chemist*, IV., 1874, 321. *Trans. Amer. Inst. Min. Eng.*, IX., 19, 1881. G. H. Williams, *Amer. Jour. Sci.*, March, 1887, 197. Rec.

[4] T. H. Holland, "Corundum": in "A Manual of the Geology of India," *Economic Geol.*, Part I., 1898, 1–69.

2.14.09. Nevada, Humboldt County. Stibnite has been known for some years in veins with quartz gangue. The Thies-Hutchens mines, about 15 miles from Lovelock station, were productive in 1891. Lander County. The most important of the American mines are the Beulah and Genesee, at Big Creek, near Austin. The vein is reported as showing three feet of nearly pure stibnite. It produced 700 tons of sulphide in 1891, and was operated in 1892.

2.14.10. Arkansas, Sevier County. Stibnite occurs in veins with quartz gangue in southwestern Arkansas. Some attempts have been made to develop them, but the ore is reported to be too remote for profitable working. The veins appear to be generally interbedded in Trenton shales and to lie along anticlinal axes, which trend northeast. They are all controlled by the United States Antimony Company, of Philadelphia.

2.14.11. New Brunswick, York County. Veins of quartz or quartz and calcite, carrying stibnite, occur over several square miles. The wall rocks are clay slates and sandstones of Cambro-Silurian age. The mines have been commercially productive. The veins vary from a few inches to six feet.

2.14.12. Example 48. Utah, Iron County. Disseminations of stibnite in sandstone and conglomerate, following the stratification. In Iron County, southwestern Utah, masses of radiating needles occur in sandstones and between the boulders of an associated conglomerate. Very large individual pieces have been obtained, but not enough for profitable mining. Blake thinks that the ore has crystallized from descending solutions. Eruptive rocks are present above the sandstones.

2.14.13. An interesting deposit of senarmontite was worked for a time in Sonora, just south of the Arizona line, but it was soon exhausted.[1]

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[1] General References: W. P. Blake, "General Distribution of Ores of Antimony," *Min. Resources of the U. S.*, 1883–84, p. 641. Arkansas: T. B. Comstock, *Geol. Survey of Kan.*, 1888, I., p. 136. F. P. Dunnington, "Minerals of a Deposit of Antimony Ores in Sevier County, Ark.," *Amer. Assoc. Arts and Sci.*, 1877. Rec. J. W. Mallet, *Chem. News*, No. 533. C. E. Waite, "Antimony Deposits of Arkansas," *Trans. Amer. Inst. Min. Eng.*, VII., 42. C. P. Williams, "Notes on the Occurrence of Antimony in Arkansas," *Idem*, III., 150. California: W. P. Blake, "Kern County," *U. S. Pac. R. R. Explor. and Survey*, Vol. V., p. 291. H. G. Hanks, *Rep. Cal. State Mineralogist*, 1884. See also subsequent reports by William

ARSENIC.

2.14.14. This metal occurs with many silver ores in the West and in arsenopyrite, or mispickel, a not uncommon arseno-sulphide in the gold quartz veins, east and west. At the Gatling mines, in the town of Marmora (more lately called Deloro), in Hastings County, Ontario, auriferous mispickel occurs in great quantity in granite, in veins with quartz gangue. Considerable oxide of arsenic has been obtained in the past from the roasters, but in recent years the cyanide process has been employed. For reference to the printed descriptions see under "Gold in Canada" (2.13.07). Considerable arsenic is also produced as a by-product in treating the ores of the Monte Cristo mines of Washington State.

BISMUTH.

2.14.15. Bismuth occurs with certain silver ores in the San Juan district, Colorado, and is referred to in the description of the country under "Silver and Gold" (2.09.10). Lane's mine, at Monroe, Conn., has furnished museum specimens of native bismuth in quartz. Some neighboring parts of Connecticut have afforded bismuth minerals, and not a few other places in the country contain traces, but the San Juan is the only serious one as yet.[1]

CHROMIUM.

2.14.16. Chromite, whose theoretical composition is $FeO.Cr_2O_3$, with Cr_2O_3 68%, often has MgO and Fe_2O_3 replacing its normal oxides. The percentage of Cr_2O_3 is thus reduced. It is always found in association with serpentine, which has resulted from the alteration of basic rocks consisting of olivine, hornblende, and pyroxene. These minerals, or at

Irelan, Jr. Mexico: E. T. Cox, "Discovery of Oxide of Antimony in Sonora," *Amer. Jour. Sci.*, XX., 421. J. Douglass, "The Antimony Deposit of Sonora," *Eng. and Min. Jour.*, May 21, 1881, p. 350. Nevada: *Idem*, 1892, p. 6. New Brunswick: L. W. Bailey, "Discovery of Stibnite in New Brunswick," *Amer. Jour. Sci.*, ii., XXXV., 150, and in *Rep. on the Geol. of New Brunswick*, 1865; also H. Y. Hind, in the same. Utah: D. B. Huntley, *Tenth Census*, Vol. XIII., p. 463.

[1] *Min. Resources of the U. S.*, 1885, p. 399. B. Silliman, "Bismuthinite from the Granite District, Utah," *Amer. Jour. Sci.*, iii., VI., 123. H. L. Wells, "Bismuthosphærite from Willimantic and Portland, Conn.," *Amer Jour. Sci.*, iii., XXXIV., 271.

least the pyroxenes, contain chromium as a base, but in the unaltered rock there is no question that chromite itself has formed one of the component minerals, just as magnetite so commonly occurs in this relation. A chrome spinel, picotite is also not unusual. The basic rocks, peridotites and pyroxenites, almost always yield on analysis some chromic oxide, and may in extreme cases afford several per cent. Vogt gives in the paper cited below a series of percentages from 0.25 to 3.55 in twelve peridotites, from various localities. The invariable association of the metal with rocks rich in magnesium is striking. Inasmuch as the chromite occurs, when mined, in serpentine, a secondary rock, it has usually been believed that it was a product set free in the change from the anhydrous original to the hydrated derivative.[1] Meunier has referred it to the action of vapors or to a pneumatolytic process in the still molten peridotite magma. Vogt, however, includes the chromium ore bodies in the category of those formed by direct crystallization from a molten magma, and regards the chromite of the serpentines simply as the original crystallizations which have resisted alteration, while their associated minerals have undergone hydration and change. As chromite is a mineral that is extremely resistant to the action of the natural solvents and reagents, this view has much to commend it. Dynamic metamorphism might afterward drag out the masses of chromite into a lineal alignment. Vogt also describes a fresh peridotite from Hestmandö under the polar circle in the extreme north of Norway,[2] that is almost or quite rich enough in chromite to be worthy of exploitation. Hydrated nickel compounds are often associated with chromite.

In recent investigations of the chromite deposits of North Carolina, J. H. Pratt[3] has reached the conclusion that the

[1] See in this connection the following, which are cited by Vogt, Cossa and Arzruni, *Zeitschr f. Krystal.*, VII., p. 1, 1883. A. v. Groddeck, *Lehre von den Lagerstätten der Erze*, 146, 1879. A. Helland, *Gesellsch. der Wissenschaften-Kristiania*, 1873. L. de Launay, *Formation Gîtes Métallifères*, 1893.

[2] J. H. L. Vogt, *Zeits. für prakt. Geol.*, 1894, 385. L. de Launay supports the same view, *Annales des Mines*, XII., 1897, 175.

[3] J. H. Pratt, "On the Occurrence, Origin and Chemical Composition of Chromite," *Trans. Amer. Inst. Min. Eng.*, New York meeting, February, 1899. Abstract in *Eng. and Min. Jour.*, December 10, 1898. Refers especially to North Carolina.

mineral has crystallized from fusion, and has become concentrated near the walls by convection currents, as described under 1.06.13.

2.14.17. The chromite of commerce should contain at least 50% Cr_2O_3. Values over this command a premium, while those below 50 suffer severe rebates. The less silica, the better. Wm. Glenn cites the following three analyses as typical of the run of the commercial product, the sources of the ore not being given. (*XVII. Annual Report Director U. S. Geol. Soc.*, Part III, 263.)

SiO_2	7.00	5.22	6.44
Cr_2O_3	39.15	51.03	53.07
FeO	27.12	13.06	15.27
MgO	16.11	16.32	16.08
CaO	3.41	2.61	1.20
Al_2O_3	7.00	12.16	8.01
	99.79	100.40	100.07

Chromite in the arts is chiefly employed in the manufacture of potassium or sodium bichromate, so essential to dyeing, but of late years it is also proving of great value as an ingredient of refractory bricks, and as a lining for furnaces.

2.14.18. Example 49. Disseminations of chromite in serpentine. Pennsylvania and Maryland. Great areas of serpentine are found in southeastern Pennsylvania and in the adjacent parts of Delaware and Maryland. Considerable mining has been done in the past. Where first obtained the chromite occurred in loose masses in the residual soil on the surface. It was identified and gathered in Harford County, Maryland, as early as 1827 by Isaac Tyson, Jr., and found a ready market abroad, to such an extent that from 1827 to 1860 the Baltimore region was the chief source of the mineral for the world. In the serpentines of neighboring parts of Maryland and in southeastern Pennsylvania other deposits were found in the years following 1827, and a very important industry sprang up. The largest proved to be the Wood Pit or Mine in Lancaster County, Pennsylvania, and it developed the most productive single deposit yet known. It has been worked to a depth of 700 feet or more —a striking thing for chromite, whose deposits, as a rule, are very limited in depth and extent, and very pockety. The so-called Texas mine near or on the Maryland-Pennsylvania line also became well known. In addition to the surface boulders and included masses, chromite sand of commercial grade has been obtained from the beds of streams in this belt, and, as stated by Wm. Glenn, the supply is renewed after an interval of about fifteen years. The work of G. H. Williams and F. D. Chester has shown the great abundance of basic, plutonic rocks, gabbros, pyroxenites, peridotites and the like in this region, and there is every reason to regard the serpentines as derivatives from such originals. During the process of alteration whatever chromite there was present in the fresh igneous rock, was reinforced by the formation of secondary chromite from the alteration of chromiferous pyroxene, and other minerals, but only rarely were sufficient amounts produced to warrant mining. Dynamic metamorphism may have strung them out in linear alignment.

2.14.19. Chromite has also been met in several places in the south, but never, as yet, in minable amounts. The Baltimore region itself has not been active for some years.[1]

2.14.20. California. As already mentioned under the precious metals, great areas of serpentine occur on the western flanks of the Sierras and in the Coast range. In Del Norte, San Luis Obispo, Placer, and Shasta counties, California, they furnish commercial amounts of chromite. In some places the ore is followed by underground mining, and in others it is

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[1] F. D. Chester, in the *Ann. Rep. Penn. Geol. Survey*, 1887, describes the Serpentine along the State line with Delaware. D. T. Day, *Mineral Resources*, and since 1894. *Ann. Reps. of the Dir. of U. S. Geol. Survey*, 1882, p. 428; especially 1883–84, p. 567. J. Eyerman, "On Woods Mine, Pa.," *Mineralogy of Penn.*, Easton, 1889. P. Fraser, "The Northern Serpentine Belt in Chester County, Pa.," *Trans. Amer. Inst. Min. Eng.*, XII., 349. *Report* C3, Lancaster Co., Penn., *Geol. Survey.* Rec. T. H. Garrett, "Chemical Examination of Minerals Associated with Serpentine," *Amer. Jour. Sci.*, ii., XIII., 45, and XV., 332. F. A. Genth, *Idem*, ii., XLI., 120. Wm. Glenn, "Chrome in the Southern Appalachian Region," *Trans. Amer. Inst. Min. Eng.*, XXV., 481. Rec. J. H. Pratt, "The Occurrence, Origin and Chemical Composition of Chromite," *Trans. Amer. Inst. Min. Eng.*, February, 1899, New York meeting. G. H. Williams, "The Gabbros and Associated Hornblende Rocks near Baltimore," *Bull. 23, U. S. Geol. Survey.* "The Geology of the Crystalline Rocks near Baltimore," distributed at the Baltimore meeting of the *Amer. Inst. Min. Eng.*, February, 1892. Rec.

gathered as float material. The irregular distribution, always characteristic of the mineral, renders underground work uncertain. Good ore should afford 50% Cr_2O_3, and in California no ore less than 47% is accepted. It brings in the East $22 to $35 per ton.[1]

2.14.21. Quebec. In the serpentine belt that extends from northern Vermont to Gaspé, and which contains the well known asbestos mines near Black Lake, chromite has been known for many years. In 1894 some productive pockets were found that have since yielded about three thousand tons of high grade ore. The mines are two miles from Black Lake station, and are in a belt of serpentine south of the asbestos belt. In the best pocket the ore occurred next a dike of granulite,[2] according to Donald, but elsewhere it lacks this associate.

2.14.22. Newfoundland. Chromite has very recently been discovered and developed at Port au Port Bay, on the west coast of Newfoundland. G. W. Maynard states that it occurs in bands of serpentine, which are themselves enclosed in diorite. The geological surroundings are thus those of the usual serpentinous and basic igneous rocks. The quantity exposed warranted the erection of a concentrating plant.[3]

COBALT (SEE UNDER "NICKEL").

MANGANESE.

2.14.23. Ores: Pyrolusite MnO_2, Mn. 63.2, braunite, Mn_2O_3, Mn 69.62. Some SiO_3, which may be chemically combined, is usually present, and small amounts of MgO. CaO, etc. Psilomelane has no definite composition, but usually contains barium or other impurities. An Arkansas variety has afforded Brackett MnO, 77.85.

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[1] E. Goldsmith, "Chromite from Monterey County, Cal.," *Proc. Phila. Acad. Sci.*, 1873, 365. Wm. Irelan, Jr., *Reports of Cal. State Mineralogist,* especially 1890, pp. 167, 189, 313, 582, 583, 638. J. J. Crawford became State Mineralogist in 1892; Chromite receives mention also in his reports.

