Department of the Interior
Roy O. West, Secretary

U. S. GEOLOGICAL SURVEY
George Otis Smith, Director

Professional Paper 144

THE COPPER DEPOSITS OF MICHIGAN

BY

B. S. BUTLER and W. S. BURBANK

IN COLLABORATION WITH

T. M. BRODERICK, L. C. GRATON, C. D. HOHL, CHARLES PALACHE
M. J. SCHOLZ, ALFRED WANDKE, and R. C. WELLS

UNITED STATES
GOVERNMENT PRINTING OFFICE
WASHINGTON
1929

ADDITIONAL COPIES

OF THIS PUBLICATION MAY BE PROCURED FROM
THE SUPERINTENDENT OF DOCUMENTS
U S GOVERNMENT PRINTING OFFICE
WASHINGTON, D. C.
AT
$2.50 PER COPY

CONTENTS

ILLUSTRATIONS

OUTLINE OF REPORT

The copper district of Keweenaw Point, in the northern peninsula of Michigan, is the second largest producer of copper in the world. The output of the district since 1845 has been more than 7,500,000,000 pounds and showed a rather steady and consistent increase from the beginning of production to the end of the World War in 1918, since which there has been a marked decrease.

GEOLOGY

General features.—In Keweenawan time a series of basaltic flows accumulated to a depth of thousands of feet. Interbedded with the flows are felsite conglomerates. In the lower part of the series the conglomerates are rather abundant and thick; in the middle part they are relatively few and thin but persist for long distances; in the upper part they make up the bulk of the rock.

Intruded into and probably also interbedded with the basalts and conglomerates are siliceous, felsitic, and porphyritic rocks of similar composition to the material that makes up the conglomerates.

The location of the fissures from which the igneous material, both extrusive and intrusive, presumably came is unknown, but there are some reasons for supposing that they were situated toward the center of the Lake Superior structural basin, under the present lake, and that the flow outward from them was in a direction opposite to the present dip of the beds. Probably the felsite bodies from which the conglomerates were derived lay in the same direction as the fissures, and the material was carried down the same slopes as the lavas. Both the flows and the sediments are believed to have accumulated on a land surface, though probably some, especially of the later sediments, were laid down in bodies of water.

The flows range in thickness from a few feet to 1,300 feet and in extent along the strike from a few hundred feet to at least 40 miles. Nearly all of them are basaltic, but there are differences in composition, expressed in textural differences, which make it possible to divide the flows into several general groups.

The intrusive rocks are mainly siliceous felsites or porphyries, but there are some, like those of Mount Bohemia and others toward the Michigan-Wisconsin boundary, that approach the Duluth gabbro in composition and texture, and these and the felsite also were probably derived from the same source as that rock.

Lava tops or amygdaloids.—The dense rock that forms the greater part of most of the thick flows is commonly called “trap”; it is everywhere overlain by more open-textured material, which is known as “amygdaloid.” The cellular tops were formed by the action of gas which was contained in the lava and was liberated during the progress of flow and consolidation. Part of this gas escaped from the surface, and part was caught as bubbles in the viscous top of the lava and thus formed a cellular mass which was later converted into amygdaloid by the filling of the vesicles. Several types of top are recognized. The most common is the cellular top, which was produced by the simple freezing in of individual bubbles of gas. Coalescing amygdaloid has resulted when many bubbles collected into an irregular layer of gas separated by material in which cavities were relatively few. This gave long connected passages in the tops. Fragmental top is due to the breaking up of the cellular top, during solidification and flow, into angular fragments which became so jumbled as to form an irregular hummocky surface. Where the fragments are piled above the general surface they also sink into the flow, so that lava top of this kind varies abruptly and irregularly in thickness. Scoriaceous top results from a working over of any of the other types by the process of erosion and sedimentation. It very commonly underlies felsite conglomerate but occurs also where there is little or no felsite sediment. From comparison with other regions it is thought that the different types have resulted from different conditions of the lava as it reached the surface. Lava that issued at a high temperature and had a low gas content produced cellular top. Lava that issued at a low temperature and had a high gas content produced fragmental top. Coalescing top was formed on lava intermediate between the other two.

Oxidation of lavas.—The tops of nearly all the flows are distinctly red, and the fragmental tops are decidedly red. Chemical analyses show that there is in general a steady decrease in the proportion of ferric iron and an increase in ferrous iron from the top of a flow nearly to the bottom. In the fragmental flows there is also more total iron in the top—as much as 40 per cent more than in the compact portion of the flow.

It is thought that the oxidation and concentration of the iron were accomplished in large part by the gases given off by the lava during solidification. The evidence indicates that at the temperature at which the lavas emerged the inclosed gases were either neutral or reducing in their action on ferric oxide, but as they cooled in their ascent through the flow they became strongly oxidizing toward ferrous oxide.

Copper in trap.—An examination of the freshest traps confirms previous observations that they contain copper in small amount. Both native copper and chalcopyrite are present. It seems probable that at least a part of the copper is a primary constituent of the traps.

Structure.—The Michigan copper region is on the southern rim of the Lake Superior syncline or basin, which was probably formed during Keweenawan time. The early Keweenawan rocks of Keweenaw Point dip steeply and the later ones progressively less steeply northwestward, toward the center of the basin. Transverse to the general strike of the Lake Superior syncline are anticlines and synclines that pitch down the dip of the larger fold; among the folds are the Keweenaw anticline, the Ontonagon syncline, and the Bessemer anticline. On these broader anticlines and synclines are several subordinate folds of similar trend, such as the Allouez anticline, the Isle Royale syncline, and the Baltic and Mass anticlines.

The greatest fault of the region is the Keweenaw fault, which bounds the copper-bearing series on the south from the end of Keweenaw Point to Lake Gogebic. This is a reverse fault of northwesterly dip, along which the basaltic series has been thrust over the “Eastern” (Cambrian) sandstone. The dip of the fault is nearly parallel to the flows, and it also follows the major anticlinal and synclinal structure of the rocks. Many branch faults and fissures are associated with the Keweenaw fault. Relatively small transverse faults and fissures are also present around the crests of the anticlines. The movement on the Keweenaw fault probably did not begin till late Keweenawan time, and much of it occurred after the “Eastern” sandstone was deposited. The transverse folding and faulting probably followed the Keweenaw faulting and preceded the period of mineralization.

ORE DEPOSITS

The copper deposits are of two main classes—lode deposits and fissure deposits.[1] The lode deposits consist of conglomerate lodes, which are mineralized beds of felsite conglomerate interbedded with the lava flows, and amygdaloid lodes, which are the mineralized vesicular or brecciated tops of the lava flows. The fissure deposits are veins along fractures that are in part parallel and in part transverse to the beds; all of them are of narrow tabular form.

The commercially important known deposits with one exception are confined to the portion of the Keweenawan series composed predominantly of lava flows. They are distributed through most of that portion of the series. The more productive lodes, from the base upward, are the Baltic amygdaloid, Isle Royale amygdaloid, Kearsarge amygdaloid, Osceola amygdaloid, Calumet & Hecla conglomerate, Allouez conglomerate, Pewabic amygdaloid, and Ashbed amygdaloid. The Nonesuch lode, named for the formation that contains it, is in the upper sedimentary portion of the series. The fissure deposits are in the same portion of the series as most of the lodes.

Conglomerate lodes.—Only two of the conglomerate beds have been extensively explored, the Calumet & Hecla and the Allouez. The Calumet & Hecla conglomerate over most of its known extent is a sandy or "scoriaceous" bed with a little felsite sand at the top. At Calumet it opens into a well-developed felsite conglomerate lens that increases in thickness and extent with increased depth. The Allouez conglomerate is thicker and more persistent than the Calumet & Hecla but in places is represented only by a clay seam. The valuable mineralized portion of the Calumet & Hecla conglomerate is confined to the conglomerate lens, and the copper content decreases abruptly where the conglomerate changes to sand. The copper occurs as native metal and mainly replaces the finer matrix of the conglomerate. The common minerals associated with the copper are feldspar and epidote, mainly deposited earlier than the copper, and quartz and calcite, contemporaneous with the copper. Zeolites are conspicuously absent. The characteristic rock alteration effected by the ore-bearing solutions was the removal of hematite, with a resultant bleaching of the lode from brown to pinkish.

Amygdaloid lodes.—All but two of the largely productive amygdaloid lodes, as well as most of those that have given some encouragement, are of the fragmental type. One, the Pewabic, is mainly of the coalescing type, though in part it is fragmental, and the Ashbed is mainly a "scoriaceous" lode, though locally fragmental. No mines have been found in the cellular amygdaloids, which are by far the most abundant.

A greater variety of minerals is associated with the copper in the amygdaloid lodes than in the conglomerates. Chlorite, feldspar, epidote, and pumpellyite are the abundant minerals that mainly preceded the copper in deposition. Abundant quartz and calcite and some prehnite and datolite were locally deposited with the copper; the zeolites laumontite and analcite, together with saponite and other minerals in small amount, were deposited later than the copper. Sericite was deposited apparently both with and later than the copper.

The rock alteration effected during the formation of the amygdaloid lodes was of two types—a removal of hematite similar to that in the conglomerate, and a partial removal of the iron of hematite and a partial chemical reduction of ferric oxide to ferrous oxide and recombination to form ferrous and ferric compounds such as pumpellyite, chlorite, and epidote.

[1]The terms "lode" and "fissure" are here applied according to local usage; for definitions see section on ore deposits, p. 101.