[2] J. T. Donald, "Chromic Iron in Quebec," *Eng. aud Min. Jour.*, September 8, 1894, 224. M. Penhale, *Idem,* December 8, 1894, 532. Wm. Glenn, "Chromic Iron, with Reference to its Occurrence in Canada," *XVII. Ann. Rep. Dir. U. S. Geol. Survey,* Part III., 261. Rec. Contains a good bibliography. J. Obolski, *Can. Min. Review,* January, 1896

[3] Geo. W. Maynard, "The Chromite Deposits on Port au Port Bay, Newfoundland," *Trans. Amer. Inst. Min. Eng.*, XXVII. 283, 1897.

There are various other oxides and hydroxides, which are rarely abundant enough to be ores. The carbonate, rhodochrosite, and the silicate, rhodonite, are rather common gangue minerals with ores of the precious metals. Franklinite is also an important source (2.07.04). Pyrolusite and psilomelane are the commonest ores the country over, but braunite is the one in the Batesville (Ark.) region. Manganese is widely distributed, and yet is commercially important in but few localities. It imitates limonite very closely in its occurrence, and is often associated with this ore of iron. To make a manganese ore valuable, at least 40% metallic manganese should be present, and this is a lower limit than was formerly admissible when the ores were chiefly used in chemical manufactures. Under present conditions, if iron is present, the ore may be suited to spiegel, although even lower in manganese than 40%. Further, there should be low phosphorus; Penrose says not over 0.2 to 0.25% in Arkansas, and not over 12% SiO_2. High-grade ores run 50 to 60% manganese.

2.14.24. The original home of manganese is in the ferro-magnesian silicates of the igneous rocks. In all of them it is known to enter as a minor base, acting much in the same way as iron. On being released from the ferro-magnesian minerals, its subsequent geological behavior is in some respects much like that of iron, but it differs from iron in that its sulphides, though known, are very rare minerals. Aqueous circulations leach the manganese from the igneous rocks, whether deep-seated or superficial, and sea-water has a strong dissolving effect upon fragmental, volcanic ejectments that are thrown into the ocean. In the latter case the peroxide of manganese finally forms pellets and incrustations on the sea-bottom, especially at great depths;[2] in the former rhodonite and rhodochrosite result as the familiar gangue minerals of many veins, and manganese oxide or carbonate enters into many fragmental sediments and limestones. Almost all the deposits of commercial importance have been produced by the subaerial alteration of these last

[1] For a short review of Manganese in Nature see L. de Launay, *Annales des Mines*, XII., 1897, 185–191. The subject is discussed at length in Penrose's Report on Manganese for the *Arkansas Geol. Survey*, Chapter XXI.

[2] John Murray, *Proc. Roy. Soc.*, London, XXIV., 528. Sir C. Wyville Thomson, *The Atlantic*, II., 14, 1873.

named, so that nodules of manganese oxides remain embedded in residual clays, precisely like many brown hematite deposits.

2.14.25. Example 50. Manganese ores, chiefly psilomelane and pyrolusite, often in concretionary masses, disseminated through residual clay, which with the ores has resulted from the alteration of limestones and shales. The deposits are entirely analogous to Examples 2 and 2*a*, under "Iron." Along the Appalachians the favorite horizon is just over the Cambrian (Potsdam) quartzite. This is the case at Brandon and South Wallingford, Vt., where the ores occur in a great bed of clay between quartzite and limestone. They are referred to under Example 2*a*, where mention is made of the associated limonites

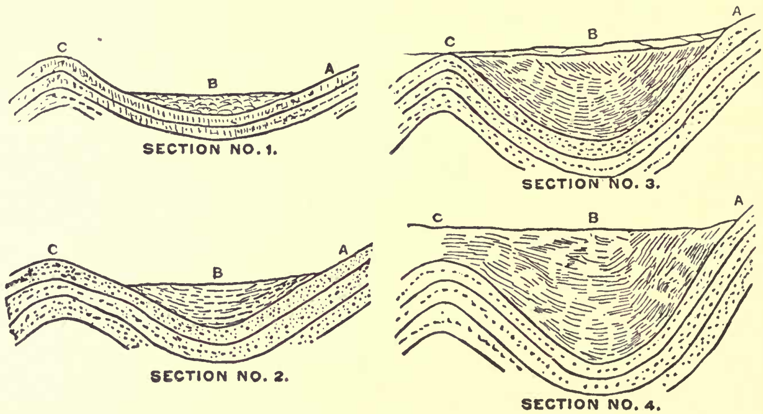

FIG. 155.—*Sections of the Crimora manganese mine, Virginia. The trough is formed by Potsdam sandstone and is filled with clay carrying nodules of ore. After C. E. Hall, Trans. Amer. Inst. Min. Eng., XX.*, 48, *June*, 1891.

and interesting lignite. They have never been important producers of manganese. Crimora, in Augusta County, Va., was formerly the largest mine in the country. The containing clay bed is very thick, as a drill hole, 276 feet deep, failed to strike rock. The ores occur in pockets, which as a maximum are 5 to 6 feet thick and 20 to 30 feet long, and of lenticular shape. Other irregular stringers and smaller masses run through the clay, which preserves the structure of the original rock. Potsdam quartzite underlies it. Other similar bodies occur at Lyndhurst and elsewhere in the Great Valley of Virginia, but Crimora is now no longer a source of ore. Cartersville, Ga.,

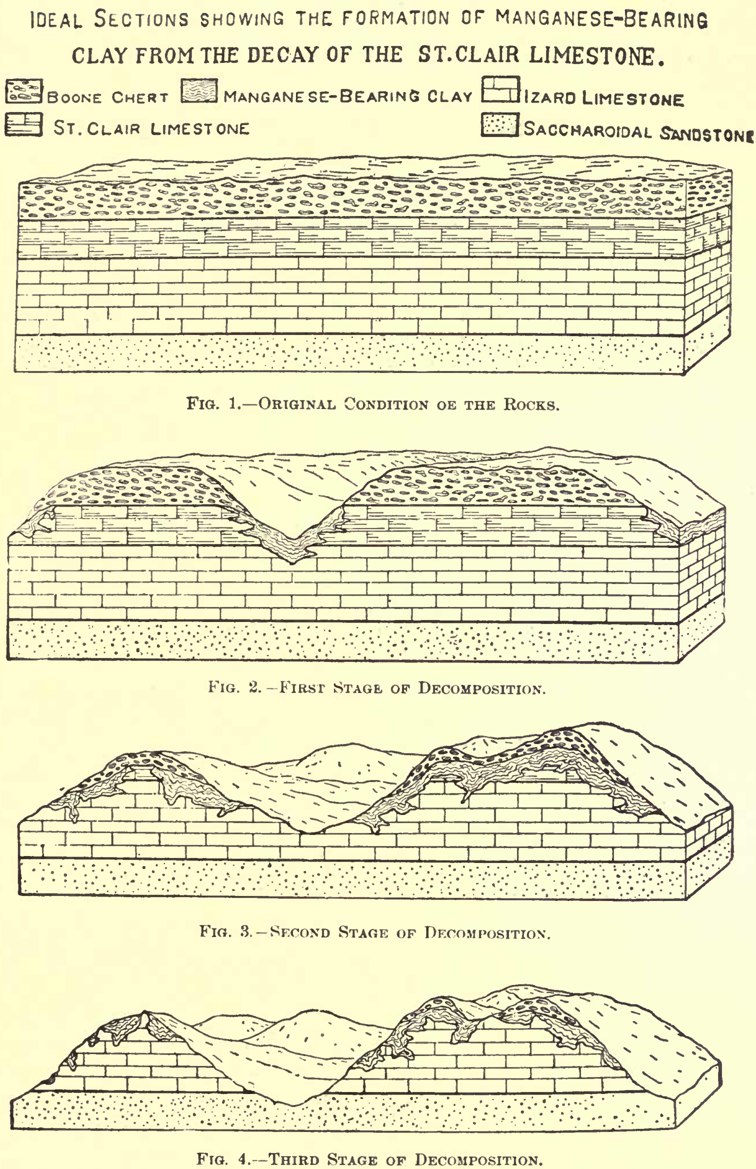

FIG. 156.—*Geological sections illustrating the formation of the manganese ores in Arkansas. After R. A. F. Penrose, Geol. Survey of Ark., 1890, Vol. I., p. 177.*

is second to Crimora in production. As at Crimora, the ores occur in pockets in stiff clay, and are associated with quartzite which is not sharply identified as yet. It may be Cambrian (Potsdam), or Upper Silurian (Medina). West of Cartersville is the Cave Spring region, where the ores occur with Lower Silurian cherts. There are numerous other localities not yet of commercial importance along the Appalachians, in Ten-

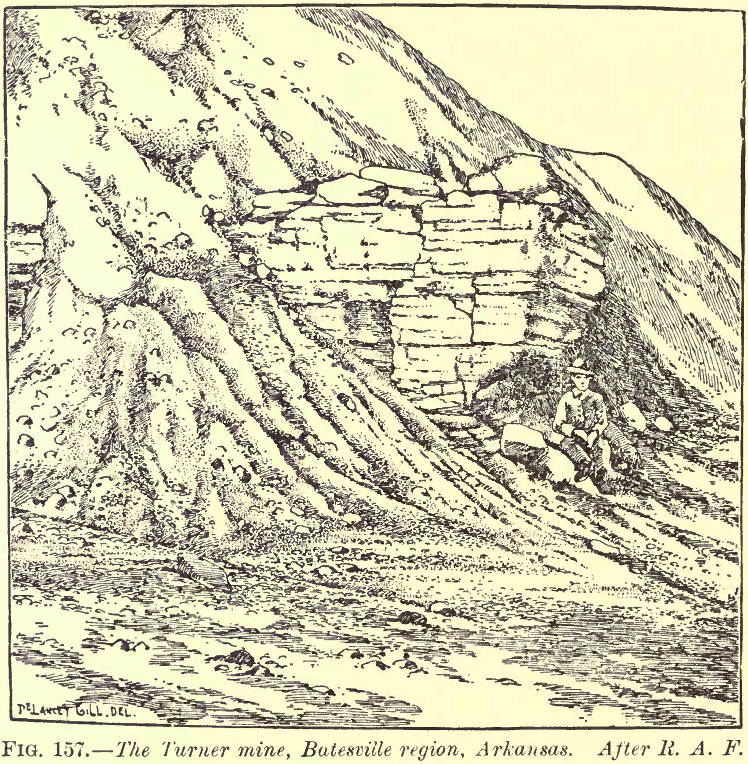

FIG. 157.—*The Turner mine, Batesville region, Arkansas. After R. A. F. Penrose, Geol. Survey of Ark.*, 1890, *Vol. I., p.* 272.

nessee and elsewhere. Full descriptions will be found in Penrose's report, cited below.

2.14.26. Batesville, Ark. The ore is braunite, and is found in masses disseminated in a residual clay which was thought by Penrose to have been left by the alteration of a limestone locally called the St. Clair. The stratigraphy has been revised in some important particulars by H. S. Williams, as noted below. The St. Clair was regarded by Penrose as of geologic age between the Trenton and Niagara periods. It is underlain by another limestone called the Izard, which is later than the Calciferous. On Penrose's St. Clair a series of cherts, called the Boone cherts, is found, which are of Subcarboniferous (Mississippian) age. The clays are sometimes in valleys, sometimes on hillsides, according to the unequal decay of the limestone. South of the Batesville district are the Boston Mountains, a range of low hills 500 feet high, and from these the manganiferous rocks form a low monocline to the north. The district is in northern central Arkansas. The ore was thought by Penrose to have been derived from the limestone, and to have separated in its decay. H. S. Williams has modified the above stratigraphy in important particulars by close paleontological determinations and the modifications bear on the origin of the ores in a very important way, changing them, as regards their original home from deep-water deposits to shallow-water ones. Williams observed that the limestone, called the St. Clair above, contained both a Lower Silurian fauna and an Upper Silurian one. In one good exposure on the Cason property they were separated by a thin band of shale, which shale contained the manganese ore. Williams therefore restricts the name St. Clair limestone to the Lower Silurian (or Ordovician) stratum, and calls the shale the Cason shale, and the overlying Upper Silurian (or Eo-Silurian) limestone the Cason limestone. Some of the clay, which was observed by Penrose to contain the nodules of ore has resulted from this shale, and it may be that the ore generally has come from the same source. The geological relations would then be closely parallel with Crimora, Va. (H. S. Williams, "Age of the Manganese Beds of the Batesville Region of Arkansas," *Amer. Jour. Sci.*, October, 1894, 325.)

2.14.27. Southwestern Arkansas contains a second district in which the ore occurs in a great stratum of novaculite of probable Lower Silurian age. The ores are of no practical importance, being too lean and too disseminated. Small amounts of manganese ore have been obtained in California, in San Joaquin County, and from Red Rock, in San Francisco harbor. The former, and perhaps others in the State, may prove important hereafter. Penrose has described an interesting deposit of manganese ore near Golconda, Nev. It is an interbedded, lenticular mass about 150 feet long and 10 feet thick as a maximum in calcareous tufa, of Pleistocene age. It is remarkable f r its content of 2.78% tungstic acid. Penrose interprets it as a superficial deposit from uprising springs, whose waters presumably formed a pool, allowing of the oxidation and precipitation of the dissolved manganese. The latter was derived from lower lying rocks, presumably igneous, although sediments are not an impossible source.[1] Leadville, Colo., is now an important source of manganese ores, the shipments going as far as Chicago. The geological relations are the same as for the lead-silver ores, earlier described.

2.14.28. Considerable manganese occurs at times in some of the Lake Superior iron ores, especially those from the Gogebic range. Cuba has also afforded some shipments notably high in this metal. In the Santiago region the ore forms nodules in the soil from which it is obtained by stripping and washing.

2.14.29. Quite productive deposits are found in pockets at Markhamville, Kings County, N.B., in Lower Carboniferous limestone. Some thousands of tons have been shipped. Other mines are situated at Quaco Head. At Tenny Cape, in the Bay of Minas, Nova Scotia, is another deposit in Lower Carboniferous limestone, which has furnished several thousand tons of ore. Others less important occur on Cape Breton.[2]

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[1] R. A. F. Penrose, "A Pleistocene Manganese Deposit," *Jour. of Geol.*, I., 275, 1893.

[2] "Manganese Mines near Santiago, Cuba," *Eng. and Min. Jour.*, November 24, 1888, p. 439. H. P. Brumell, "Notes on Manganese in Canada," *Amer. Geol.*, August, 1892, p. 80. D. de Cortazar, "General Review of Occurrence and Manufacture," *Reps. and Awards, Group I., Centen. Exposition*, p. 196. D. T. Day, *Mineral Resources*, 1882, p. 424; 1883–84, p. 550. F. P. Dunnington, "On the Formation of the Deposits of Oxides of Manganese," *Amer. Jour. Sci.*, iii., XXXVI., 175. Rec. W. M. Fontaine, "Crimora Manganese Deposits," *The Virginias*, March, 1883, pp. 44–46. Rec. C. E. Hall, "Geological Notes on the Manganese Ore Deposits of Crimora, Va.," *Trans. Amer. Inst. Min. Eng.*, June, 1891. E. Halse, "Notes on the Occurrence of Manganese Ore, near Mulegé, Baja California, Mexico," *Trans. N. of Eng. Min. and Mech. Eng.*, XLI., 302, 1892. H. Hoy, "Ores of Manganese and their Uses," *Proc. and Trans. N. S. Inst. Nat. Sci.*, Halifax. II., 1864–65, p. 139. "Manganese Mining in Merionethshire, England," *Eng. and Min. Jour.*, December 18, 1886, p. 438. R. A. F. Penrose, *Ann. Rep. Ark Geol. Survey*, 1890, Vol. I. The best work published. Rec. "Origin of the Manganese Ores of Northern Arkansas," etc., *Amer. Assoc. Adv. Sci.*, XXXIX., 250. "The Chemical

2.14.30. Panama. Manganese ores have been shipped in large quantities from the mainland of South America, just east of the base of the Isthmus of Panama, although still in the province of that name. The ores occur about 5 to 6 miles from the coast and 8 miles from the dock, in the valley of the Rio Viento Frio. Great masses of the oxides of manganese (both braunite and pyrolusite) occur in residual clay. More or less quartz is associated with them. The original rock seems from the very decomposed pieces available to have been a clastic one, chiefly of feldspathic fragments. The ores are rich in manganese and low in phosphorus. There had been shipped to the close of 1896, 18,215 tons.[1]

Relation of Iron and Manganese in Sedimentary Rocks," *Jour. of Geol.*, I., 356, 1893. J. D. Weeks, *Mineral Resources of the U. S.*, 1885, p. 303 (Rec.); 1886, p. 180; 1887, p. 144. D. A. Wells, "On the Distribution of Manganese," *Amer. Assoc. Adv. Sci.*, VI., 275. C. L. Whittle, "Genesis of the Manganese Deposits at Quaco, N. B.," *Proc. Bost. Soc. Nat. Hist.*, XXV., p. 253.

[1] E. J. Chibas, "Manganese Deposits of the Department of Panama, Republic of Colombia," *Trans. Amer. Inst. Min. Eng.*, XXVII., 63, 1897. "Railroad Building and Manganese Mining in Colombia," *Eng. Mag.*, December, 1896, Vol. XII., 426. "Construction of a Light Mountain Railroad in the Republic of Colombia," *Trans. Amer. Soc. Civ. Eng.*, XXXVI., 65, 1896.

CHAPTER XV.

THE LESSER METALS, CONTINUED—MERCURY, NICKEL AND COBALT, PLATINUM, TIN.

MERCURY.

2.15.01. Ores: Cinnabar, HgS. Hg. 86.2, S. 13.8. Metacinnabarite is a black sulphide of mercury. Native mercury also occurs. Tiemannite the selenide HgSe, and onofrite the sulphoselenide, Hg(SeS) have been met at Marysvale, in southern Utah.[1]

Mercury, usually called quicksilver in commerce, has been discovered in workable quantities at a number of places along the Pacific coast of North America. Its chief localities are in the Coast ranges of California, where, though formerly more productive, it is still quite largely obtained. The deposits extend into Oregon, but are of no great importance. In small amount it has been mined in Nevada and Utah, and has recently been discovered in promising although not demonstrated quantity in western Texas. Many localities are known in Mexico, but Guadalcázar, in the State of Guerrero, and Huitzuco, in San Luis Potosi, have proved most productive. In South America, the mines at Huancavelica, in Peru, have been in the past of vast productiveness. In Europe, Almaden in Spain, is much the most important of all the deposits known to-day, but Idria in Austria, and Avala in Servia are still of value. Several other well-known mining districts of former years have lapsed into inactivity. In Asia the great deposits of Kwei-Chau are described as being of great possibilities.

[1] G. J. Brush and W. J. Comstock, "American Sulpho-selenides of Mercury, with Analyses of Onofrite from Utah," *Amer. Jour. Sci.*, April, 1881, 312. G. F. Becker describes this as Tiemannite, *Monograph XIII.*, p, 385, *U. S. Geol. Survey*, 1888; *Mineral Resources*, 1892–5; *Tenth Census*. XIII., 463, 1880.

2.15.02. In their geological relations the ores of quicksilver are quite invariably associated with igneous rocks, although the walls are often sedimentary.

2.15.03. G. F. Becker[1] has recently given an admirable review of quicksilver deposits, the world over, their mineralogical associates and probable methods of origin, and the same subject has been treated by A. Schrauf.[2] Becker has tabulated the minerals associated with cinnabar from twenty-eight world-wide localities, and has made it evident that silica, either as quartz or in the opaline state, and calcite are the common gangue associates. Pyrite or marcasite is almost invariably present and bitumen is very widespread. Various other antimony, arsenic, silver, lead, copper and zinc minerals, as well as gold, are of somewhat irregular occurrence. Becker reaffirms his previously cited theory of origin, that the cinnabar has come up in solution as a double sulphide with the alkaline sulphides, but lays stress upon the precipitating properties of bituminous substances, which reactions were corroborated by experiment. He favors the view that the cinnabar has impregnated porous or decomposed rock, rather than that it has actually replaced it by metasomatic processes. The probable source of the ore in deep-seated and widely-distributed granitic rocks, and especially in such portions as overlie the foci of volcanic activity is affirmed.

2.15.04. Example 50. New Almaden. Cinnabar with subordinate native mercury, in a gangue of crystallized and chalcedonic quartz, calcite, dolomite, and magnesite, forming a stockwork, or "chambered vein," in shattered metamorphic rocks (pseudo-diabase, pseudo-diorite, serpentine and sandstone). There are two main fissures, making a sort of V, with a wedge of country rock between. The ore bodies are in the fissures and also in the intervening wedge. They are associated with much attrition clay. A great dike of rhyolite runs nearly parallel to the fissures, and to this Becker attributes the activity of circulations which filled the vein. The uprising solutions have often been influenced by the seams of clay and

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[1] G. F. Becker, "Quicksilver Ore Deposits, with Statistical Tables," *Mineral Resources of the United States*, 1892.

[2] A. Schrauf, "Aphorismen ueber Zinnober," *Zeits. für prakt. Geol.*, January, 1894, p. 10.

appear to have especially deposited the ore along the lower sides of them. The ore has found a lodgment in the crevices of all sorts on the general line of disturbance, and has impregnated porous rocks, when they occurred in its course. It has been deposited simultaneously with the various gangue minerals. The wall rocks are of Neocomian (Early Cretaceous) age, but have suffered extreme metamorphism. Long after this ceased came the intrusion of the rhyolite, and probably the formation of the fissures now holding the ore. The introduction of the ore was in either Pliocene or post-Pliocene time, certainly not earlier. Several other mines, of which the Enriquita and Guadalupe are most important, are near New

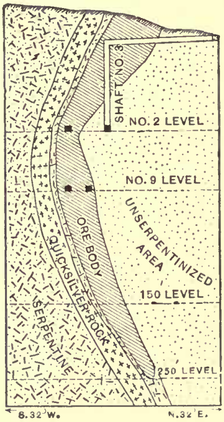

FIG. 158.—*Section of the Great Western cinnabar mine. After G. F. Becker, Monograph XIII., U. S. Geol. Survey, p.* 360.

Almaden, but the New Almaden is much the largest of all the North American deposits yet developed. New Idria is farther south, high up toward the summit of the Coast range. The ore is deposited in shattered metamorphic rocks of Neocomian (Lower Cretaceous) age, and in overlying Chico beds. The ore is accompanied by bitumen. Basalt is abundant ten miles away. North of San Francisco other mines have been opened, among which are the Oat Hill, Great Eastern, and Great Western. The mines are in a region pierced by eruptions of basalt and andesite, which doubtless gave impetus to the ore-bearing solutions. The ores are deposited in both metamorphic and unaltered sedimentary rocks.

2.15.05. Example 50*a*. Sulphur Bank. This is in the same general region as the last, but from its peculiar character has been one of the best known of ore deposits. A great flow of basalt has come down to the shores of Clear Lake from the west. Waters charged with alkaline (including ammonia) carbonates, chlorides, borates, and sulphides, and with CO_2, H_2S, SO_2, and marsh gas, have circulated through it. Sulphur and sulphuric acid have formed at the surface, and the latter has dissolved the bases of the rock, leaving pure white silica behind. Lower down, cinnabar is found, both in the basalt and in the underlying sedimentary rocks, with other sulphides and chalcedony. Le Conte attributed its precipitation to cold surface waters, charged with sulphuric acid, which trickled down and met the hot alkaline solutions. Becker refers the same to the ammonia set free toward the surface by diminished heat and pressure. The California cinnabar deposits have been often, but wrongly, referred to vapors of the sulphide volatilized by internal heat and condensed above.

2.15.06. Example 50*b*. Steamboat Springs, Nev. These springs are in Nevada, only six miles from the Comstock Lode. Granite is the principal rock, while on it lie metamorphic varieties of the Jura-Trias, and much andesite and basalt. Issuing through small fissures, the hot springs deposit chalcedony in some places, carbonates in others, and cinnabar as well as gold. The following minerals have been noted: "Sulphides of arsenic and antimony; sulphides or sulphosalts of silver, lead, copper, and zinc; oxide and possibly sulphide of iron; manganese, nickel and cobalt compounds, and a variety of the earthy minerals" (Becker). Becker thinks the source of the cinnabar is in all cases in the underlying granite, and that it has come up in solution with sodium sulphide, and has been precipitated toward the surface by the other compounds in the hot alkaline waters, with which it would remain in solution at greater depths, temperatures and pressures. The Steamboat Springs are often and properly cited as metalliferous veins in active process of formation.[1]

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[1] W. P. Blake, "Quicksilver Mine at Almaden, Cal.," *Amer. Jour. Sci.*, ii., XVII., 438. G. F. Becker, "Quicksilver Deposits of the Pacific Slope," *Monograph XIII.*, *U. S. Geol. Survey*, Chap. 17. Rec. "On New Almaden," *Cal. Geol. Survey*, I., p. 68. S. D Christy, "On the Genesis of Cin-

2.15.07. Cinnabar has recently been reported by W. P. Blake from southwestern Texas, in a rough, broken and almost uninhabited district some 10 to 12 miles from the Rio Grande River. The cinnabar occurs "in massive limestone and in a siliceous shale, and a white earthy clay-like rock, and in part in a true breccia of grayish, white, siliceous shale, dense and compact, imbedded and cemented in a red and chocolate-colored ferruginous mass, also dense and hard." The age of the nearest determinable beds is Lower Cretaceous. The quicksilver ore seems to impregnate the beds, and also to lie along a shattered or brecciated belt. It is oftentimes in concentric layers with oxide of iron, with which it seems to have in general a common origin, but to have been laid down in intervals of changed conditions of deposition. In addition to the disseminated granules, there are bunches of soft, friable cinnabar in the shales, limestones and breccia. It is undemonstrated as yet, whether the deposits are workable or not. The conditions are somewhat hard because water is lacking, and the location is remote.[1]

NICKEL AND COBALT.

2.15.08. These two metals almost always occur together.[2]

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nabar Deposits," *Amer. Jour. Sci.*, June, 1878, p. 453; *Eng. and Min. Jour.*, August 2, 1879, p. 65. D. de Cortazar, "General Review of Occurrence, etc., of Mercury," *Reps. and Awards, Group I., Centennial Exposition*, p. 196. William Irelan, *Ann. Reps. Cal. State Mineralogist.* Laur, "On Steamboat Springs," *Annales des Mines*, 1863, 423. J. Le Conte and Rising, "Metalliferous Vein Formation at Sulphur Bank," *Amer. Jour. Sci.*, July, 1882; *Eng. and Min. Jour.*, August 26, 1882, p. 109. J. Le Conte, "On Steamboat Springs," *Amer. Jour. Sci.*, June, 1883, p. 424. "Genesis of Metalliferous Veins," *Idem*, July, 1883. J. A. Phillips, "On Sulphur Bank, California," *Phil. Mag.*, 1871. p. 401; *Quar. Jour. Geol. Sci.*, XXXV., 1879, p. 390. Rolland, *Annales des Mines*, XIV., 384, 1878. B. Silliman, "Notes on the New Almaden Quicksilver Mines," *Amer. Jour. Sci.*, ii., XXXVII., 190. Siveking, *B. und H. Zeitung*, 1876, p. 45.

[1] W. P. Blake, "Cinnabar in Texas," *Trans. Amer. Inst. Min. Eng.*, XXV., 68.