Ore shoots.—The minable copper occurs in shoots, of which many are large but all far less extensive than the lodes that contain them. The ore of the shoots was deposited in the more permeable parts of the lodes by solutions whose movement was directed by barriers of relatively impermeable material. Two types of environment have most commonly favored the formation of shoots—a "bed," conglomerate or amygdaloid, that is prevailingly impermeable but contains permeable portions of great downward extension, like the Calumet & Hecla conglomerate shoot and the Kearsarge amygdaloid shoot, and a "bed," such as the Osceola amygdaloid, that is prevailingly permeable but contains impermeable streaks which cause a concentration of solutions beneath them.

Mineralized fissures.—Most of the veins in the north end of the district are in cross fissures on the Keweenaw and Allouez anticlines. The mineralization of the fissures has occurred near the intersections with strong amygdaloids and under the "slide" at the base of the Greenstone flow.

The fissures at the south end of the district are mainly strike fissures dipping more steeply than the beds; they also are mineralized near the intersection with strong conglomerates or amygdaloids.

Changes with depth.—All the larger known ore shoots have-had as rich ore at some place near their outcrop as at any greater depth. Any changes in grade to the present depth of development may be attributed more to changes in the character of the lode rock than to distance from the outcrop. Decrease in grade in the fissures and possibly in some of the lodes may be due mainly to depth.

Genesis of the deposits.—Two differing explanations of the genesis of the deposits have been advanced. One assumes that they are due to descending solutions, that the copper was derived from the lavas or from overlying beds, and that reaction of the oxidized copper-bearing solutions with the ferrous iron of the lavas produced metallic copper and ferric compounds. The other assumes that they were formed by ascending potential sulphide-bearing solutions which derived their copper from an igneous source, and that the reaction of these solutions with the ferric iron of the rocks resulted in the oxidation of the solutions, the reduction of the ferric iron, and the precipitation of native copper.

The theory of deposition by descending waters appears untenable for several reasons. There is, in the first place, no adequate source of the copper, for although copper is present in the traps there is no evidence of its removal. It is difficult, also, to believe that gravity circulation could have been adequate to form the deposits, for the gravity circulation of solutions in the deep levels of the mines is almost nil, and many of the deposits are on the under sides of impermeable barriers. The deposits, moreover, were formed in beds rich in ferric iron and poor in ferrous iron. The ferric iron was partly removed and partly reduced to the ferrous state—a reaction which does not seem likely to occur in the presence of oxidized solutions.

In the ascensional hypothesis it is assumed that the copper solutions originated in the underlying Duluth gabbro and that they either entered the lode-forming layers directly where the downward extensions of these layers were in contact with the magma or passed from the magma to the places of deposition by way of fissures. Solutions thus originating must have been highly heated, in the early stages gaseous, and under great pressure, and they could therefore easily make their way along fissures and permeable layers.

The principal facts that cause the authors to favor this hypothesis are that the solutions became concentrated and deposited ore on the under sides of barriers and that they were reducing in character—they carried sulphides, and they deposited native copper in beds rich in ferric iron, which they partly reduced or removed.

[PLATE 1. Implements used by early Indians in mining copper and tools made from copper.]

PART 1. GENERAL FEATURES

INTRODUCTION

FIELD WORK AND AUTHORSHIP

The field work on which this report is based was begun in the spring of 1920 by the Calumet & Hecla Consolidated Copper Co. under the supervision of Prof. L. C. Graton. The work done under these conditions was continued till the spring of 1924. T. M. Broderick, B. S. Butler, C. D. Hohl, and Alfred Wandke were engaged in the survey for the greater part or all of the period; Prof. Charles Palache for the summers of 1920 and 1921. Professor Graton spent each summer and short periods at other seasons in the district.

Messrs. Broderick, Butler, and Hohl worked mainly on the general field problems, Professor Palache gave special attention to mineralogy, and Mr. Wandke worked partly in the field but gave special attention to the petrographic and mineralogic studies in the laboratory. Robert Hoffman spent the summer of 1920 and E. R. Lovell the summer of 1921 in the work. By a cooperative arrangement between Harvard University, the National Research Council, and the United States Geological Survey, R. C. Wells at the same time made a study of the chemistry of the formation of native copper. The chemists of the Calumet & Hecla Co. contributed analyses and other chemical data, especially in the early stages of the investigation. Augustus Locke was in frequent consultation with the other workers, and short periods were spent on the work by J. Volney Lewis, William Burns, and G. N. Bjorge. W. O. Hotchkiss and H. R. Aldrich, who have been working on the geology of the Keweenawan rocks for the Wisconsin Geological and Natural History Survey, visited the district and made interesting contributions to the discussion of the broader relations of the Keweenawan. Prof. A. C. Lane likewise gave the benefit of his long experience in the district.

On the completion of the Calumet & Hecla investigation in the spring of 1924, an arrangement had been made by the United States Geological Survey after consultation with the other companies of the district, by which the general geologic results of the Calumet & Hecla study were turned over to the Geological Survey, which extended the study throughout the productive part of the district. Mr. Butler, reappointed on the Geological Survey, and W. S. Burbank were assigned to this work, which was carried on till August, 1925. A large part of this field work was done in association with the geological department of the Calumet & Hecla Co.

During the last few years certain electrical methods of prospecting have been tried in the district with indifferent results, and in connection with this work Messrs. Broderick and Hohl started dip-needle surveys, which were successful in indicating the trend of different formations on the bedrock surface beneath the extensive covering of glacial drift. The results obtained were of such general interest that these gentlemen have kindly prepared a chapter on "geophysical methods applied to exploration and geologic mapping," which has been incorporated in this report.

Miss Marie J. Scholz compiled most of the statistical data for both the Calumet & Hecla Consolidated Copper Co. and the Geological Survey and did most of the clerical work on the report. The drafting of the surface map and considerable of the other drafting was done by Carlos V. Rawlings.

The general features of the geology and the occurrence of the copper and much of the detail for the north end of the district, as presented in this report, were mainly worked out during the Calumet & Hecla investigation by the men engaged in that work. The names of all these men appear in the title-page with the addition of W. S. Burbank. The report as it now stands was prepared by B. S. Butler and W. S. Burbank.

SCOPE OF REPORT

The difficulty and high cost of obtaining geologic data in this generally drift-covered district has made it desirable to collect and to put on record all such data that are available. Field observations have therefore been presented in the text and on the maps and sections in greater detail than has been customary in reports of this character. The attempt has been made also to show on the maps all known developments in the district, with the hope that this would promote the most effective planning of future developments.[1] The facts of the occurrence of copper have been set forth as they have been ascertained, and a general discussion of the origin of the ores is given. The attempt has been made to keep fact and speculation distinct, and it is hoped that the reader will draw his own conclusions from the facts rather than unqualifiedly accept those here presented. In the section on the application of geology to mining are described methods in the search for ore deposits that seem to give most promise of success. I

ACKNOWLEDGMENTS

It is hardly necessary to say that any geologic report on an old district is likely to be but one of a series each based on the data accumulated by many others in addition to the authors, up to the time that it was made. This report is no exception to the rule and contains much information derived from earlier reports. The last general account of the region, however, was written about 15 years ago, and the mining developments that have been carried on, at times very actively, during the period that has since elapsed have added greatly to the body of geologic fact that was then available.

The main sources of information, apart from the work of the authors, have been the reports of the Michigan Geological Survey, previous reports by the United States Geological Survey, and the data accumulated by the operating companies. The Michigan Geological Survey generously furnished all material in its possession. All the mining companies of the district gave that hearty cooperation which was essential to the success of the report and without the assurance of which the survey would not have been undertaken. The help given by the different companies has, of course, not been equal. Those who had much gave much; some had little and could give no more than they had. The Calumet & Hecla Consolidated Copper Co. made the outstanding contribution, starting the work, and paying for a large part of it; and without this cooperation the report by the Geological Survey would not have been undertaken. Whatever of usefulness comes to the district from this report should be largely credited to that company.

Acknowledgment to individuals who have published the results of their investigations is made under the heading "Previous investigations." Acknowledgment to individuals for the data coming from companies is not easy, because information on any one topic has usually been accumulated over a long period and has been gathered by several individuals. The authors trust that they will be pardoned, therefore, if they do not try to accredit each borrowed fact to its original author but merge their acknowledgments of indebtedness in one expression of most cordial thanks to the officials of the companies. Several engineers of the district, especially Mr. R. R. Seeber and Mr. Herman Fesing, have furnished data for companies with which they were formerly connected but which at the time of the investigation were not operating. Mr. A. H. Meuche contributed many data on the south end of the district collected both while he was a member of the Michigan Geological Survey and later. Chemists of the Calumet & Hecla Co. have helped both by their interest and by analyses. For analyses the authors are indebted to Messrs. W. F. Hillenbrand and H. C. Kenney.

In addition to the acknowledgments for contributions to the report, the authors wish to express appreciation for courtesies extended, especially by the Calumet & Hecla Co., to the Geological Survey and to them personally, which added much to the convenience and effectiveness of the work.

To Mr. F. C. Calkins, of the Geological Survey, the authors are indebted for a critical reading of the report, which resulted in many helpful suggestions.

[1]See note on p. 233.

PREVIOUS INVESTIGATIONS

Few other districts of the country have received such numerous and repeated examinations by geologists and engineers as have been made in the copper country of Michigan. Altogether a vast amount of information has been assembled regarding this district. Of that which has been published, most has been afforded by the State surveys of Michigan, Wisconsin, and Minnesota and by the United States Geological Survey. All known publications on the geology of the district are listed in the bibliography, but the contributions of several groups of workers are of so outstanding importance as to deserve special mention.

Douglass Houghton,[1a] in 1841, first brought the district effectively to the attention of mining men. His valuable work was terminated in its midst four years later by his death.

The next general report was made by Raphael Pumpelly and his associate, A. R. Marvine,[2] who laid the foundation for the systematic study of the stratigraphy of the district, studied the mineralogy of the deposits in detail, and set up a theory of the deposition of the ores that for 50 years has exerted a controlling influence on geologic thought regarding the district. The value of Pumpelly's pioneer work in mineralogy and rock alteration is too well recognized to need extended comment.

The work of R. D. Irving[3] and his associates gave a broad view of the copper-bearing rocks and their stratigraphic and structural relations and added much to the knowledge of the mineralogy and petrography of these formations.

[1a]Houghton, Douglass, Michigan State Geologist [Fourth] Ann. Rept.: Michigan H. R. Doc. 27, 1841.

[2]Michigan Geol. Survey, vol. 1, pt. 2, 1873.

[3]Irving, R. D., The copper-bearing rocks of Lake Superior: U. S. Geol. Survey Mon. 5, 1883.

L. L. Hubbard,[4] as State geologist, contributed especially to our knowledge of the felsite masses and the general structure in the north end of the district, and later, as an operator, he was successful in applying geology to the location of profitable lodes, notably in the Champion mine.

The final report by A. C. Lane,[5] as State geologist, brought together the results of years of study by himself and other members of the Michigan Geological Survey. This report is the great storehouse of fact concerning the stratigraphy of the district. In it is presented a theory of the origin of the copper deposits considerably modifying that set forth by Pumpelly. The value of this report is too well known to require comment.

Van Hise and Leith,[6] in their monograph on Lake Superior geology, made evident the setting of the copper district in the larger province. They definitely broke away from the Pumpelly theory of formation of the ores.

Many others have contributed to our knowledge of the district, as will appear in the following pages and as can be seen by consulting the bibliography. Some of them, notably Prof. A. E. Seaman, have made a far more extensive and intimate study of the district than the bibliography would indicate.

[4]Hubbard, L. L., Michigan Geol. Survey, vol. 6, 1898.

[5]Lane, A. C., The Keweenaw series of Michigan: Michigan Geol. and Biol. Survey Pub. 6, 2 vols., 1911.

[6]Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: U. S. Geol. Survey Mon. 52, 1911.

BIBLIOGRAPHY

[See also p. 233]

ACKERMANN, HERMANN W.

Die Kupferführenden Schichten am Lake Superior: Naturw. Gesell. Isis Dresden Sitzungsber. 1875, pp. 101-105, 1876.

AGASSIZ, ALEXANDER.

On the position of the sandstone of the southern slope of a portion of Keweenaw Point, Lake Superior: Boston Soc. Nat. Hist. Proc., vol. 11, pp. 244-246, 1867.

On underground temperatures at great depth: Am. Jour Sci., 3d ser., vol. 50, pp. 503-504, 1895.

AGASSIZ, GEORGE RUSSELL.

Alexander Agassiz, 1835-1910: Letters and publications of Alexander Agassiz, with a sketch of his life and work, Boston and New York, Houghton Mifflin Co., 1913.

AGASSIZ, LOUIS.

Lake Superior; its physical characters, vegetation, and animals, Boston, 428 pp., 1850.

On Marcou's "Geology of North America": Am. Jour. Sci., 2d ser., vol. 27, pp. 134-137, 1859.

ALDRICH, H. R.

Magnetic surveying on the copper-bearing rocks of Wisconsin: Econ. Geology, vol. 18, pp. 562-574, 1923.

ALLEN, ROLLAND CRATEN.

Progress of the geological survey of Michigan; geology and topography: Michigan Acad. Sci. Rept. 13, pp. 69-78, 1911.

(and Ruthven, A. G.) Progress of the geological and biological survey of Michigan: Michigan Acad. Sci. Rept. 14, pp. 33-36, 1912.

ALLEN, ROLLAND CRATEN—Continued.

(and others) Mineral resources of Michigan, with statistical tables of production and value of mineral products for 1910 and prior years: Michigan Geol. Survey Pub. 8 (Geol. ser. 6), 465 pp., 1912.

Biennial report of the director: Michigan Geol. Survey Pub. 17 (Geol. ser. 14), 104 pp., map, 1914.

(and Barrett, L. P.) A revision of the sequence and structure of the pre-Keweenawan formations of the eastern Gogebic iron range of Michigan: Michigan Geol. Survey Pub. 18 (Geol. ser. 15), pp. 33-61, map, 1915; [in part], Jour. Geology, vol. 23, pp. 689-703, map, 1915.

(and Barrett, L. P.) Contributions to the pre-Cambrian geology of northern Michigan and Wisconsin: Michigan Geol. Survey Pub. 18 (Geol. ser. 15), pp. 13-164, maps, 1915.

(and Smith, R. A., and Barrett, L. P.) Geological map of Michigan, scale 1:750,000: Michigan Geol. Survey Pub. 23, 1916.

Mineral resources of Michigan, with statistical tables of production and value of mineral products for 1912 and prior years: Michigan Geol. Survey Pub. 13 (Geol. ser. 10), 255 pp., 1913. Idem for 1913, Pub. 16 (Geol. ser. 13), 150 pp., 1914; for 1914, Pub. 19 (Geol. ser. 16), 359 pp., 1915; for 1915, Pub. 21 (Geol. ser. 17), 402 pp., map, 1916; for 1916, Pub. 24 (Geol. ser. 20), 291 pp., 1917; for 1917, Pub. 27 (Geol. ser. 22), 225 pp., map, 1918; for 1918, Pub. 29 (Geol. ser. 24), 214 pp., 4 figs., 1920.

ANONYMOUS.

The silver of the Lake Superior mineral region: Min. Mag., vol. 1, pp. 447-454, 1853.

BARNES, GEORGE ORVILLE.

Field notes on the Ontonagon district [Lake Superior region]: 31st Cong., 1st sess., S. Ex. Doc. 1, pt. 3, and H. Ex. Doc. 5, pt. 3, pp. 627-636, 1849.

BARRETT, L. P. (See Allen, R. C, and Smith, R. A.)

BAUERMANN, HILARY.

Remarks on the copper mines of the State of Michigan: Geol. Soc. London Quart. Jour., vol. 22, pp. 448-463, 1866; abstract, Geol. Mag., vol. 3, pp. 225-226, 1866.

BAYFIELD, H. W.

Outlines of the geology of Lake Superior: Quebec Lit. and Hist. Soc. Trans., vol. 1, pp. 1 43, 1829.

BAYLEY, WILLIAM SHIRLEY.

Basic massive rocks: Jour. Geology, vol. 1, pp. 433-456, 587-596, 1893.

The Sturgeon River tongue [Michigan]: U. S. Geol. Survey Mon. 36, pp. 458-487, 1899; Nineteenth Ann. Rept., pt. 3, pp. 146-151, 1899.

BELL, ROBERT.

Geology of Lakes Superior and Nipigon: Canada Geol. Survey Rept. Progress for 1866-1869, pp. 313-364, 1870.

Report on the country north of Lake Superior, between the Nipigon and Michipicoten Rivers: Canada Geol. Survey Rept. Progress for 1870-1871, pp. 322-351, 1872.

Report on the country between Lake Superior and Lake Winnipeg: Canada Geol. Survey Rept. Progress for 1872-1873, pp. 87-111, 1873.

The mineral region of Lake Superior: Canadian Naturalist and Geologist, 2d ser., vol. 7, pp. 49-51, 1875.

Report on an exploration in 1875, between James Bay and Lakes Superior and Huron: Canada Geol. Survey Rept. Progress for 1875-1876, pp. 294-342, 1877.

Report on geological researches north of Lake Huron and east of Lake Superior: Canada Geol. Survey Rept, Progress for 1876-1877, pp. 193-220, 1878.

BENEDICT, C. H.

(and Kenny, H. C.) Ammonia leaching of Calumet & Hecla tailings: Am. Inst. Min. Eng. Trans., vol. 70, pp. 595-610, 1924.|

Calumet & Hecla reclamation plant: Lake Superior Min. Inst. Bull., 1925.

BERKEY, CHARLES PETER.

The occurrence of datolite on the north shore of Lake Superior [abstract]: Minnesota Acad. Nat. Sci. Bull., vol. 4, pp. 42-43, 1896.

The occurrence of copper minerals in hematite ore, Montana mine, Soudan, Minn.: Lake Superior Min. Inst. Proc, vol. 4, pp. 73-79, 1896; Minnesota Univ. Eng. Year Book, vol. 5, pp. 110-117, 1897.

On the occurrence of native copper and other copper minerals in the hematite ore of the Montana mine, Soudan, Minn, [abstract]: Science, new ser., vol. 6, pp. 363-364, 1897.

BIGSBY, JOHN JEREMIAH.

Notes on the geography and geology of Lake Superior: Quart. Jour. Sci., vol. 18, pp. 1-34, 228-269, 1824-25; abstract, Bull. sci. nat., Paris, vol. 7, pp. 8-13, 1826.

On the physical geography, geology, and commercial resources of Lake Superior: Edinburgh New Philos. Jour., vol. 53, pp. 55-62, 1852.