[2] The following general papers on nickel and cobalt are important: F. D. Adams, "On the Igneous Origin of Certain Ore Deposits," *Gen. Min. Assoc. Prov. Quebec*, January 12, 1894. P. Argall, "Nickel: The Occurrence, Geological Distribution and Genesis of its Ore Deposits," *Proc. Col. Sci. Soc.*, December 4, 1893. W. L. Austin, "Nickel: Historical Sketch," *Idem*, same date. H. B. v. Foullon, "Ueber einige Nickelerzvorkommen,"

Their ores embrace the following general classes: (1) Compounds with arsenic and rarely with antimony, or with arsenic (or antimony) and sulphur; (2) Sulphur compounds, including nickeliferous pyrrhotite and pyrite; (3) Oxidized ores, mostly hydrated silicates related to serpentine.[1] Although the number of minerals involving nickel and cobalt is quite large, the ores, properly speaking, are comparatively few; nickeliferous pyrrhotite is much the most important, especially as concerns this country, but the oxidized ores may yet prove serious. Only the ores (*i.e.*, minerals commercially important) are mentioned in the table below.

Niccolite........	NiAs,		Ni.44.06		As.55.94
Millerite........	NiS,		Ni.64.83		S. 35.17
Linnæite.......	$(CoNi)_3S_4$	Co.21.34,	Ni.30.53	Fe. 3.37	S. 41.54
Pentlandite....	(NiFe) S,		Ni.34.23	Fe.30.25	S. 33.42
Genthite........	$2NiO,2MgO,SiO_2,6H_2O$. Ni.22.6.				
Garnierite......	$H_2O(Ni,Mg)O.SiO_2+\frac{1}{2}H_2O$ Ni.25.0.				
Zaratite........	$NiCO_3,2Ni(OH)_2+4H_2O$ Ni.46.8.				

To these nickeliferous pyrrhotite and pyrite should be added, the former being the most important of all.

2.15.09. Niccolite was reported years ago at Tilt Cove, Newfoundland, in some quantity, but elsewhere has not been found in any serious amount in North America. It also occurs in some of the western openings of the Sudbury district. Millerite furnished a small portion of the nickel at the Gap Mine, Pennsylvania, as noted below. Linnæite, variety siegenite, occurs in a sandstone bed at Mine la Motte in disseminated octahedra, and although small attempts have been made to utilize it, the amounts are, so far as known, not large enough for success. Pentlandite must be mentioned together with nickeliferous pyrrhotite. It has been somewhat of a question among mineralogists in just what relations the nickel occurs in pyrrhotite;

Jahrbuch d. k. k. geol. Reichsanstalt, Vienna, XLII., 223, 1892. D. Levat, *Annales des Mines*, 1892, Part II. J. H. L. Vogt, "Nikkelforkomster og Nikkelproduktion" (Occurrence and Production of Nickel), *Norwegian Geol. Survey*, Kristiania, 1892; a résumé in German accompanies the paper. "Sulphidische Ausscheidungen von Nickelsulphiderzen," etc., *Zeits. für prakt. Geol.*, April, 1893, 125.

[1] This is practically the same grouping that is given by J. H. L. Vogt, *Zeits. für prakt. Geol.*, April, 1893, 125. See also P. Argall, *Proc. Colo. Sci. Soc.*, December 4, 1894.

whether replacing the iron in Fe_7S_8, or some other variety of Fe_nS_{n+1}, to the extent of a fraction of one per cent. up to five, or whether there is an isomorphous or distinct nickel or iron-nickel sulphide intermingled with the pyrrhotite. As far back as 1843 Scheerer identified pentlandite from southern Norway, and several other related minerals, such as polydymite, have been less definitely described. More recently it has been shown that the nickel-rich portions of the pyrrhotitic ores are quite feebly magnetic, and processes have even been suggested for concentrating the nickel based on this principle.[1] Pentlandite is non-magnetic, and possibly this mineral in very fine disseminations may contribute of its richer percentage of nickel to raise the total of the pyrrhotites as mined. Some nickel, however, always remains in the strongly magnetic residues, so that we are not yet justified in abandoning the earlier view that this metal replaces some of the iron of the pyrrhotite. Pyrrhotite is the chief ore at Sudbury, and was the ore at the Gap Mine, Pennsylvania, until the workings were dismantled in 1894. In southeast Missouri, but more especially at Mine la Motte, nickeliferous pyrite accompanies the galena (see 2.05.09), and has furnished a considerable amount as a by-product in the metallurgy of lead. Of the oxidized ores it is not easy to speak as regards their individual importance. The hydrated silicates are of extremely variable composition, and while one or two illustrations of the type are selected for the table, no one of them is yet seriously mined in America.

2.15.10. Example 16*c*. (See 2.03.16 and 2.04.02.) Pyrrhotite Beds or Veins. Lenticular masses of pyrrhotite interbedded in gneisses and schists as described for pyrite They are known at various places in the East. Openings have been made at Lowell, Mass., Chatham and Torrington, Conn., and on the mountain on the east bank of the Hudson, called Anthony's Nose.[2] The last is much the largest of those named,

[1] See in this connection D. H. Browne, "On the Sudbury Ores," *Eng. and Min. Jour.*, December 2, 1893. Rec. S. H. Emmens, "The Constitution of Nickeliferous Pyrrhotite," *Jour. Amer. Chem. Soc.*, XIV., No. 10.

[2] H. Credner, *Berg. und Huett. Zeit.*, 1866, p 17. Dana's Treatise on Mineralogy, 6th Edition, under Pyrrhotite, gives several analyses from Putnam County, N. Y. J. F. Kemp, "The Nickel Mine at Lancaster Gap, Penn., and the Pyrrhotite Deposits at Anthony's Nose, on the Hudson," *Trans. Amer. Inst. Min. Eng.*, XXIV., 620 and 883.

and though never mined for the nickel which is known to be present, it was utilized as a material for sulphuric acid fumes during the ten years succeeding 1865. The geological relations give it especial interest. The ore body is entirely analogous to the magnetite lenses, which are not rare in the Highlands of the Hudson. It lies in a light-colored gneiss, conformably to the laminations, and must have attained 20 or 30 feet in thickness. It has been mined down 300 or 400 feet, and apparently for 50 feet or more on the strike. About 100 yards west is found a basic gneiss, consisting of green hornblende and plagioclase, with a little biotite. The wall rock contains quartz, plagioclase and very subordinate hornblende. In the thin section it appears fully as acidic as a quartz-diorite.

Much hornblende is associated with the pyrrhotite, and occasional lumps of magnetite, with which are found titanite and apatite. The ore yielded about 28% sulphur as used for years in the chemical works, and was especially prized because it contained no trace of arsenic. The geological relations give no reason for regarding the ore body as a basic segregation of a gabbroic magma, but quite the contrary. Several of the magnetite mines in this region, it may be added, are troubled with pyrrhotite in the ore, but whether it is nickeliferous has not been determined.[1]

Similar pyrrhotites, low in nickel, occur in Ontario.[2]

2.15.11. Example 13*a*. Gap Mine, Penn.; Sudbury, Ont. Bodies of nickeliferous pyrrhotite and chalcopyrite with very subordinate pyrite, in the outer portions of intrusions of basic igneous rocks, which may be metamorphosed to amphibolites. Cobalt is present in less amount than nickel and varies much in its relative proportions. Secondary millerite sometimes forms in cracks, as do quartz, siderite and one or two other minerals, but in variety of species ore bodies of this type are exceptionally barren. The type is of world-wide distribution, as noted by Vogt, and is well known in Norway, Sweden and one or two other European localities. The number of the Ex-

[1] W. H. Hoffman, "The late Discovery of Large Quantities of Magnetic and Non-magnetic Pyrites in the Croton Magnetic Iron Mines, N. Y.," *Trans. Amer. Inst. Min. Eng.*, June, 1892. J. C. Smock, *Bulletin of New York State Museum*. Dunderberg Mine, p. 18; Hobby Opening, p. 24.

[2] F. D. Adams. *Geol. Survey Canada*, Vol. VI., 1891–93, Part J.

ample indicates its genetic parallelism with the titaniferous magnetites of 2.03.11.

2.15.12. The Gap Mine, in Lancaster County, southeastern Pennsylvania,[1] was originally opened for copper in the preceding century. The copper enterprises were all failures, and not until in the fifties was the presence of nickel recognized. The mine then became the largest single producer of its day, and remained active until 1893, since which time it has been abandoned. As shown in the accompanying map and sections a lenticular outcrop or mass of greenish black rock, about 2,000 feet in length and 500 feet as a maximum width, is found in the midst of mica schist, and apparently conformable to the laminations. It strikes nearly east and west, and is contracted along the section AA, where it was most productive. It seemed to pinch in somewhat in depth, so far as the workings extended (about 250 feet). The ore was chiefly found at the eastern end of the lense, and was much less abundant where followed to the westward on the south side with a drift, as far as is colored black. Prospect holes still further west proved the presence of the amphibolite, but failed to show ore. A dike of olivine-diabase of the familiar Triassic sort common in southeastern Pennsylvania outcrops about 1,500 feet southeast, but it is much later in time than the amphibolite, with which and with the ore it has no apparent connection. The ore is pyrrhotite in far the largest amount, but when cut in thin sections along with the containing amphibolite, it is seen under the microscope that a light yellow mineral, presumably pyrite, is mixed all through the bronze-colored pyrrhotite. The ore is richest near the contact and fades into lean disseminations as this is left. The lense consists in far the largest part of green hornblende of the common variety, quite pale in thin section, and with pleochroism from green to yellow. Many specimens are formed of this and nothing else, except scattered grains of

[1] P. Fraser, "Report CCC," *Second Penn. Geol. Survey.* A geological description and historical sketch are given, and also an outline map in the accompanying atlas, on which the figure here used is based. The description, however, gives the impression that the ore is millerite, and hardly mentions pyrrhotite, whereas the millerite is a comparatively rare mineral. Joseph Wharton, "Analysis of the Nickel Ore from the Gap Mine, Lancaster County, Penn.," *Proc. Phila. Acad. Sci.*, 1870, p. 6.

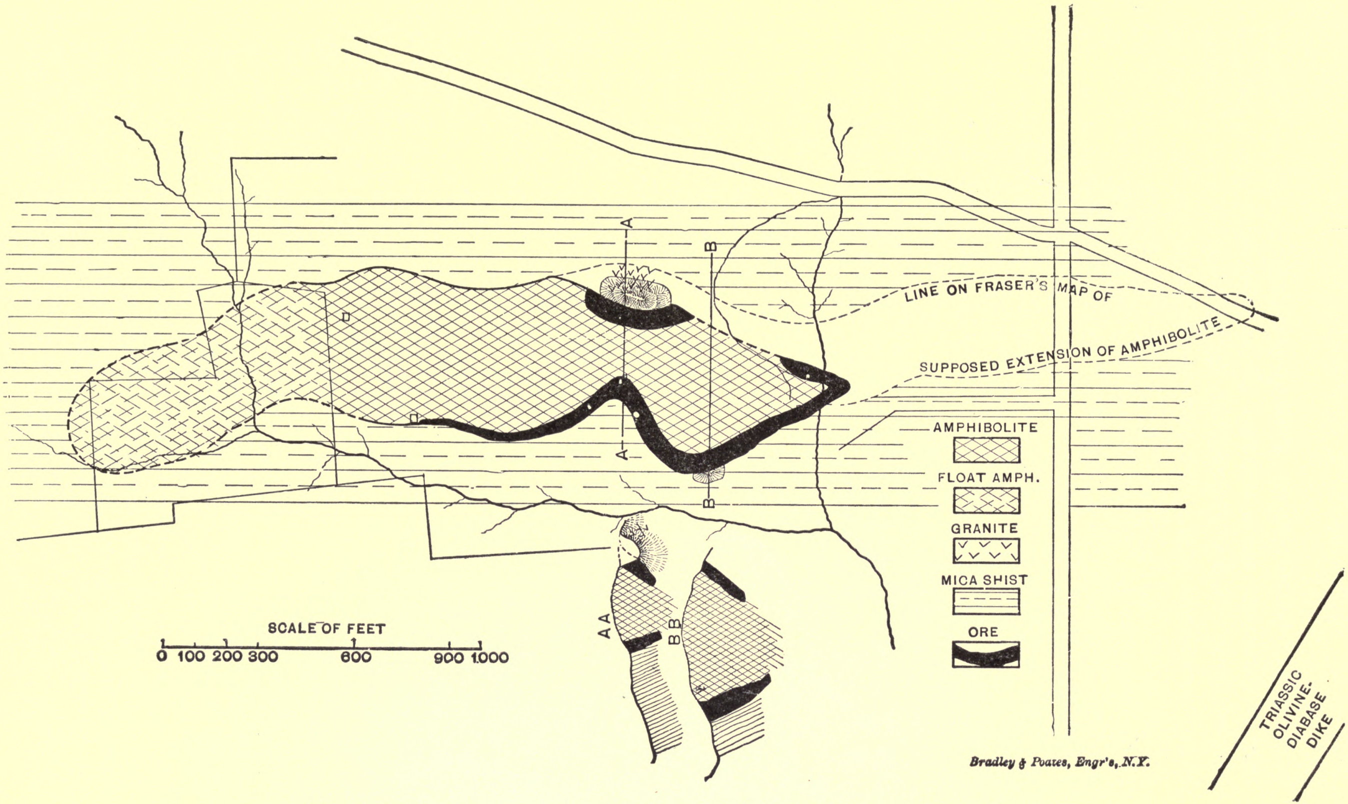

FIG. 159.—*Map and sections of Gap Nickel Mine, Lancaster Co., Penn.*

pyrrhotite. Others show a little plagioclase, and a few flakes of biotite. Recognizable remains of orthorhombic pyroxene and olivine were detected despite the general and thorough metamorphism of the rock. No more accurate name can be given it than amphibolite, although there is little doubt that it originally was a very basic gabbro or pyroxenite. The ore contains considerable secondary millerite, which forms crusts on the cracks of pyrrhotite, and often veins and stringers of quartz traverse it. In vuggs in these, beautiful crystals of vivianite are rarely met. The close parallel that the ore body affords in its geology to several Norwegian mines figured by Vogt in the *Zeitschrift für prakt. Geologie*, April, 1893, Plates V. and VI., is very striking. (See especially Meinkjär Grubenfeld, Fig. 3 of Plate VI.) The views of Vogt on the origin of such ore bodies by differentiation of a basic igneous magma in cooling, and by concentration of the early crystallizations at the contacts, according to Soret's principle, were outlined earlier in the discussion of the table of classification of ore deposits. In a metamorphosed rock, such as the Gap amphibolite, there is a reasonable ground for regarding the ore as a contact deposit due to deposition from solutions, but after seeing the larger, less metamorphosed but otherwise closely analogous ore bodies of the Sudbury district, the writer (J. F. Kemp) sees no escape from the conclusion that they and it are original crystallizations from the igneous magma as much as any other component minerals of the intruded mass.[1]