BLAKE, WILLIAM P.

Review of a portion of the geological map of the United States and British provinces, by Jules Marcou: Am. Jour. Sci., 2d ser., vol. 22, pp. 383-388, 1856.

BLANDY, JOHN F.

Topography with especial reference to the Lake Superior copper district: Am. Inst. Min. Eng. Trans., vol. 1, pp. 75-82, 1873.

The origin of the native copper in the Michigan deposits: Eng. and Min. Jour., vol. 70, pp. 278-279, 1900.

(See also Williams, C. P.)

BOOTH, JOHN C.

(and Hulburt, E. J.) Geological and topographical map of the mineral district of Lake Superior, Mich., New York, 1855.

BORIE, JULES.

Notice sur le lac Supérieur et ses mines de cuivre de la rive américaine: Soc. ind. min. Bull., vol. 6, pp. 233-284, 1860; vol. 7, pp. 185-251, 1861; vol. 8, pp. 270-271, 1862; Allgem. Berg- u. hüttenm. Zeitung, vol. 4, pp. 448-450, 457-460, 469-471, 1862.

BRADISH, ALVA.

Memoir of Douglass Houghton, first State geologist of Michigan; with an appendix containing reports or abstracts of the first geological survey, and a chronological statement of the progress of geological exploration in Michigan, 302 pp., Detroit, 1889.

BRAUNS, R.

Native copper in basalt: Zeitschr. Kryst. Min., 1911, p. 493; Centralbl. Mineralogie, 1908, pp. 705-709.

BRINSMADE, ROBERT BRUCE.

The Michigan copper mines and methods: Min. World, vol. 32, pp. 549-552, 1910.

BRISTOL, T. W. (See Houghton, Jacob, jr.)

BRODERICK, THOMAS MONTEITH.

The relation of the titaniferous magnetites of northeastern Minnesota to the Duluth gabbro: Econ. Geology, vol. 12, pp. 663-696, 1917.

BROOKS, THOMAS BENTON.

On the youngest Huronian rocks south of Lake Superior, and the age of the copper-bearing series: Am. Jour. Sci., 3d ser., vol. 11, pp. 206-211, 1876.

Classified list of the rocks observed in the Huronian series south of Lake Superior: Am. Jour. Sci., 3d ser., vol. 12, pp. 194-204, 1876.

BROOKS, THOMAS BENTON—Continued.

(and Pumpelly, R.) On the age of the copper-bearing rocks of Lake Superior: Am. Jour. Sci., 3d ser., vol. 3, pp. 428-432, 1872.

(and Julien, A. A.) Lithology [of the Upper Peninsula]: Michigan Geol. Survey, vol. 2, pp. 199-212, 1873.

BROUGHTON, SAMUEL H.

Remarks on the mining interest and details of the geology of Ontonagon County [Mich.], 24 pp., map, Philadelphia, 1863.

BURT, WILLIAM A.

Topography and geology of the survey of a district of township lines, south of Lake Superior, 1845: 29th Cong., 1st sess., S. Ex. Doc. 357, pp. 2-19, 1846.

Geological report of survey [in Lake Superior region]: 31st Cong., 1st sess., S. Ex. Doc. 1, pt. 3, and H. Ex. Doc. 5, pt. 3, pp. 811-832, 842-875, 933-935, maps, 1849.

CALLENDER, JOHN A.

The Lake Superior copper mines: Min. Mag., vol. 2, pp. 249-253, 1854.

CAMPBELL, J. B.

[Lake Superior region]: 28th Cong., spec, sess., S. Ex. Doc. 175, pp. 4-8, 1845.

CASE, ERMINE COWLES.

(and Robinson, W. I.) The geology of Limestone Mountain and Sherman Hill, in Houghton County, Mich.: Michigan Geol. Survey Pub. 18 (Geol. ser. 15), pp. 165-181, 1915: Jour. Geology, vol. 23, pp. 256-260, 1915.

CHAMBERLIN, THOMAS CHROWDER.

The copper-bearing series of Lake Superior: Science, vol. 1, pp. 453-455, 1883.

(and Strong, Moses) Geology of the upper St. Croix district: Geology of Wisconsin, vol. 3, pp. 363-428, 1880.

(See also Irving, Roland Duer.)

CLARKE, ROBERT E.

Notes from the copper region [Lake Superior]: Harpers Mag., vol. 6, pp. 433-448, 577-588, 1853.

CLEMENTS, JULIUS MORGAN.

A contribution to the study of contact metamorphism: Am. Jour. Sci., 4th ser., vol. 7, pp. 81-91, 1899.

CORDIER, LOUIS.

Note sur une masse de cuivre natif provenant des rives du lac Supérieur aux États-Unis d'Amérique: Compt. Rend., vol. 28, pp. 161-162, 1849.

COREY, G. W.

The Nonesuch sandstone [Porcupine district, Mich.]: Eng. and Min. Jour., vol. 82, p. 778, 1906.

CREDNER, HERMANN.

Die Gliederung der eozoischen (vorsilurischen) Formationsgruppe Nord Amerikas: Zeitschr. ges. Naturwiss., Band 32, pp. 353-405, 1868.

Die vorsilurischen Gebilde der "Obern Halbinsel von Michigan" in Nord Amerika: Deutsch. geol. Gesell. Zeitschr., Band 21, pp. 516-554, 1869.

Beschreibung einiger charakteristischer Vorkommen des gediegenen Kupfers auf Keweenaw Point am Oberen See Nord-Amerika's: Neues Jahrb., 1869, pp. 1-14.

Gewaltige Kupfermassen am Lake Superior: Neues Jahrb., 1870, p. 86.

Ueber Nordamerikanische Schief erporphyroide: Jahrb Mineralogie, 1870, pp. 970-984.

Elemente der Geologie, 4th ed., 726 pp., 1878.

CROOKS, H. F. (See Savage, T. E.)

DAWSON, JOHN W.

On the geological structure and mineral deposits of the promontory of Mamainse, Lake Superior: Canadian Naturalist, vol. 2, pp. 1-12, 1857.

DEROUX, H.

Die Kupfergruben des Oberen See's Lake Superior: Berghüttenm, Zeitung, vol. 20, pp, 305-307, 329-381, 1861.

DESOR, ÉDOUARD.

[On the clay and drift deposits in the vicinity of Lake Superior]: Boston Soc. Nat. Hist. Proc, vol. 3, pp. 235-236, 1850.

[On the sand dunes of Lake Superior]: Boston Soc. Nat. Hist. Proc, vol. 3, p. 207, 1850; vol. 4, pp. 41-42, 1851.

[On the origin of some of the elements of the so-called Tertiary or drift of Lake Superior]: Boston Soc. Nat. Hist. Proc, vol. 4, pp. 28-29, 1851.

On the Silurian rocks of the Lake Superior land district: Am. Assoc. Adv. Sci. Proc. 5th meeting, pp. 64, 65, 1851.

On the superficial deposits of this district, in Foster, J. W., and Whitney, J. D., Report on the geology of the Lake Superior land district, pt. 2: 32d Cong., spec, sess., S. Ex. Doc 41, pp. 232-270, 1851; in part, Am. Jour. Sci., 2d ser., vol. 13, pp. 93-109, 1852.

DICKENSON, GEORGE J.

[Report on Isle Royale]: 31st Cong., 1st sess., S. Ex. Doc 1, pt. 3, and H. Ex. Doc. 5, pt. 3, pp. 503-506, 1849.

DIEFFENBACH, OTTO.

Bemerkungen über den Kupferbergbau in den Vereinigten Staaten von Nordamerika: Berg- u. hüttenm. Zeitung, Band 17, pp. 47-48, 66-68, 75-76, 1858.

DOUGLASS, JAMES.

The native copper mines of Lake Superior: Quart. Jour. Sci., vol. 11, pp. 162-180, 1874; Canadian Naturalist, new ser., vol. 7, pp. 318-336, 1874.

The copper resources of the United States: Sci. Am. Suppl. vol. 34, pp. 14183-14186, 1893.

DUPARC, LOUIS.

Note sur la région cuprifère de l'extrémité nord-est de la péninsule de Keweenaw (Lac Supérieur): Arch. sci. phys. nat., 4th ser., vol. 10, pp. 518-538, 1900.

DUPEE, J. A.

[On copper deposits of Keweenaw Point, Lake Superior]: Boston Soc. Nat. Hist. Proc., vol. 5, pp. 279-280, 1856.

DUTTON, T. R.

Observations on the basaltic formation on the northern shore of Lake Superior: Am. Jour. Sci., 2d ser., vol. 4, pp. 118-119, 1847.

EAMES, HENRY H.

Geological reconnaissance of the northern, middle, and other counties of Minnesota, 58 pp., St. Paul, 1866.

Report of the State geologist on the metalliferous region bordering on Lake Superior, 21 pp.; 2d ed., 23 pp., St. Paul, 1866.

EGLESTON, THOMAS.

Copper mining on Lake Superior: Am. Inst. Min. Eng. Trans., vol. 6, pp. 275-312, 1879.

[The conglomerates of the Lake Superior copper region]: Am. Inst. Min. Eng. Trans., vol. 6, pp. 606-611, 1879.

EIGHTS, JAMES.

Outlines of the geological structure of Lake Superior mineral region: New York and Lake Superior Mining Co. First Ann. Rept., appendix, 21 pp., Albany, 1846.

ELFTMAN, ARTHUR HUGO.

The geology of the Keweenawan area in northeastern Minnesota: Am. Geologist, vol. 21, pp. 90-109, map, 175-188; vol. 22, pp. 131-149, map, 1898.

ÉLIE DE BEAUMONT, LÉONCE.

[On the age of the Lake Superior sandstone]: Soc. Geol. France Bull., 2d ser., vol. 7, p. 209, 1850.

EMMONS, EBENEZER.

(Copper mines of Lake Superior), American geology, vol. 1, pt. 1, pp. 171-173, 1855.

FINLAY, J. R.

Appraisal of mining properties of Michigan by the State Board of Tax Commissioners, 1911,

FOSHAG, WILLIAM F.

(and Larsen, E. S.) Eakleite from Isle Royale, Mich.: Am, Mineralogist, 7th ser., vol. 2, pp. 23-24, 1922.

FOSTER, JOHN WELLS.

[Report of field work in the Lake Superior land district]: 30th Cong., 2d sess., S. Ex. Doc 2, pp. 159-163, 1849.

(and Whitney, J. D.) Synopsis of the explorations . . . in the Lake Superior land district in the northern peninsula of Michigan; 31st Cong., 1st sess., S. Ex. Doc 1, pt. 3, and H. Ex. Doc. 5, pt. 3, pp. 605-626, maps, 1849.

[Field notes of work in Lake Superior region]: Idem, pp. 766-801.

(and Hill, S. W.) Statistics of the mines of Keweenaw Point: Idem, pp. 759-765.

(and Whitney, J. D.) Mineral reports [Lake Superior land district]: 31st Cong., 2d sess., H. Ex. Doc 9 (Gen. Land Office Rept., 1850), pp. 147-152, 1850.

(and Whitney, J. D.) Report on the geology and topography of a portion of the Lake Superior land district in the State of Michigan, pt. 1, Copper lands: 31st Cong., 1st sess., H. Ex. Doc 69, 224 pp., maps, 1850.

(and Whitney, J. D.) On the age of the sandstone of Lake Superior, with a description of the phenomena of the association of igneous rocks: Am. Assoc Adv. Sci. Proc, vol. 5, pp. 22-38, 1851.

(and Whitney, J. D.) Sur les terrains siluriens du district métallifère du lac Supérieur: Soc Géol. France Bull., 2d ser., vol. 8, pp. 89-100, 1851.

Catalog of rocks, minerals, etc, collected by J. W. Foster: Smithsonian Rept., 1854, pp. 384-387.

(and Whitney, J. D.) On the origin and stratigraphical relations of the trappean rocks of Lake Superior (abstract): Ann. Sci. Discovery for 1861, p. 285, 1861.

GAY & STURGIS (publishers).

Copper, a weekly review of the Lake Superior mines (A. L. Carnahan, editor), vols. 1, 2, and 3, Apr. 4, 1908, to Nov. 19, 1910.

GORDON, W. C.

The Black River section near Bessemer [Mich.]: Michigan Acad. Sci. Rept. 7, pp. 188-195, 1905.

(assisted by Lane, A. C.) A geological section from Bessemer down Black River: Michigan Geol. Survey Rept. for 1906, pp. 397-507, map, 1907.

GRANT, U. S.

Note on the Keweenawan rocks of Grand Portage Island, north coast of Lake Superior: Am. Geologist, vol. 13, pp. 437-439, 1894; abstract, Minnesota Univ. Quart. Bull., vol. 2, p. 92, 1894.

Preliminary report on the copper-bearing rocks of Douglas County, Wis.: Wisconsin Geol. Survey Bull. 6 (Econ. ser. 33), 525 pp. maps, Madison, Wis., 1900.

Junction of Lake Superior sandstone and Keweenawan traps in Wisconsin (abstract): Geol. Soc. America Bull., vol. 13, pp. 6-9, 1901.

Gray, A. B.

Mineral lands of Lake Superior region: 28th Cong., spec. sess., S. Ex. Doc. 175, pp. 14-22, 1845.

Report on mineral lands on Lake Superior: 29th Cong., 1st sess., H. Doc 211, 23 pp., map, 1846.

Grout, Frank Fitch.

Keweenawan copper deposits: Econ. Geology, vol. 5, pp. 471-476, 1910.

(and Soper, E. K.) Geology of Minnesota: U. S. Geol. Survey Bull. 678, pp. 70-105, 2 pls. (incl. map), 3 figs., 1919.

Contribution to the petrography of the Keweenawan: Jour. Geology, vol. 18, pp. 633-657, map, 1910.

The pegmatites of the Duluth gabbro: Econ. Geology, vol. 13, pp. 185-197, 1918.

Grout, Frank Fitch—Continued.

The lopolith, an igneous form exemplified by the Duluth gabbro: Am. Jour. Sci., 4th ser., vol. 46, pp. 516-522, 1918.

Internal structures of igneous rocks; their significance and origin; with special reference to the Duluth gabbro: Jour. Geology, vol. 26, pp. 439-458, 1918; abstract, with discussions by W. J. Miller and M. E. Wilson: Geol. Soc. America Bull., vol. 29, pp. 100 101, 1918.

Guck, Homer.

Geology of the Michigan copper district: Eng. and Min. Jour., vol. 108, pp. 948-949, 1919.

Hall, Christopher Webber.

Field report: Minnesota Geol. Survey Seventh Ann. Rept., pp. 26-29, 1878.

Report of Professor C. W. Hall, Minnesota Geol. Survey Eighth Ann. Rept., pp. 126-138, 1879.

A brief history of copper mining in Minnesota: Minnesota Acad. Nat. Sci. Bull., vol. 3, pp. 105-111, 1889; abstract,

Minnesota Univ. Quart. Bull., vol. 1, p. 91, 1893.

Keweenawan area of eastern Minnesota: Geol. Soc. America Bull., vol. 12, pp. 313-342, map, 1901.

Hall, James.

On the Silurian system of the Lake Superior region: Am. Jour. Sci., 2d ser., vol. 17, pp. 181-194, 1854.

Hayes, Augustus Allen.

On the occurrence of massive datolite in the mines of Lake Superior: Boston Soc. Nat. Hist. Proc, vol. 8, pp. 62-64, 1861.

Henwood, William Jory.

On the native copper of Lake Superior: Royal Geol. Soc. Cornwall Trans., vol. 8, pp. 385-489, 1871.

Hill, Samuel W. (See Foster, John Wells.)

Hodge, James Thacher.

On the mineral region of Lake Superior: Am. Assoc. Adv. Sci. Proc., vol. 2, pp. 301-308, 1850.

Hopper, Walter E.

Michigan copper industry in 1915: Michigan Geol. Survey Pub. 21, (Geol. ser. 17), pp. 11-56, 1916.

Hore, Reginald Edwin.

In the Michigan copper country: Canadian Min. Jour., vol. 30, pp. 421-422, 1909.

The copper-mining industry of Michigan: Min. World, vol. 36, pp. 601-603, 656-658, 707-710, 763 767, 1912.

The copper industry of Michigan: Michigan Geol. Survey Pub. 8 (Geol. ser. 6), pp. 15-115, 1912.

The Michigan copper industry in 1913: Michigan Geol. Survey Pub. 16 (Geol. ser. 13), pp. 11-37, 1914.

Michigan copper deposits: Michigan Geol. Survey Pub. 19, pp. 19-161, 1915.

Hotchkiss, William Otis.

Mining and mineral resources of Wisconsin: Am. Min. Cong. 9th Ann. Sess. Rept. Proc, pp. 220-225, 1907.

Report of the Director of the Survey: Wisconsin Geol. and Nat. Hist. Survey Twelfth Bienn. Rept., 37 pp., 2 figs., 1920.

The Lake Superior geosyncline: Geol. Soc. America Bull., vol. 34, pp. 669-678, 1923.

(See also Thwaites, F. T.)

Houghton, Douglass.

Report of the State geologist: Michigan H. Doc. 14, S. Doc. 16, 37 pp., 1838.

Second annual report of the State geologist of the State of Michigan, 39, 123 pp., Detroit, 1839.

Third annual report of the State geologist of the State of Michigan: Michigan H. Doc. 8, 124 pp., map, 1840.

Fifth annual report of the State geologist: Michigan H. Doc. 2, sess. 1842, pp. 436-441, 1842.

Houghton, Douglass—Continued.

Metalliferous veins of the northern peninsula of Michigan: Am. Jour. Sci., vol. 41, pp. 183-186, 1841; Assoc. Am. Geologists Rept., 1843, pp. 35-38.

Sixth annual report of the State geologist: Michigan Legisl. Doc. 8, sess. 1843, pp. 398-402, 1843.

Seventh annual report of the State geologist: Michigan Legisl. 1844, Joint Doc. 11, 3 pp., 1844.

Copper on Lake Superior: Am. Jour. Sci., vol. 47, pp. 107, 132, 1844.

Fourth annual report of the State geologist: Michigan H. Doc. 27, 184 pp., 1841. In part, with title General geology of the Upper Peninsula: 29th Cong., 2d sess., H. Rept. 591, pp. 6-38, map, 1846.

Report on the copper of Lake Superior, in Schoolcraft, H. R., Narrative of an expedition through the upper Mississippi to Itasca Lake, pp. 287-292, New York, 1834; also in Schoolcraft, H. R., Summary narrative, pp. 526-531, Philadelphia, 1855.

Lithology [of the Upper Peninsula]: Michigan Geol. Survey, vol. 2, pp. 239-246, 1873.