2.15.13. The Sudbury nickel mines are of quite recent development, as they were opened in 1886, although discovered earlier. They are situated forty miles north of Georgian Bay, an arm of Lake Huron, and on the eastern portion of the original Huronian belt. The Laurentian granites and gneisses, which to the east form a vast, monotonous stretch of low glaciated hillocks and swamps, are covered near Sudbury, and for a hundred miles west, by a great area of later Huronian sediments (gray-

[1] Literature on the Gap Mine, W. P. Blake, *Mineral Resources*, 1882, p. 399. J. Eyerman, "Mineralogy of Pennsylvania," P. Fraser, Report CCC, *Second Penn. Geol. Survey*, p. 163. J. F. Kemp, "The Nickel Mine at Lancaster Gap, Penn., and the Pyrrhotite Deposits at Anthony's Nose, on the Hudson," *Trans. Amer. Inst. Min. Eng.*, XXIV., 620, 883, 1884. J. Wharton, "Analysis of Nickel Ore from the Gap Mine," *Proc. Phila Acad. Sci.*, 1870, p. 6.

wackes, quartzites, schists) and by immense intrusions and dikes of norites and more acid rocks, at times more or less metamorphosed; eruptive breccias and other interesting varieties too numerous to cite in detail are also present. The geology is very

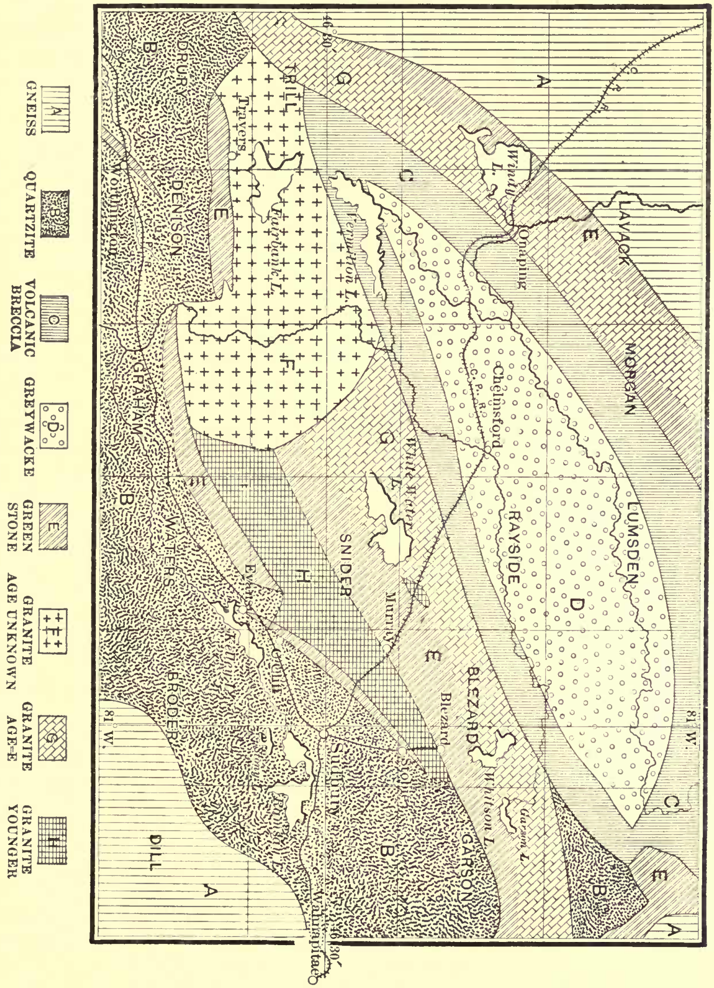

Fig. 160.—Geological sketch-map of the Sudbury district, Ontario. After T. L. Walker, Quarterly Journal of the Geological Society of London, LIII, 64, 1897.

complex, and is in large part concealed by swamps and almost impenetrable thickets. It is evident, however, that several great intrusions now identified as norite run northeast and southwest through the Huronian area. One on the southeast has along its own southeastern side some rich deposits, including the Evans, Copper Cliff, Stobie and Blezard. The Evans is on a small outlier from the main mass, and the Stobie and Blezard are further in from the actual contact than is the Copper Cliff. Some miles west of the great diorite dike just referred to is the large Murray mine in another intrusion, with a stretch of supposed Laurentian granite between. Some twenty miles southwest, and in connection with a still different diorite dike are found the Worthington mine and several undeveloped openings in Drury and Denison townships. About the same distance northwest of Sudbury is a region around Wahnapitae Lake, well thought of, but not yet productive.

2.15.14. In a recent valuable paper[1] T. L. Walker has traced out the petrographical character of the basic intrusives that contain the ore. In crossing the dikes, the rock in its unmetamorphosed condition remote from the contacts is a norite. As the edge and therefore the ore body are approached, the hypersthene changes to bastite, and finally in the mines to hornblende, which has occasioned the use of the name diorite. Titaniferous magnetite accompanies the ore, and has been observed enclosed in it. Walker concludes that the sulphides have crystallized directly from the fused magma, just as have the usual components of an igneous rock. It would seem that the change of hypersthene to hornblende at the borders would indicate some considerable metamorphism apparently dynamic in its nature.

2.15.15. The ore bodies betray their presence by great outcrops of rusty gossan, consisting of limonite in layers and cellular masses, which have resulted from the decay of the pyrrhotite and chalcopyrite. The outcrop of this gossan may run with local interruptions for long distances. When it was penetrated in the early prospecting the chalcopyrite lying below attracted attention, and the deposits were regarded as copper mines. Later the presence of the nickel in the pyrrhotite was recognized, and the nickel became the principal object. The two ores are inseparably intermingled and themselves form irregular masses often of great size in the diorite. It is stated by Peters

[1] T. L. Walker, "Geological and Petrographical Studies of the Sudbury Nickel District, Canada," *Quar. Jour. of the Geol. Soc.*, 1897, 40.

FIGS. 161 AND 162.—*View of the Copper Cliff Mine, near Sudbury, Ontario. The mine is in diorite. The ridge at the background is granite. From photographs by T. G. White, 1894.*

that the early work at the Stobie showed ore over 100 feet across. The diorite is a dense black rock resembling most closely black basalt in its appearance. Quite pure pieces of sulphides of large size are at times obtained, but practically all the ore contains rock up to 30% or more of its weight, and the sulphides form irregular masses in it. Great heaps of rock too lean to work, but showing bits of sulphides through the pieces, are thrown out on the dumps. The workings are in the form both of open cuts and of shafts, from which the drifts wander out somewhat irregularly in search of the ore-masses. While it is truly said the ores favor the contacts, this should not be too closely interpreted. The mines and the gossan do lie along the outer portions of the diorite masses, yet as now mined at all the large producers they are entirely in the diorite, and often very considerable distances from the actual contact, of which no evidence appears from the workings. Included masses of granite occur with the ore at Copper Cliff, and as a general thing have a rim of chalcopyrite. Some small, secondary and insignificant quartz veins ramify through the diorite, and contain chalcopyrite and some pyrrhotite, both of which are secondary, but they are trifling in amount. On the contrary, the masses of the sulphides are irregularly distributed, often as small isolated bits, throughout the fresh, dense diorite, and leave one no reasonable alternative but to conclude that they are as much an original crystallization from the igneous magma as any other of the minerals in the rock. Evidence of disturbance has been found in the region, and apparent fault lines are not lacking, but the great open cuts of the mines show no evidence of them. The method of igneous origin has been somewhat attacked. Posepny, for example, refers to it as something extraordinary when in his great essay on "The Genesis of Ore-Deposits," he cites Vogt's work, and controverts it strongly; but it appears to the writer, after having seen the mines, that no process of solution and replacement can be conceived of as introducing these scattered masses of sulphides into dense, undecomposed and apparently unbroken igneous rock, which would not strain the faith of a conservative observer to a far greater degree.[1]

[1] D. H. Browne gives in the *School of Mines Quarterly* for July, 1895 p. 297, a very suggestive paper on "Segregation in Ores and Mattes." The

2.15.16. It is an interesting fact that sperrylite, the unique arsenide of platinum, occurs in the Sudbury region, but was not first discovered in a nickel mine. Traces are, however, said to occur in the nickel ores. Cobalt is in comparatively small amount, much less than in some other nickel regions. The ores vary in richness in different mines and in different parts of the same mine. They run from over 1% to over 5% nickel, and have a copper percentage somewhat under the nickel. The Worthington has yielded a little gersdorffite (NiAsS), and niccolite (NiAs) in secondary quartz veins, and a vein is reported from Denison township containing both these. A galena vein is reported from the same region, and a little millerite is said to have been found in the Copper Cliff mine. Traces of zincblende have also been noted in some of the ores, but aside from these the mineralogy is limited to the two principal sulphides.[1]

2.15.17. Example 49*a*. Riddle's, Douglass County, Oregon. Irregular deposits of hydrated silicates of nickel and magnesia, in serpentine formed by the alteration of peridotites or related rocks. Limonite, chalcedonic quartz and chromite are quite invariable associates, as are clays and other products

results of a long experience with mattes show that in the matte pot the copper tends to collect at the top and sides, the nickel in the center. Parallels are drawn with the ore bodies, in the central parts of which the nickel is in excess of the copper, while at the edges the copper exceeds the nickel.

[1] On Sudbury see F. D. Adams, "The Igneous Origin of certain Ore Deposits," *General Min. Assoc., Prov. Quebec*, January 12, 1894. A. E. Barlow, "The Nickel and Copper Deposits of Sudbury, Ont.," *Ottawa Naturalist*, June, 1891. R. Bell, *Geol. Survey of Can.*, 1890–91; F. 5, 91. *Bull. Geol. Soc. Amer.*, II., p. 125. T. G. Bonney, "Notes on a part of the Huronian Series near Sudbury," *Quar. Jour. Geol. Soc.*, XLIV., 32, 1888. D. N. Browne, *Eng. and Min. Jour.*, September 16 and December 2, 1893. E. R. Bush, "The Sudbury Nickel Region," *Idem*, March 17, 1894, p. 245. F. W. Clarke and C. Catlett, "Platiniferous Nickel Ore from Canada," *Amer. Jour. Sci.*, iii., XXXVII., 372. J. H. Collins, "Note on the Sudbury Copper Deposits," *Quar. Jour. Geol. Soc.*, XLIV., 834. J. Garnier, "Mines du Nickel, Cuivre et Platine, du District du Sudbury," *Memoires de la Sociétié des Ingenieurs Civils.*, Paris, March, 1891. W. H. Merritt, *Trans. Amer. Inst. Min. Eng.*, XVII., 295. E. D. Peters, "On Sudbury Ore Deposits," *Idem*, October, 1889; *Eng. and Min. Jour.*, October 26, 1889. *Berg. u. Huett. Zeit.*, L., 149, 1891. *Mineral Resources of the U. S.*, 1888, 110.

of alteration. The ore occurs in loose boulders on the surface, and as a coating on the walls of small cracks and veinlets that penetrate the more massive serpentine. The largest deposits of this character, so far as yet opened in this country, are in the Coast range, southwest of Riddle's Station, Douglass County, Oregon, on the Oregon and California Railroad. The mines occur on a steep hillside, in serpentine that has resulted from the alteration of the variety of peridotite, called harzburgite, *i.e.*, bronzite and olivine. Open cuts, small drifts and test pits have served to show the nickel silicates, richest at the outcrop and fading out into small veinlets and reticulations in depth, until beyond the zone of superficial decay, they disappear. The openings are still in the condition of prospects, and productive mining is yet to be begun. The nickel has been shown by J. S. Diller to have been derived from the olivine of the rock, as chemical analysis of this mineral indicated 0.26% NiO By the familiar and ready alteration of the olivine the nickel has separated as the silicate, and has finally been concentrated sufficiently to be noticeable.[1] At Webster, in North Carolina, are surface deposits of nickel silicate which have attracted attention. They occur in the variety of peridotite, which is chiefly olivine, and is called dunite. The geological relations and origin are practically the same as those in Oregon, just cited. The mines are not yet producers.[2] Green crusts of oxidized nickel compounds have been found with the chromite in the town of Texas, Penn., but are of no practical importance. Such superficial discolorations are very common in serpentinous districts, but it is a curious fact that they are notably lacking in the dioritic varieties of Example 13*a*.

The greatest deposits in serpentines are found in New Caledonia, in the South Pacific, where they have been mined for some years past, and have furnished in the last decade the largest part of the world's supply. The ores occur, as is the

[1] F. W. Clarke and J. S. Diller, "Nickel Ores from Riddle's, Webster and New Caledonia," *Amer. Jour. Sci.*, iii., XXXV., 483. H. B. v. Foullon, "On Riddle's," *Jahr. d. k. k. Geol. Reichsanstalt*, 1892, 224. Rec.