HOUGHTON, JACOB, JR.

(and Bristol, T. W.) Reports of Wm. A. Burt and Bela Hubbard on the geography, topography, and geology . . . of the south shore of Lake Superior, 109 pp., map, Detroit, 1846.

The ancient copper mines of Lake Superior: Wisconsin Hist. Soc. Coll., vol. 8, pp. 140-151, 1879.

HOVEY, EDMUND OTIS.

An analcite copper boulder from the Keweenaw Range, Michigan: Science, vol. 22, p. 93, 1893.

HUBBARD, BELA.

General observations upon the geology and topography of the district south of Lake Superior: 29th Cong., 1st sess., S. Ex. Doc. 357, pp. 20-29, 1846.

Geological report [of field work in Lake Superior land district]: 31st Cong., 1st sess., S. Ex. Doc. 1, pt. 3, and H. Ex. Doc. 5, pt. 3, pp. 833-842, 882-932, 1849.

HUBBARD, LUCIUS LEE.

Macroscopic minerals of Michigan: Michigan Geol. Survey Rept. for 1891-92, pp. 174-176, 1893.

Two new geological cross sections of Keweenaw Point: Lake Superior Min. Inst. Proc, vol. 2, pp. 79-96, 1894.

The relation of the vein at the Central mine, Keweenaw Point, to the Kearsarge conglomerate: Lake Superior Min. Inst. Proc, vol. 3, pp. 74-83, 1895.

Keweenaw Point with particular reference to the felsites and their associated rocks: Michigan Geol. Survey, vol. 6, pt. 2, 155 pp., maps, 1898.

Sixth annual report of the State geologist, 9 pp., Lansing, 1899.

Work of the Geological Survey in the Upper Peninsula: Michigan Miner, vol. 3, No. 3, p. 9, 1901.

Geological notes on the Lake Superior copper formation: Lake Superior Min. Inst. Proc, vol. 17, pp. 9-11, 1912.

In the Lake Superior area what influence, if any, did the thickness and contour of footwall beds have upon the subsequent deposition and distribution of copper in overlying beds? [with discussion]: Lake Superior Min. Inst. Proc, vol. 17, pp. 227-237, 1912.

(See also Koenig, G. A.)

HULBERT, E. J. (See Booth, John C.)

HUNT, T. STERRY.

On some points in American geology: Am. Jour. Sci., 2d ser., vol. 31, pp. 392-414, 1861.

The geognostical history of the metals: Am. Inst. Min. Eng. Trans., vol. 1, pp. 313-334, 1873.

The origin of metalliferous deposits: Idem, pp. 413-426.

HUNT, T. STERRY—Continued.

The geology of the north shore of Lake Superior (supplementary note): Am. Inst. Min. Eng. Trans., vol. 2, pp. 58-59, 1873.

Azoic rocks, part 1: Second Pennsylvania Geol. Survey Rept. E, 253 pp., 1878.

The history of some pre-Cambrian rocks in America and Europe: Am. Jour. Sci., 3d ser., vol. 19, pp. 268-283, 1880.

IRVING, ROLAND DUER.

On the age of the copper-bearing rocks of Lake Superior and on the westward continuation of the Lake Superior synclinal: Am. Jour. Sci., 3d ser., vol. 8, pp. 46-56, map, 1874.

On some points in the geology of northern Wisconsin: Wisconsin Acad. Sci. Trans., vol. 2, pp. 107-119, 1874.

Note on the age of the crystalline rocks of Wisconsin: Am. Jour. Sci., 3d ser., vol. 13, pp. 307-309, 1877.

Note on the stratigraphy of the Huronian series of northern Wisconsin and on the equivalency of the Huronian of the Marquette and Penokee districts: Am. Jour. Sci., 3d ser., vol. 17, pp. 393-398, 1879.

Geological structure of northern Wisconsin, with maps: Wisconsin Geol. Survey, vol. 3, pt. 1, pp. 1-25, 1880.

Geology of the eastern Lake Superior district, with atlas: Wisconsin Geol. Survey, vol. 3, pt. 3, pp. 51-238, 1880.

The copper-bearing rocks of Lake Superior: U. S. Geol. Survey Mon. 5, xvi, 464 pp., maps, 1883; Third Ann. Rept., pp. 89-188, map, 1883.

The copper-bearing rocks of Lake Superior: Science, vol. 1, pp. 140-141, 359-360, 422, 1883.

The copper-bearing rocks of Lake Superior: Am. Jour. Sci., 3d ser., vol. 29, pp. 258-259, 1885.

(and Chamberlin, T. C.) Observations on the junction between the Eastern sandstone and the Keweenaw series on Keweenaw Point, Lake Superior: U. S. Geol. Survey Bull. 23, 124 pp., 1885; review, Am. Geologist, vol. 1, pp. 44-57, 1888.

On the classification of the early Cambrian and pre-Cambrian formations: U. S. Geol. Survey Seventh Ann. Rept., pp. 365-454, 1888.

JACKSON, CHARLES THOMAS.

[On minerals from Keweenaw Point, Lake Superior]: Boston Soc. Nat. Hist. Proc, vol. 1, p. 203, 1845.

[On copper ores of the Lake Superior region]: Boston Soc. Nat. Hist. Proc, vol. 2, pp. 57-58, 1845.

On the copper and silver of Keweenaw Point, Lake Superior [with discussion by C. U. Shepard]: Am. Jour. Sci., vol. 49, pp. 81-93, 1845; Assoc. Am. Geologists Proc, vol. 6, pp. 53-61, 1845.

Sur le gisement de cuivre et d'argent natifs des bords du lac Supérieur: Compt. Rend., vol. 20, pp. 593-595, 1845; Soc. géol. France Bull., 2d ser., vol. 2, pp. 317-319, 1845; abstract, Neues Jahrb., 1845, pp. 479-480.

[On the copper and silver ores of the Lake Superior region]: Boston Soc Nat. Hist. Proc, vol. 2, pp. 110-114, 1846.

Chemical analyses of the [copper] ores [of the Lake Superior region]: 29th Cong., 1st sess., H. Rept. 591, pp. 38-44, 1846.

Ores and minerals from Lake Superior: Boston Soc. Nat. Hist. Proc, vol. 2, pp. 256, 259, 260, 1847.

Mineral lands of Lake Superior: 30th Cong., 2d sess., S. Ex. Doc. 2, No. 2, pp. 153-163, 1847.

[Report on the survey of the mineral lands in Michigan]: Idem, pp. 175-230.

Report on the progress of the geological survey of the mineral lands of the United States in Michigan: Idem, pp. 185-191.

JACKSON, CHARLES THOMAS—Continued.

[Notes on the Lake Superior region]: Boston Soc. Nat. Hist. Proc, vol. 3, pp. 76-77, 228, 1848.

Report on the geological and mineralogical survey of the mineral lands of the United States in the State of Michigan: 31st Cong., 1st sess., S. Ex. Doc. 1, pt. 3, and H. Ex. Doc 5, pt. 3, pp. 371-502, maps, 1849.

Copper of the Lake Superior region: Am. Jour. Sci., 2d ser., vol. 7, pp. 286-287, 1849.

On the geological structure of Keweenaw Point: Am. Assoc. Adv. Sci. Proc, vol. 2, pp. 288-301, 1850; Am. Jour. Sci., 2d ser., vol. 10, pp. 65-77, 1849; Annales des mines, 4th ser., vol. 17, pp. 103-115, 1850.

Remarks on the geology, mineralogy, and mines of Lake Superior: Am. Assoc. Adv. Sci. Proc, vol. 2, pp. 283 287, 1850; Soc. géol. France Bull., 2d ser., vol. 7, pp. 667-673, 1850.

Analyses of pitchstone porphyry from Isle Royale and of a crystal of phosphate of lime from Hurdstown, N. J.: Boston Soc Nat. Hist. Proc, vol. 4, pp. 39-41, 1851; Am. Jour. Sci., 2d ser., vol. 11, pp. 401-403, 1851.

On the age of the sandstones of the United States: Boston Soc. Nat. Hist. Proc, vol. 3, pp. 335-339, 1850.

Rain-drop and air-bubble impressions: Boston Soc. Nat. Hist. Proc, vol. 4, pp. 131-132, 1853.

Igneous origin of calcite veins: Idem, pp. 308-309.

Geology, mineralogy, and topography of the lands around Lake Superior: 32d Cong., 1st sess., S. Ex. Doc. 112, pp. 232-244, 1853.

Ueber den Metall-führenden Distrikt am Oberen See im Staate Michigan: Archiv Mineralogie, vol. 25, pp. 656-667, 1853.

Observations sur quelques mines des États-Unis et sur le grès rouge du lac Supérieur: Compt. Rend., vol. 39, pp. 803-807, 1854.

Catalog of rocks, minerals, and ores collected during the years 1847 and 1848 on the geological survey of the United States mineral lands in Michigan: Smithsonian Inst. Ann. Rept., vol. 9, pp. 338-367, 1855.

[Trap dikes]: Boston Soc. Nat. Hist. Proc. vol. 6, pp. 23-24, 1856.

[On the Ashbed and the origin of the copper]: Boston Soc. Nat. Hist. Proc, vol. 5, pp. 280-281, 1856; vol. 7, p. 31, 1859.

Age of the Lake Superior sandstone: Boston Soc. Nat. Hist. Proc, vol. 7, pp. 396-398, 1860.

On domeykite from the vicinity of Portage Lake, Lake Superior: Boston Soc. Nat. Hist. Proc, vol. 8, p. 258, 1862.

Sur les mines de cuivre du lac Supérieur et sur un nouveau gisement d'étain dans l'État du Maine: Compt. Rend., vol. 69, pp. 1082-1083, 1869.

JACKSON, J. F.

Copper mining in Upper Michigan, a description of the region, mines, and some of the methods and machinery used: Mines and Minerals, vol. 23, pp. 535-540, 1903.

JOY, CHARLES A.

Examination of a few American minerals: New York Lyc. Nat. Hist. Annals, vol. 8, pp. 120-125, 1865.

JULIEN, ALEXIS ANASTAY.

Lithology: Michigan Geol. Survey, Upper Peninsula, vol. 2, pp. 1-197, 1873.

Microscopical examination of eleven rocks from Ashland County, Wis.: Wisconsin Geol. Survey, vol. 3, pp. 224-238, 1880.

Notes on a feldspar from the Calumet copper mine, Keweenaw Point, Mich, [abstract]: Science, new ser., vol. 9, p. 719, 1899; New York Acad. Sci. Annals, vol. 12, pp. 650-654, 1900.

(See also Brooks, Thomas Benton.)

KELLER, H. F.

(and Lane, A. C.) Chloritoid von Champion, Mich., U. S. A.: Zeitschr. Kryst. Min., vol. 19, pp. 383-385, 1891.

(See also Lane, A. C.)

KLOOS, J. H. (See Streng, A.)

KENNY, H. C. (See Benedict, C. H.)

KOCH, FRIEDRICH KARL LUDWIG.

Die Mineralgegenden der Vereinigten Staaten Nord-Amerikas am Lake Superior, 72 pp., Göttingen, 1851.

Kupfer- und Eisenerze am Lake Superior: Deutsch. geol. Gesell. Zeitschr., vol. 3, pp. 355-358, 1851.

Die Mineral-Regionen der obern Halbinsel Michigan's (N. A.) am Lake Superior und die Isle Royale, 248 pp., map, Göttingen, 1852; Göttingischer Ver. bergmännischer Freunde (J. F. L. Hausmann) Studien, vol. 6, pp. 1-248, map, 1854; abstract, Min. Mag., vol. 1, pp. 261-268, 1853.

KOENIG, GEORGE AUGUSTUS.

(and Hubbard, L. L.) On powellite from a new locality [Houghton County, Mich.]: Am. Jour. Sci., 3d ser., vol. 46, pp. 356-358, 1893; Zeitschr. Kryst. Min., vol. 22, pp. 463-466, 1894.

Ueber Mohawkit, Stibiodomeykit, Domeykit, Algodonit und einige künstliche Kupferarsenide: Zeitschr. Kryst. Min., vol. 34, pp. 67-77, 1901; Am. Jour. Sci., 4th ser., vol. 10, pp. 439-448, 1900 (translation?).

On the new species melanochalcite and keweenawite, with notes on some other known species: Am. Jour. Sci., 4th ser., vol. 14, pp. 404-416, 1902.

On artificial production of crystallized domeykite, algodonite, argentodomeykite, and stibiodomeykite: Am. Philos. Soc. Proc., vol. 42, pp. 219-237, 1903.

KRAUS, EDWARD HENRY.

Occurrence and distribution of celestite-bearing rocks: Am. Jour. Sci., 4th ser., vol. 19, pp. 286-293, 1905; abstract, Am. Geologist, vol. 35, p. 130, 1905; Geol. Soc. America Bull., vol. 16, p. 574, 1906; Sci. Am. Suppl., vol. 59, p. 24326, 1905.

LANE, ALFRED CHURCH.

(and Keller, H. F., and Sharpless, F. F.) Notes on Michigan minerals: Am. Jour. Sci., 3d ser., vol. 42, pp. 499-508, 1891.

(and Keller, H. F.) Chloritoid von Champion, Mich., U. S. A.: Zeitschr. Kryst. Min., vol. 19, pp. 383-385, 1891.

Microscopic characters of rocks and minerals of Michigan: Michigan Geol. Survey Rept. for 1891-92, pp. 176-183, 1893.

The geology of Lower Michigan with reference to deep borings [edited from notes of C. E. Wright]: Michigan Geol. Survey, vol. 5, pt. 2, 100 pp., map, 1895.

Geological report on Isle Royale, Mich.: Michigan Geol. Survey, vol. 6, pt. 1, 281 pp., map, 1898.

Isle Royale; what has been accomplished in unearthing its mineral wealth: Michigan Miner, vol. 1, No. 11, pp. 18-21; No. 12, pp. 14-18, 1899.

The geothermal gradient in Michigan: Am. Jour. Sci., 4th ser., vol. 9, pp. 434-438, 1900.

The Geological Survey; annual report of the State geologist for the year ending Dec. 31, 1899: Michigan Miner, vol. 2, No. 3, pp. 9-13, 1900.

Suggestions from the State geologist: Michigan Miner, vol. 3, No. 10, p. 9, 1901.

Suggested changes in nomenclature of Michigan formations: Michigan Miner, vol. 3, No. 10, p. 9, 1901.

The economic geology of Michigan in its relations to the business world: Michigan Miner, vol. 4, No. 1, pp. 9-15, 1901.

LANE, ALFRED CHURCH—Continued.

Annual report of the State geologist [for 1900]: Michigan Miner, vol. 3, No. 2, pp. 13-21, 1901.

Third annual report of the State geologist ... for the year 1901: Michigan Geol. Survey Rept. for 1901, 304 pp., maps, 1902.

Recent work of the Geological Survey: Michigan Acad. Sci. Rept., vol. 3, pp. 38-39, 1902.

Geothermal gradient: Michigan Geol. Survey Rept., for 1901, pp. 244-251, 1902.

Economic geology [of Michigan]: Michigan Geol. Survey Rept. for 1901, pp. 121-137, 1902.

Variation of geothermal gradient in Michigan [abstract]: Science, new ser., vol. 15, p. 88, 1902; Geol. Soc. America Bull., vol. 13, pp. 528-529, 1903.

Annual report Geological Survey of Michigan [for 1902]: Michigan Miner, vol. 5, No. 2, pp. 16-26 (reprinted, 26 pp., map), 1903.

The economic geology of Michigan [abstract]: Science, new ser., vol. 17, p. 218, 1903; Eng. and Min. Jour., vol. 75, p. 152, 1903; Sci. Am. Suppl, vol. 55, p. 22666, 1903.

Fifth annual report of the State geologist, for the year 1903: Michigan Geol. Survey Rept. for 1903, 342 pp., maps, 1905; Sixth. . . for 1904: Idem for 1904; pp. 113-168, 1905; Seventh . . . for 1905: Idem for 1905, pp. 535-571, 1906; Eighth . . . for 1906: Idem for 1906, pp. 573-594, 1907; Ninth ... for 1907: Idem for 1907, pp. 3-31, 1908; Tenth . . . for 1908: Idem for 1908, pp. 1-19, map, 1909.

Magnetic phenomena around deep borings: Michigan Acad. Sci. Rept., vol. 4, pp. 166-167, 1904.

Historical review of the geology of Michigan: Michigan Acad. Sci. Rept., vol. 5, pp. 184-195, 1904.

The theory of copper deposition: Michigan Miner, vol. 6, No. 2, pp. 9-11, No. 3, pp. 9-11, 1904; Am. Geologist, vol. 34, pp. 297-309, 1904; Michigan Geol. Survey Rept. for 1903, pp. 239-249, 1905.

Waters of the Upper Peninsula of Michigan: Michigan Geol. Survey Rept. for 1903; pp. 111-167, 1905.

The Tamarack mine cross section and the Keweenawan lodes: Michigan Geol. Survey Rept. for 1903, pp. 251-270, 1905.

Comment on the “Report of the special committee on the Lake Superior region”: Jour. Geology, vol. 13, pp. 457-461, 1905.

Underground waters of Michigan: U. S. Geol. Survey Water-Supply Paper 114, pp. 242-247, map, 1905.

Black River work: Michigan Geol. Survey Rept. for 1904, pp. 158-162, 1905.

The geology of Keweenaw Point, a brief description: Lake Superior Min. Inst. Proc, vol. 12, pp. 81-104, 1907, abstract, Mines and Minerals, vol. 27, pp. 204-206, 1906.

The formation of Lake Superior copper: Science, new ser., vol. 25, p. 589, 1907.

Different manifestations of the ophitic texture [abstract]: Science, new ser., vol. 25, pp. 774-775, 1907.

(and Seaman, A. E.) Notes on the geological section of Michigan; Part I, The pre-Ordovician: Jour. Geology, vol. 15, pp. 680-695, 1907.

Ophitic texture (abstract): Geol. Soc. America Bull., vol. 18, pp. 648-649, 1908.

Mine waters: Lake Superior Min. Inst. Proc, vol. 13, pp. 63-152, 1908.

Summary of the surface geology of Michigan: Michigan Geol. Survey Rept. for 1907, pp. 89-152, map, 1908.

Salt water in the Lake mines: Lake Superior Min. Inst. Proc, vol. 12, pp. 154-163, 1907; Michigan Miner, vol. 11, No. 4, pp. 24-26, 1909.

LANE, ALFRED CHURCH—Continued.

Notes on the geological section of Michigan; Part II, From the St. Peters up: Michigan Geol. Survey Rept. for 1908, pp. 43-105, 1909.