[2] Clarke and Diller, as cited in preceding reference. S. H. Emmens, "The Nickel Deposits of North Carolina," *Eng. and Min. Jour.*, April 30, 1892, p. 476. H. Wurtz, "On the Occurrence of Cobalt and Nickel in Gaston County, North Carolina," *Amer. Assoc. Adv. Sci.*, XII., 221; *Amer. Jour. Sci.*, ii., XXVII., 24.

usual case, associated with serpentine, and along the contact of the serpentine with overlying beds of red clay.[1]

2.15.18. Example 23*a*. Mine la Motte. Considerable pyrite occurs with the lead ores mentioned under Example 23, and is separated in the ore-dressing and treated by itself, as it contains nickel and cobalt. Such pyrite is most abundant at Mine la Motte, and considerable matte is made and shipped abroad. Siegenite, a variety of linnæite, is also found impregnating a bed of Cambrian sandstone that underlies the lead-bearing dolomite. It is not abundant enough to be of practical importance.[2]

2.15.19. Nickel ores have also been reported from Salina County, Arkansas.[3] Millerite occurs in a vein with quartz gangue in black shales. It is not practically productive. Nickel is also reported in a rather fine conglomerate from Logan County, Kansas. It occurs with manganese and limonite in the cementing material of the rock.[4] Oxidized nickel ores have also been reported at the Lovelock mines, Churchill County, Nevada, which passed in depth into sulphides.[5] Although they were originally regarded as promising, they have not proved a productive source as yet. At the Gem mine, Colorado, sulphide ores have also been produced. Millerite occurs as an interesting mineral in many other places (St. Louis, Mo.; with red hematite in Jefferson County, New York, etc.), but is only a rarity. Its interesting position at the former locality, in hair-like tufts in the midst of geodes indicates that

[1] F. Benoit, "Etude sur les Mines de Nickel de la Nouvelle Caledonie," *Bull. de las Société de l'Ind. Minerale*, VI., 753, 1892. J. Garnier, "Memoire sur les Gisements de Cobalt, de Chrome et de Fer à la Nouvelle Caledonie," *Soc. des Ingenieurs Civils.*, 1887. S. Heard, Jr., "New Caledonia Nickel and Cobalt," *Eng. and Min. Jour.*, August 11, 1888, p. 103. D. Levat, *Assoc. Française pour l'Advanc. des Sci.*, Paris, 1887. L. Pelaton, "Carte Geologique de la Nouvelle Caledonie," *Genie civile*, 1891.

[2] J. M. Neill, "Notes on the Treatment of Nickel and Cobalt Mattes at Mine la Motte," *Trans. Amer. Inst. Min. Eng.*, XIII , 634. For additional literature see under 2.05.09.

[3] *Ark. Geol. Survey*, 1888, Vol. I., pp. 34, 35.

[4] F. P. Dewey, "On the Nickel Ores of Russell Springs, Logan County Kansas," *Trans. Amer. Inst. Min. Eng.*, XVII., 636.

[5] A. D. Hodges, "Notes on the Occurrence of Nickel and Cobalt Ores in Nevada," *Trans. Amer. Inst. Min. Eng.*, X., 657. S. B. Newberry, "Nickel Ores from Nevada," *Amer. Jour. Sci.*, iii., XXVIII., 122.

nickeliferous solutions must have circulated rather widely in these limestones. In Jefferson County it probably resulted from the decaying pyritous mineral to which Smyth refers the iron ore, as outlined earlier.

PLATINUM.

2.15.20. Some hundreds of ounces of platinum are annually gathered from placer washings in northern California, and two or three times as much more from British Columbia. Much iridium and osmium are associated with it. In October, 1889, F. L. Sperry, the chemist of the Canadian Copper Company, of Sudbury, discovered a heavy crystalline powder in the concentrates of a small gold-quartz mine in the district of Algoma. He detected the presence of platinum, and sent the material to Professors Wells and Penfield, of Yale, by whom it was analyzed and crystallographically determined to be the arsenide of platinum, $PtAs_2$, the first compound of platinum, other than an alloy, detected in nature. It has been appropriately named sperrylite by Wells, and although not at present a source of platinum, it may merit attention, as the price of the metal has sometimes approximated that of gold. The chief reliance of the world for platinum is Russia, whose deposits are in the Urals. More or less comes also from Colombia, South America, and from placer washings elsewhere. Serpentine is very generally its mother-rock.[1]

TIN.

2.15.21. Ores: Cassiterite, SnO_2, Sn. 78.67, O. 21.33. The sulphide stannite is a rather rare mineral.

[1] California: *Eng. and Min. Jour.*, June 29, 1889, 587. B. Silliman, "Cherokee Gold Washings, California," *Amer. Jour. Sci.*, iii., VI., 132. Canada: F. W. Clarke and Ch. Catlett, "Platiniferous Nickel Ore from Canada," *Amer. Jour. Sci.*, iii., XXXVII., 372. H. L. Wells and S. L. Penfield, "Sperrylite, a New Mineral," *Idem*, iii., XXXVII., 67. Russia: A. Daubree, "On the Platiniferous Rocks of the Urals," *Trans. French Acad. Sci.*, March, 1875; *Amer. Jour. Sci.*, iii., IX., 470. General paper by C. Bullman, *The Mineral Industry for 1882*, p. 373. Rec.

[2] An elaborate review of the tin mines of the world by C. M. Roelker will be found in the *XVI. Ann. Rep. of the Director of the U. S. Geol. Survey*, Part III., pp. 458–538, 1895. E. Reyer has given a general discussion in "Zinn, eine geologisch-montanistisch-historische Monographie," Berlin, 1881. A general, genetic discussion is given by J. H. L. Vogt, "Die Zinnstein gang-gruppe," *Zeits. für prakt. Geol.*, 1895, 145.

Cassiterite occurs in small stringers and veins on the borders of granite knobs or bosses, either in the granite itself or in the adjacent rocks, in such relations, that it is doubtless the result of fumarole action consequent on the intrusion of the granite. It appears that the tin oxide has probably been formed from the fluoride. A favorite rock for the ore is the so-called greisen, a mixture of quartz and muscovite or lithia mica, and probably an original granite altered by fumarole action. Topaz, tourmaline, and fluorite are found with the cassiterite, and indicate fluoric and boracic fumaroles. Wolframite, scheelite, zinnwaldite and one or two other minerals are characteristic associates. Cassiterite seems also to crystallize out of a granite magma with the other component minerals. Cassite-

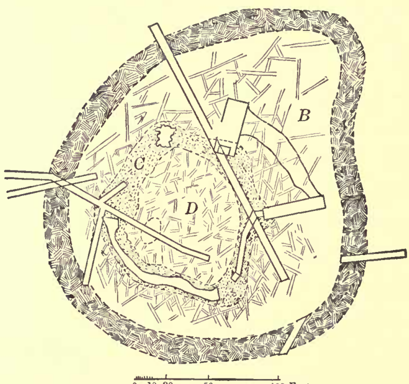

FIG. 163.—*Horizontal section of the Etta granitic knob, Black Hills, S. D. After W. P. Blake. Mineral Resources*, 1884, *p.* 602.

rite, being a very heavy mineral, accumulates in stream gravels, like placer gold, affording thus the stream tin. When of concentric structure the ore is called wood tin. It is not yet demonstrated that the United States have workable tin mines.

2.15.22. Example 51. Black Hills. Cassiterite disseminated in masses of albite and mica and associated with immense crystals of spodumene, which are contained in knobs of granitic rock. Columbite, tantalite, and beryl are also found. There are two granite knobs which are best known, the Etta and the Ingersoll. The former is a conical hill, which pierces mica and garnetiferous slates and which is 250 feet high by 150 feet by 200 feet. Tunnels show it to have a concentric structure—first, a zone of mica; second, a zone of great spodumene crystals, with an albitic, so-called greisen which carries cassiterite in its interstices; lastly, a mixture of quartz and feldspar as a core. Other tin-bearing granites occur as dikes, or veins, as much as 80 feet wide, and bearing the so-called greisen and tin ore in quartz. They are called segregated veins by Carpenter, who doubts their true igneous character, probably on good ground. No tin is yet commercially produced. The tin deposits extend also into Wyoming.[1]

2.15.23. Pebbles of stream tin have been found in gold washings in Montana and Idaho. Tin is also known in the Temescal Mountains, southern California. The area has recently been described by H. W. Fairbanks, who summarizes the geological relations as follows: "A semi-circular area of granite, over two miles in diameter, surrounded on the north-west and south by porphyries, and joined on the east to a great body of granitic rocks extending indefinitely in that direction. Around the border of this granite protuberance are many dikes of a fine-grained granite. Cutting through the granite in a northeast and southwest direction are black tourmaline veins, which form the gangue of the tin ore when it is present." While tourmaline is a common associate of tin ores, this great abundance of it is unusual. The ore occurs as a yellow, uncrystalline variety, in layers, and as a brown, granular, massive form, or in brown crystals. The ore and veinstone seem to have replaced the usual minerals of the granite, doubtless by fumarole action along fissures. The mining proved unsuccessful after a serious attempt.[2]

[1] W. P. Blake, *Mineral Resources*, 1883–84, p. 602. Rec. *Amer. Jour. Sci.*, September, 1883, p. 235; *Eng. and Min. Jour.*, September 8, 1886. "Tin Ore Deposits of the Black Hills," *Trans. Amer. Inst. Min. Eng.*, XIII., 691. F. R. Carpenter, *Prelim. Rep. Dak. School of Mines*," 1888; also *Trans. Amer. Inst. Min. Eng.*, XVII., 570. "Tin in the Black Hills," *Eng. and Min. Jour.*, November 28, 1884, p. 353. *Mineral Resources of the U. S.*, annually under "Tin." W. P. Headden, "Notes on the Discovery and Occurrence of Tin Ore in the Black Hills," *Colo. Sci. Soc.*, III., 347. A. J. Morse, "Harney Peak Tin Mines," *Eng. and Min. Jour.*, November 17, 1894, p. 463.

[2] W. P. Blake, "Occurrence of Wood Tin in California, Idaho, and Montana," *Min. and Sci. Press*, San Francisco, August 5, 1882. H. W. Fairbanks, "The Temescal Tin District," *Eleventh Rep. Cal. State Mineralogist*, 1893, pp. 111–114. A fuller paper will be found in the *Amer. Jour. Sci.*, July, 1897, 39. H. G. Hanks, *Rep. Cal. State Mineralogist*, 1884, p. 121.

2.15.24. Narrow veins carrying cassiterite have been exploited in the granite and schistose rocks of Rockbridge and Nelson counties, Virginia, in North Carolina, and in Alabama. Companies have been formed to work the two former, but as yet without a notable output.[1]

2.15.25. Cassiterite has been discovered in narrow veins in mica schists with lepidolite and fluorite at Winslow, Me., and is known at other places in Maine and New Hampshire. A salted tin prospect several years ago spread the impression that tin was to be found in Missouri.[2]

Narrow quartz veins have been recently discovered near El Paso, Tex., with cassiterite richly disseminated through them.

2.15.26. Mexico. Tin ores occur in a great number of places in Mexico, and small amounts of tin have been produced during and since the time of the Aztecs. W. R. Ingalls has carefully described the deposits in the State of Durango, and has shown that those at Potrillos are in veinlets or small veins in rhyolitic tuffs, with associated topaz, chalcedony and hyalite. The cassiterite is in irregular bunches and nodules, but as in practically all the Mexican mines, the amount is too small to be the basis of extended mining. Alluvial gravels were earlier worked but have been long since exhausted. At Cacária, likewise in Durango, the wall rock is described as quartz-porphyry, but near the city of Durango, and at Sain Alto, Zacatecas, the rhyolite tuffs are again the country rock.[3] The tin of Durango runs high in antimony.

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[1] H. D. Campbell, "Tin Ore, Cassiterite, in the Blue Ridge in Virginia," *The Virginias*, October, 1883. A. R. Ledoux, "Tin in North Carolina," *Eng. and Min. Jour.*, December 14, 1889, p. 521; see also February, 1887, p. 111. McCreath and Platt, *Bull. Iron and Steel Assoc.*, November 7, 1883, p. 209. W. Robertson, *London Min. Jour.*, October 18, 1884. A. Winslow, "Tin Ore in Virginia," *Eng. and Min. Jour.*, November, 1885, Rec.

[2] W. P. Blake, *Mineral Resources*, 1884, p. 538. C. H. Hitchcock, "Discovery of Tin Ore and Emery at Winslow, Me.," *Eng. and Min. Jour.*, October 2, 1880, p. 218. T. S. Hunt, "Remarks on the Occurrence of Tin Ore at Winslow, Me.," *Trans. Amer. Inst. Min. Eng.*, I., 573. C. T. Jackson, "Tin Ore at Winslow, Me.," *Proc. Bost. Soc. Nat. Hist.*, XII., 267.

[3] F. A. Genth, "On the Cacária Ores," *Proc. Amer. Philo. Soc.*, XXIV., 1887, p. 23. W. R. Ingalls, "The Tin Deposits of Durango," *Trans. Amer. Inst. Min. Eng.*, XXV., 146. C. W. Kempton, "Note on Tin Ores at Sain Alto, Zacatecas," *Idem*, 997.

CHAPTER XVI.

CONCLUDING REMARKS.

2.16.01. In review of the western border of the country, we note the elevated plateau rising from the Mississippi to the Rocky Mountain system, which consists of various ranges of general north and south or northwest and southeast trend, with broad valleys between. To the west the Colorado Plateau is met, and then the Wasatch Mountains and the Great Basin, with its various, subordinate, north and south ranges. These are succeeded by the Sierra Nevada, and the great valley of California, the Coast range, and finally the Pacific Ocean.

From the Archean to the close of the Carboniferous there were granitic islands around which active sedimentation proceeded. At the close of the Carboniferous the elevation of the Wasatch and the region of eastern Nevada occurred. At the close of the Jurassic the elevation of the Sierra Nevada took place. The chief upheaval of the Rocky Mountain system came at the close of the Cretaceous and that of the Coast range at the close of the Miocene Tertiary. Smaller and less important oscillations have occurred before and since. Each elevation was accompanied by foldings, faultings, and extensive outpourings of eruptive rocks. The resultant fractures and the circulation of hot and chemically active solutions, occasioned by the dying volcanic activity, constitute the primary cause of the formation of the ore deposits, which in some cases lie in ranges along the lines of faulting or of disturbances, and in others are irregularly scattered. We may recognize the Coast range belt with mercury and chromium; the California gold belt in the western Sierras; the silver belt of Utah on the western flank of the Wasatch; a belt in Arizona from southeast to northwest, along the contact between Paleozoic limestone, mostly Carboniferous, and the Archean; and the great stretch of lead-silver mines in the Carboniferous limestones of Colorado. The other areas are scattered, and apparently exhibit no such grand general relations to these geographical and geological phenomena.[1]

2.16.02. In the Mississippi Valley, W. P. Jenney has remarked the connection of the antimony and silver deposits of Arkansas with the Ouachita uplift that traverses that State and Indian Territory; the location of the Missouri lead and zinc ores along the Ozark uplift; and he has referred the Wisconsin lead and zinc mines, as well as those in the neighboring parts of Iowa and Illinois, to an uplift south of the Archean area of Wisconsin. The limitation of the Lake Superior copper deposits to the Keweenawan system may be mentioned, and such parallelism as prevails among the Lake Superior iron ores. In the East the great belt of Clinton ores; the long succession of Siluro-Cambrian limonites in the Great Valley; the black-band ores and clay-ironstones of the Carboniferous; the closely similar geological relations of non-titaniferous, magnetite lenses in the Archean gneisses; and the general association of titaniferous magnetites with rocks of the gabbro family the country over—all are striking illustrations of broad, general geological features that may characterize extended series of ore deposits. To these may be appended the great series of pyritous veins in the slates and schists of the East, the gold belt of the Southeastern States, and the small copper deposits associated with the Triassic traps and sandstones. Aside from the groups mentioned, while there are important mines not included in the list, the others do not exhibit the same widespread uniformities of structure or associations.[2] Yet, from the

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[1] G. F. Becker, *Amer. Jour. Sci.*, Third Series, Vol. XXIII., 1884, p 209. W. P. Blake, *Rep. Cal. State Board of Agriculture*, 1866. S. F. Emmons, "The Structural Relations of Ore Deposits," *Trans. Amer. Inst. Min. Eng.*, XVI., 804. R. W. Raymond, "Geographical Distribution of Mining Districts in the United States," *Idem*, I., 33. *Fortieth Parallel Survey*, Vol. III., Chapter I. "Precious Metals," *Tenth Census*, Vol. XII.

[2] It is only proper in this connection to refer to the paper by T. F. Van Wagenen, on "System in the Location of Mining Districts," *School of Mines Quarterly*, January, 1898, p. 189. The author regards the location of the veins and the mining districts as having been determined by the lines of terrestrial, magnetic currents, which converge at the magnetic

list cited, it forcibly appears that similar conditions have brought about related ore bodies over great stretches of country; and while in the opening schemes of classification points of difference were emphasized, in the closing pages points of resemblance may be with equal right brought to the foreground.

2.16.03. A few general conclusions suggest themselves from the preceding pages.

(1) The extreme irregularity in the shape of metalliferous deposits, and from this the unwisdom of the United States law in the West, which is based on well-defined fissure veins. The only practicable method is that a man should own all that is embraced in his property lines, whether the ore body outcrops outside or not. "A square location is the square thing" (Raymond).

(2) The very general proximity of eruptive rocks in some form to the ore bodies. Except in the case of iron, there are only a few where these are not present, and apparently strong factors in the circulations which formed the ore. The lead and zinc deposits of eastern and western Missouri and the neighboring States, and of New York and Virginia, are almost the only ones, and we are justified in concluding that eruptive rocks are of great importance.

(3) We know from the investigations of Sandberger and others that the dark silicates of many rocks contain percentages of the common metals. The choice is open whether to refer the ore to original disseminations in these, and to derive it by gradual concentration, probably at great depths, or to some indefinite unknown source, which can only be described as "below."

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pole of the earth. They therefore are independent of the great lines of mountain making and igneous outbreaks. The latter are, however, regarded by the present writer as of paramount importance. See above paragraph.

APPENDIX I.

In the following pages the principal schemes of classification of ore deposits are grouped according to certain relationships and similarities that run through them. It would be interesting to arrange them in chronological order, but points of likeness and unlikeness would not thus be brought out, nor can the influence of one writer on another be so clearly emphasized. The underlying object, aside from showing in a bird's-eye view what has been done, is to lead up to the purely genetic classification which appears in Chapter VI, Part I., and which would properly come in after No. 16. In the earlier editions of the book it was so placed, and all the schemes formed part of Chapter VI, but so many have appeared in later years that it has seemed wiser not to overload the main text with matter that is largely a subject of reference, and that can be treated with greater freedom in an appendix. The importance of the genetic principle has been more and more appreciated in recent years, and it is a striking fact that the more weighty recent contributions on ore deposits have been dominated by it.

In reading this appendix it should be further appreciated that the schemes were originally grouped so as to lead up to the one on page 56 as a climax, and that in it mere form is eliminated to the last degree, and well-recognized geological phenomena are brought to the foreground. It has indeed been said with force that the origin of ore deposits is a subject which is very largely a matter of hypothesis, and that it involves profound subterranean causes, of which we know but little. Still, it is held that an acquaintance with what has been accomplished in recent years by our best workers, and a rigid adherence to well-recognized principles in geology and mineralogy, especially as developed in rock study (*i.e.*, in that department of geology that of late years we have grown to call petrology), will establish much that cannot be questioned, and will aid in differentiating the cases which are still objects of reasonable doubt. It is, however, true that among the subjects on which human imagination, often superstitious, has run to wild extremes, and on which cranky dreamers have exercised their wits, the origin of ore deposits stands out in particularly strong relief.

A. *Schemes Involving only the Classification of Veins.*

(1)

G. A. von Weissenbach.[1] *Gangstudien*, 1850, p. 12.
- (*a*) Sedimentärgänge (Sedimentary Veins).
- (*b*) Kontritionsgänge (Attrition Veins).
- (*c*) Stalactitische oder Infiltrationsgänge (Stalactitic or Infiltration Veins).
- (*d*) Plutonische oder Gebirgsmassengänge (Masses, dikes, knobs, bosses, etc., not necessarily with ores).
- (*e*) Ausscheidungsgänge (Segregated Veins).
- (*f*) Erzgänge (True or Fissure Veins).

(2)

B. von Cotta, in comments on Von Weissenbach's Scheme. *Gangstudien*, 1850, p. 79. According to the vein filling.
1. Gesteinsgänge (Dikes).
   - (*a*) Not crystalline (Sandstone).
   - (*b*) Crystalline (Granite).
2. Mineralgänge (Veins).
   - (*a*) Of one non-metallic mineral.
   - (*b*) Of several non-metallic minerals.
3. Erzgänge. Ore veins.

(3)

B. von Cotta, *Idem*, p. 80. According to Shape and Position.
- I. Wahre, einfache Spaltengänge (Fissures).
   - (*a*) Querdurchsetzende (Cross fissures).
   - (*b*) Lagergänge (Bed veins).
   - (*c*) Klüfte (Cracks), Adern (Veinlets).

[1] See also Whitney's *Metallic Wealth of the U. S.*, 1854, p. 44.

II. Gangzüge (Linked Veins).[1]
III. Netzgänge (Reticulated Veins).
IV. Contaktgänge (Contact Veins).
V. Lenticulargänge (Lenses).
VI. Stockförmige Gänge (Stocks, Masses).

(4)

B. von Cotta, *Idem*, p. 80. According to the texture of the vein filling.

I. Dichte Gänge (Compact Veins).
II. Krystallinische Gänge.
III. Krystallinisch, kornige (granular) Gänge.
IV. Krystallinisch, massige (massive) Gänge.
V. Gänge mit Lagentextur (Banded veins).
  (*a*) Ohne Symmetrie der Lagen (unsymmetrical).
  (*b*) Mit Symmetrie der Lagen (symmetrical).
VI. Gänge mit Breccien oder Conglomerattextur.

(5)

J. Le Conte, *Amer. Jour. Sci.*, July, 1883, p. 17.

1. Fissure Veins.
2. Incipient Fissures, or Irregular Veins.
3. Brecciated Veins.
4. Substitution Veins.
5. Contact Veins.
6. Irregular Ore Deposits.

In von Weissenbach's table the sedimentary veins are much the same as the "sandstones dikes" which J. S. Diller has recently described. (*Bull. Geol. Soc. Amer.*, I., 411.) They and the stalactitic veins have small practical value, although of great scientific interest. Under (*d*), the stockworks with tin ores are the principal illustration of economic prominence. The attrition veins are an important class, and increasing study has widened the application of this or

[1] Gangzüge is happily translated "linked veins," by Dr. G. F. Becker (*Quicksilver Deposits*, p. 410). Any attempt to render the original by preserving the figure of a flock of birds or of a school of fish, etc., is, as Mr. Becker remarks, infelicitous, if not impossible.

synonymous terms. Segregated veins and true veins are well-known forms. In the comments of von Cotta, which follow von Weissenbach's paper, veins are grouped from every possible standpoint, von Weissenbach's scheme being taken as the one based on origin. Nos. 2 and 4 have small claims to attention. No. 3 foreshadows the drift of many subsequent writers. The meanings of the terms are self-evident, except perhaps *Gangzüge* (linked veins). This refers to a group of parallel and more or less overlapping veins, deposited along a series of opening, evidently of common origin. It is a convenient term.

The terms used by Le Conte may be passed without comment as being self-evident in their meaning, except (4) and (6). The scheme was devised, as a perusal of the citation will show, after the author had set forth some original views of the causes which lead to the precipitation of ores, and had forcibly stated others very generally accepted. In the explanatory text some quite curious associations are found, which are cited by way of illustration. Thus, under group (4), stalactites, caves, gash veins, and the Leadville ore bodies are considered examples, and under group (6) the grouping together of beds, igneous masses, and all other forms of so-called irregular deposit is decidedly open to criticism. This is the more emphatic because the concluding sentences of the paper (of whose general value and excellence there can be no question) give the impression that the author felt he had cleared up all the points in the origin of ore bodies which would be of interest or importance to a purely scientific investigator as contrasted with a practical miner.

B. *General Schemes Based on Form.*

(6)

Von Cotta and Prime. *Ore Deposits*, New York, 1870.

- I. Regular Deposits.
  - A. Beds.
  - B. Veins.
    - (*a*) True (Fissure) Veins.
    - (*b*) Bedded Veins.
    - (*c*) Contact Veins.
    - (*d*) Lenticular Veins.

II. Irregular Deposits.
  C. Segregations.
    (*a*) Recumbent.
    (*b*) Vertical.
  D. Impregnations (Disseminations).

(7)

Lottner-Serlo, *Leitfaden zur Bergbaukunde*, 1869.
I. Eingelagerte Lagerstätten (Inclosed Deposits).
  A. Plattenförmige (Tabular).
    (*a*) Gänge (Veins).
    (*b*) Flötze und Lager (Strata, beds, seams).
  B. Massige Lagerstätten (Massive Deposits.)
    (*a*) Stöcke, (*b*) Stockwerke } Masses.
  C. Andere unregelmässige Lagerstätten (other irregular deposits).
    (*a*) Nester (Pockets).
    (*b*) Putzen.
    (*c*) Nieren (Kidneys).
II. Aufgelagerte Lagerstätten (Superficial Deposits).
  D. Trümmerlagerstätten (Placers).
  E. Oberflächliche Lager (Surface beds).

(8)

Koehler, *Lehrbuch der Bergbaukunde*, 1887.
I. Plattenförmige Lagerstätten (Tabular Deposits).
  (*a*) Gänge (Veins).
  (*b*) Flötze und Lager (Strata, beds, seams).
II. Lagerstätten von unregelmässige Form (Deposits of irregular Form).
  (*a*) Stöcke und Stockwerke (Masses).
  (*b*) Butzen, Nester, und Nieren (Pockets, concretions, etc.).

(9)

Callon, *Lectures on Mining*, 1886 (Foster and Galloway's translation).
I. Veins.
II. Beds.
III. Masses (*i.e.*, not relatively long, broad, and thin).

The scheme of von Cotta and Prime carries out the principle of form to its logical and somewhat trivial conclusion. Thus under irregular deposits it is a matter of extremely small classificatory moment whether an ore body is recumbent or vertical. Otherwise the scheme is excellent, and its influence can be traced through most of those that are of later date. The original draft came out in the German in 1859. All the others are from treatises on mining, in which this subject plays a minor rôle, and indicates the tendency, referred to above, of mining engineers, when writing theoretically, to imagine certain fairly definite forms, which are to be exploited. As previously remarked, however, considering the uncertainty of ore bodies and their variability in shape, it is here argued that the genetic principle might better take precedence. Several of the German terms are difficult to render into English mining idioms, as for example, Stock, Butzen (Putzen), Nester, and Nieren.

C. *Schemes, Partly Based on Form, Partly on Origin.*

(10)

J. D. Whitney, *Metallic Wealth of the United States*, 1854.

I. Superficial.

II. Stratified.

(*a*) Constituting the mass of a bed or stratified deposit.

(*b*) Disseminated through sedimentary beds.

(*c*) Originally deposited from aqueous solution, but since metamorphosed.

III. Unstratified.

A. Irregular.

(*a*) Masses of eruptive origin.

(*b*) Disseminated in eruptive rocks.

(*c*) Stockwork deposits.

(*d*) Contact deposits.

(*e*) Fahlbands.

B. Regular.

(*f*) Segregated veins.

(*g*) Gash veins.

(*h*) True or fissure veins.

(11)

J. S. Newberry, *School of Mines Quarterly*, March, 1880, May, 1880.

I. Superficial.

II. Stratified.
- (*a*) Forming entire strata.
- (*b*) Disseminated through strata.
- (*c*) Segregated from strata.

III. Unstratified.
- (*a*) Eruptive masses.
- (*b*) Disseminated through eruptive rock.
- (*c*) Contact deposits.
- (*d*) Stockworks.
- (*e*) Fahlbands.
- (*f*) Chambers.
- (*g*) Mineral veins.
  1. Gash veins.
  2. Segregated veins.
  3. Bedded veins.
  4. Fissure veins.

(12)

J. A. Phillips, *Ore Deposits*, 1884.

I. Superficial.
- (*a*) By mechanical action of water.
- (*b*) By chemical action.

II. Stratified.
- (*a*) Deposits constituting the bulk of metalliferous beds formed by precipitation from aqueous solution.
- (*b*) Beds originally deposited from solution but subsequently altered by metamorphism.
- (*c*) Ore disseminated through sedimentary beds, in which they have been chemically deposited.

III. Unstratified.
- (*a*) True veins.
- (*b*) Segregated veins.
- (*c*) Gash veins.
- (*d*) Impregnations.
- (*e*) Stockworks.

(*f*) Fahlbands.
(*g*) Contact deposits.
(*h*) Chambers or pockets.

It is at once apparent that Whitney's scheme contains the essentials of the others, which are merely slight modifications. Newberry introduces impregnations, chambers, and bedded veins.. The first named is a useful term, although it is not always easy to distinguish impregnations from others earlier given. Thus, they may be very like the division, disseminated through strata, or disseminated through eruptive rock, or, if in metamorphic rock, fahlbands. The word is also used to indicate places along a vein where the ore has spread into the walls. The term "chambers," or "caves," has found application in the West, and is a useful addition. Bedded veins appear also in von Cotta above (No. 6). Phillips seeks to explain the methods of origin in his use of Whitney's scheme and clearly feels the importance of emphasizing the genetic principle more strongly. Much of it is implied in the simpler phraseology, however, and the extended sentences lack the incisiveness of the earlier schemes. The arrangement as set forth by Whitney is worthy of high praise, and the scheme is one of the many valuable things in a book that has played a large part in the economic history of the United States.

D. *Schemes Largely Based on Origin.*

(13)

J. Grimm, *Lagerstätten*, 1869.

I. Gemengtheile oder grössere Einschlüsse in den Gebirgsgesteinen. Einsprengung, Imprägnation. (Essential component minerals and inclusions in country rock. Impregnations.)
- (*a*) Ursprungliche Einsprengung. (Original with the inclosing rock.)
- (*b*) Von anderen Lagerstätten weggeführte Bruchtheile, etc. (Fragments brought from a distance. Placers, ore-bearing boulders. Breccias.)

II. Untergeordnete Gebirgsglieder oder besondere Lagerstätten. (Subordinate terranes or special forms of Deposits.)
- (*a*) Plattenförmige Massen. (Tabular masses.)
  1. Lager oder Flötze. Bodensatzbildung. (Beds, strata.)
  2. Gänge, Klüfte, Gangtrümmer, etc. (Veins of varying sizes.)
  3. Plattenförmige Erz-ausscheidungen und Anhäufungen. (Segregated veins.)
- (*b*) Stöcke und regellos gestaltete Massen. (Stocks and irregular masses.)
  1. Lagerstöcke Linsenstöcke, Linsen. (Lenticular deposits, etc.)
  2. Stöcke, Butzen, Nester, etc. (Masses, pockets, etc.)
  3. Stockwerke. (Stockworks.)

(14)

A. von Groddeck, *Lehre von den Lagerstätten der Erze.*, 1879, p. 84.

I. Ursprüngliche Lagerstätten (Primary deposits).

A. Gleichzeitig mit dem Nebengestein gebildet. (Formed at the same time with the walls.)

1. Geschichtete. (Stratified.)
- (*a*) Derbe Erzflötze. (Entire beds in a stratified series.)
- (*b*) Ausscheidungsflötze. (Disseminated in beds.)
- (*c*) Erzlager. (Lenticular beds, mostly in schists.)

2. Massige. (Massive; the word is nearly synonymous with igneous.)

B. Später wie das Nebengestein gebildet. (Formed later than the walls.)

3. Hohlräumsfüllungen. (Cavity fillings.)
- (*a*) Spaltenfüllungen oder Gänge. (Fissure fillings or veins.)
  - (1) In massigen Gesteinen. (In igneous rocks.)

(2) In geschichteten Gesteinen. (In stratified rocks).

(*b*) Höhlenfüllungen. (Chambers.)

4. Metamorphische Lagerstätten. (Alterations, replacements, etc.)

II. Trümmer-lagerstätten. (Secondary or detrital deposits.)

(15)

R. Pumpelly, *Johnson's Encyclopædia*, 1886, VI., 22.

I. Disseminated concentration. (*a*) Impregnations, Fahlbands. II. Aggregated Concentration. (*a*) Lenticular aggregations and beds. (*b*) Irregular masses. (*c*) Reticulated veins. (*d*) Contact deposits.	Forms due to the texture of the inclosing rock, or to its mineral constitution, or to both causes.
III. Cave deposits. IV. Gash veins. V. Fissure veins.	Forms chiefly due to pre-existing open cavities or fissures.
VI. Surface deposits. (*a*) Residuary deposits. (*b*) Stream deposits. (*c*) Lake or bog deposits.	

These three are all excellent, and give some interesting variations in the several points of view from which each writer regarded his subject. There are instances in the two German schemes where it is difficult to render the original into a corresponding English term and recourse has been had to the explanatory text. Grimm especially writes an obscure style. He divides accordingly as the ore forms an essential and integral part of the walls or a distinct body. Von Groddeck has in view the relative time of formation as contrasted with the walls. Grimm afterward emphasizes geometrical shape, but this von Groddeck practically does away with, and continues more consistently genetic. His scheme might perhaps come more appropriately in the next section.

Pumpelly's conception varies considerably from the others. He writes, as his full paper states, in the belief that the metals have all been derived primarily from the ocean, whence they have passed into sedimentary, and, by fusion of sediments, into igneous rocks. The group of residuary surface deposits, carrying out as it does a favorite idea of Professor Pumpelly, as set forth in his papers on the secular decay of rocks, is an important distinction.

E. *Schemes Entirely Based on Origin.*

(16)

H. S. Munroe. Used in the Lectures on Mining in the School of Mines, Columbia University.

I. Of surface origin, beds.
- (*a*) Mechanical (action of moving water).
  1. Placers and beach deposits.
- (*b*) Chemical (deposited in still water).
  1. By evaporation (salt, gypsum, etc.).
  2. By precipitation (bog ores).
  3. Residual deposits from solution of limestone, etc. (hematites).
- (*c*) Organic.
  1. Vegetable (coal, etc.).
  2. Animal (limestone, etc.).
- (*d*) Complex (cannel coal, bog ores, etc.).

II. Of subterranean origin.
- (*a*) Filling fissures and cavities formed mechanically.
  1. Fissure veins, lodes.
  2. Cave deposits—lead, silver, iron ores.
  3. Gash veins. The cavities of 2 and 3 are enlarged by solution of limestone.
- (*b*) Filling interstitial spaces and replacing the walls.
  1. Impregnated beds.
  2. Fahlbands.
  3. Stockworks.
  4. Bonanzas.
  Masses

This scheme covers all forms of mineral deposits, whether metalliferous or not, while most of those previously given, as well as the one that follows, concern only metalliferous bodies. The scheme is consistently genetic and was elaborated because such an one filled its place in lectures on mining better than one based on form. The general principle on which the main sub-division is made differs materially from any hitherto given. Deposits formed on the surface are kept distinct from those originating below, even though the first class may afterward be buried. It is immediately after this scheme that the one in paragraph 1.06.05 finds its place.

In the report of the State Geologist of Michigan for 1891-92 (issued January, 1893), pp. 144, 145, Dr. M. E. Wadsworth has published a "Preliminary Classification of Metalliferous or Ore Deposits." The main outline is as follows:

I. Eruptive Deposits	(*a*) Non-Fragmental.
	(*b*) Fragmental.
II. Mechanical Deposits	(*a*) Unconsolidated.
	(*b*) Consolidated.
III. Chemical Deposits	(*a*) Sublimations.
	(*b*) Water Deposits.
	(*c*) Impregnations or Replacements.
	(*d*) Segregations or Cavity Deposits.

Each of the above, except III. (*d*), is then subdivided so that the table becomes practically a classification of rocks. Indeed, a moment's consideraton will show that the scheme in its main divisions is closely modeled after the prevailing classification of rocks. III. (*d*) Segregations or Cavity Deposits contains the following: 1. Pockets. 2. Chambers. 3. Contact Deposits. 4. Veins, including Gash Veins, Segregated Veins, Reticulated Veins or Stockworks, Contact Veins, Fissure or Fault Veins.

The author states in some appended comments that the table is not limited to those deposits now practically worked (which we ordinarily understand the expression *ore* deposits to mean), but is intended to include all that have been or may be of value. But in this respect there is good ground for preferring to make our classifications in ore deposits, as in mineralogy, zoölogy, etc., embrace only the authenticated varieties, expecting additions to be incorporated as discovered and suitably described.

The same general grouping as this scheme employs is independently adopted by R. S. Tarr, in the *Economic Geology of the United States*, 1894.

For the meeting of the American Institute of Mining Engineers, held in connection with the various congresses at the World's Fair in Chicago, July, 1893, Professor Franz Posepny, of Vienna, contributed a grand essay on the "Origin of Ore Deposits." The materials for it were specially assembled by Professor Posepny while giving a course of lectures at the Pribram Mining Academy in the ten years following 1879. The paper is a theoretical discussion of the origin of ores, with illustrations selected from all parts of the world, but especially from Europe and America. It forms one of the most important contributions to the literature that has yet been made. Posepny distinguishes at the outset between rocks and mineral deposits; *i.e.*, between original materials, such as wall rock, and secondary introductions, such as veins, etc. The former he calls "idiogenites," the latter "xenogenites," basing the names on the familar Greek terms that run through all our literature. The latter are especially characterized by "crustification," by which term is indicated what has been called "banded structure," on p. 47. The subject of cavities is then taken up, and, while minute pores are stated to be in all rocks, a distinction is made between the larger openings, which originate in a rock mass as a part of its own structure, such as contraction joints in igneous rocks, amygdaloids, and the like, and those induced by outside causes, such as fault fissures.

The circulation of water through these is next treated: first, surface waters or "vadose" circulations, which descend; second, ascending waters from great depths, such as springs in deep mines, hot springs, etc. The common salts in solution in these latter are tabulated, being of course mostly alkaline carbonates, sulphates, chlorides, etc. The "exotic" metallic admixtures which would bear on the origin of ores are next discussed, so far as possible with analyses of actual cases. The alterations produced by mineral springs in rocks and the structural relations of the deposits of mineral springs, especially as expressed by "crustification," are then described. This preliminary material clears the way for the general discussion of the origin of ore bodies. The argument running all through the paper is that ore bodies, even when apparently interbedded with sedimentary rocks, are of secondary introduction and, in general for veins, are from deep-seated sources. Precipitation from descending solutions and filling by lateral secretion are strongly controverted.

The discussion of origin follows in its arrangement the following classification of ore deposits:

I. Filling of spaces of discission (fissures).
II. Filling of spaces of dissolution in soluble rocks.
III. Metamorphic deposits in soluble rocks; in simple sediments; in crystalline and eruptive rocks.
IV. Hysteromorphic (*i.e.*, later or last formed) deposits. Secondary deposits due to surface action (*i.e.*, placers, etc.).

The treatment, both in the introductory pages and in the later discussions, is often strikingly similar to that of this book, and the underlying argument is much the same. The standpoint in both essays is essentially a genetic one, and the main difference lies in the fact that the one is an exposition of an individual's views, fortified by examples from all parts of the world; the other endeavors to be a judicial statement, with a fairly complete description of the ore bodies of the United States and Canada alone. The writer differs with Posepny however in the greater weight given to the ores of igneous origin.

1.06.28. An extended treatise on the useful minerals, earthy as well as metallic, by MM. E. Fuchs and L. De Launay, has recently appeared (*Traité des Gîtes Minéraux et Métallifères*, Paris, 1893). The book is based on the lectures on economic geology delivered in the Ecole Supérieure des Mines, at Paris, in the last fifteen years by the two authors. (Professor Fuchs died in 1889, and was succeeded by Professor De Launay.) A vast amount of valuable information is brought together and discussed from various points of view, useful applications and methods of treatment being set forth as well as geological occurrence. The work is encyclopedic in scope and affords a reader descriptions of mineral resources and references to their literature in every quarter of the world. So far, however, as the United States are concerned the authors have suffered from the unavoidable limitations of those not native and conversant in a discriminating way with our literature. Nevertheless they have endeavored to give a large share of their space to this country, and where prominent monographs have appeared they have been read with care, but in many cases reference to later papers and descriptions would have improved the text. A later edition will doubtless correct these.

The classification of ore deposits as well as other useful minerals on a genetic principle has evidently been in many minds in the last few years. Mr. Frederick Danvers Power,[1] of Melbourne, Victoria, reviewed the subject in 1892, and after giving the schemes of others and summing up the various characteristics of veins, has formulated a classification whose main divisions are as follows: I. Contemporaneous; Indigenous. II. Metasomatic or Chemical Alteration of the Original Constituents. III. Subsequently Introduced; Exotic. Each of these has then a number of subdivisions too numerous to be repeated here.

Prof. William O. Crosby,[2] of Boston, has recently discussed the same subject in a very suggestive way. The main headings are: A. Deposits of Igneous Origin (Igneous rocks); B. Deposits of Aqueo-Igneous Origin; C. Deposits of Aqueous Origin. The first and last are then subdivided at considerable length, but the second is chiefly limited to the pegmatite (granitic) veins which attend many plutonic intrusions. Lack of space prevents the full reproduction of both these schemes, but sufficient has been mentioned, it is hoped, to indicate the line of attack and to place a reader desiring to look the subject up in touch with the originals.

[1] "The Classification of Valuable Mineral Deposits," *Trans. Australas. Inst. Min. Eng.*, 1892.

[2] "A Classification of Economic Geological Deposits based on Origin and Original Structure," *Amer. Geol.*, April, 1894, p. 240. The paper also appears in the *Technological Quarterly*.

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