Geology of the Porcupine Mountains: Michigan Min. World, vol. 30, pp. 1115-1117, 1909.

Mine waters and their field assay: Geol. Soc. America Bull., vol. 19, pp. 501-512, 1909.

The decomposition of a boulder in the Calumet & Hecla conglomerate, and its bearing on the distribution of copper in the Lake Superior copper lodes as indicating the trend and characters of the waters forming the chute: Econ. Geology, vol. 4, pp. 158-173, 1909.

Michigan iron mines and their mine waters: Min. World, vol. 31, pp. 413-416, 1909.

(and Seaman, A. E.) Notes on the geological section of Michigan for geologists, teachers, and drillers, Part I, The Ordovician: Michigan Geol. Survey Rept. for 1908, pp. 21-42, 1909.

The Keweenaw series of Michigan: Michigan Geol. Survey Pub. 6 (Geol. ser. 4), 2 vols., 983 pp., maps, 1911.

Native copper deposits: Canadian Min. Inst. Quart. Bull., vol. 13, pp. 81-87, 1911; Canadian Min. Inst. Jour., vol. 14, pp. 316-322, 1912; reprinted in Types of ore deposits (ed. by H. F. Bain), pp. 133-139, 1911.

Unexplored parts of the copper range of Keweenaw Point I [with discussion]: Lake Superior Min. Inst. Proc, vol. 17, pp. 127-143, 1912.

Diamond drilling at Point Mamainse, Province of Ontario; with introduction by Alfred W. G. Wilson: Canada Mines Branch Bull. 6, 59 pp., map, 1912.

The age of the Keweenawan series [abstract]: Michigan Acad. Sci. Rept. 14, pp. 107-108, 1912.

New light on the Keweenaw fault [abstract]: Geol. Soc. America Bull., vol. 24, p. 718, 1913.

Mine-water composition an index to the course of ore-bearing currents: Econ. Geology, vol. 9, pp. 239-263, 1914; Tufts Coll. Studies, vol. 4, No. 1, pp. 239-263, 1914.

Keweenaw fault: Geol. Soc. America Bull., vol. 27, pp. 93-100, 1916.

The origin of the mirabilite from the Isle Royale mine [Houghton, Mich.]: Am. Mineralogist, vol. 2, pp. 63-64, 1917.

(See also Gordon, W. C; Wright, F. E.)

LANG, S. S.

Porphyry intrusions of the Michigan copper district: Eng. and Min. Jour., vol. 107, p. 452, 1919.

Copper deposits of Lake Superior: Min. and Sci. Press, vol. 121, pp. 407-408, 1920.

LAPHAM, INCREASE A.

The Penokee Iron Range: Wisconsin Agr. Soc. Trans., vol. 5, pp. 391-400, with map, 1860.

LARSEN, E. S. (See Foshag, Wm. F.)

LAWSON, ANDREW COWPER.

The correlation of the pre-Cambrian rocks of the region of the Great Lakes: California Univ. Dept. Geology Bull., vol. 10, pp. 1-19, 1916.

LEITH, CHARLES KENNETH.

A summary of Lake Superior geology, with special reference to recent studies of the iron-bearing series: Am. Inst. Min. Eng. Bimonthly Bull., vol. 3, pp. 453-507, map, 1905; Am. Inst. Min. Eng. Trans., vol. 36, pp. 101-153, map, 1907; reprinted in part in Emmons, S. F., Ore deposits, pp. 633-656, map, 1913.

(See also Van Hise, C. R.)

LEVERETT, FRANK.

Glacial lakes and their correlative ice borders in the Superior basin [abstract]: Michigan Acad. Sci. Ann. Rept., vol. 19, pp. 101-102, 1917.

LINDGREN, WALDEMAR.

Genesis of copper with zeolites in basic rocks: Min. and Eng. World, vol. 35, No. 27, p. 1311, 1911.

Some modes of deposition of copper ores in basic rocks: Econ. Geology, vol. 6, No. 7, pp. 687-700, 1911.

LOCKE, JOHN.

Geology of Porters Island and Copper Harbor: Am. Philos. Soc. Trans., vol. 9, pp. 311-312, maps, 1846.

Observations made . . . to determine the magnetical dip and the intensity of magnetical force in several parts of the United States [includes notes on geology of stations]: Am. Philos. Soc. Trans., new ser., vol. 9, pp. 283-328, 1846.

[Geological observations in the Upper Peninsula of Michigan]: Gen. Land Office Rept. for 1847 (30th Cong., 1st sess., S. Ex. Doc. 2), pp. 183-199, 1847.

Catalog of rocks, minerals, ores, and fossils collected by Dr. John Locke [Lake Superior region]: Smithsonian Inst. Ann. Rept., vol. 9, for 1854, pp. 367-383, 1855.

LOGAN, WILLIAM E.

Remarks on the mining region of Lake Superior, and a report on mining locations claimed on the Canadian shores of the lake, 31 pp., with maps, Montreal, 1847.

On the geology and economic minerals of Lake Superior: Canada Geol. Survey Rept. Progress for 1846-47, pp. 8-34, 1847.

Report on the north shore of Lake Huron, 51 pp., Canada Geol. Survey, 1849.

On the age of the copper-bearing rocks of Lakes Superior and Huron: Am. Jour. Sci., 2d ser., vol. 14, pp. 224-229, 1852.

Considerations relating to the Quebec group and the upper copper-bearing rocks of Lake Superior: Canadian Naturalist, vol. 6, pp. 199-207, 1861.

Geology of Canada, 983 pp., with atlas, Montreal, 1863.

Kupfererzeführende Gesteine am Obern See: Jahrb. Mineralogie, 1864, p. 741.

Notes on the report of Mr. Robert Bell on the Nipigon region: Canada Geol. Survey Rept. Progress for 1866-1869, pp. 471-475, 1870.

LONGYEAR, CLYDE S.

Results of drilling in the Nonesuch formation between the White Pine mine and Lake Superior: Michigan Geol. Survey Pub. 24 (Geol. ser. 20), pp. 19-20, 1916.

MCCRACKEN, STEPHEN B.

The State of Michigan, embracing sketches of its history, position, resources, and industries [Mineral resources, pp. 48-73], 136 pp., Lansing, Mich., 1876.

MCDERMOTT, WALTER.

The Silver Islet vein, Lake Superior: Eng. and Min. Jour., vol. 23, pp. 54-55, 70-71, 1877; Inst. Min. Met. Trans.,: vol. 18, pp. 220-231, 1909; Canadian Min. Jour., vol. 30, pp. 135-138, 1909.

MACFARLANE, THOMAS.

[Report on the geology of Lake Superior]: Canada Geol. Survey Rept. Progress for 1863-1866, pp. 115-148, 1866.

On the rocks and cupriferous beds of Portage Lake, Mich.: Canada Geol. Survey Rept. Progress for 1863-1866, pp. 149-164, 1866; Canadian Naturalist, new ser., vol. 3, pp. 1-18, 1866.

On the geological formations of Lake Superior: Canadian Naturalist, new ser., vol. 3, pp. 177-201, 241-256, 1867-68.

On the geology and silver ore of Wood's Location, Thunder Cape, Lake Superior: Canadian Naturalist, 2d ser., vol. 4, pp. 37-48, 459-463, 1869.

MCINTYRE, JAMES.

Report on Isle Royale: 31st Cong., 1st sess., S. Ex. Doc. 1, pt. 3, and H. Ex. Doc. 5, pt. 3, pp. 506-509, 1849.

MARCOU, JOHN BELKNAP.

(and Marcou, Jules.) Geologic maps of Michigan: U. S. Geol. Survey Bull. 7, pp. 77, 78, 79, 80, 81, 82, 83, 85, 87, 88, 1884.

MARCOU, JULES.

Réponse a la lettre de MM. Foster et Whitney sur le lac Supérieur: Soc. géol. France Bull., 2d ser., vol. 8, pp. 101-105, 1851.

A geological map of the United States and the British provinces of North America, with an explanatory text, geological sections, etc., 92 pp., Boston, 1853.

Dyas et Trias, ou le nouveau gres rouge en Europe, dans l'Amérique du Nord et dans l'Inde, 63 pp., Zurich, 1859.

(See also Marcou, John Belknap.)

MARVINE, ARCHIBALD ROBERTSON.

General structure and lithology of the Eagle River section; descriptive cross section of the Eagle River district: Michigan Geol. Survey, vol. 1, pt. 2, pp. 95-140, 1873.

Correlation of the rocks of Houghton and Keweenaw Counties: Idem, pp. 47-61, 95-140.

MATTICE, ASA EDSON.

How Michigan was made: Michigan Miner, vol. 2, No. 1, pp. 15-17; No. 2, pp. 9-14; No. 3, pp. 13-17; No. 4, pp. 20-22; No. 5, p. 9, 1899-1900.

MEADS, ALFRED.

The copper district on Lake Superior: Eng. and Min. Jour., vol. 70, p. 694, 1900.

MEUCHE, A. H.

The development of the copper mines of Lake Superior and their geological relations: Michigan Geol. Survey Pub. 6 (Geol. ser. 4), vol. 2, pp. 887-931, 1911.

Some practical suggestions for diamond-drill explorations: Lake Superior Min. Inst. Proc, vol. 16, pp. 77-81, 1911.

MONROE, H. S.

The losses in copper dressing at Lake Superior: Am. Inst. Min. Eng. Trans., September, 1879.

MOSLER, CHR.

Der Kupferbergbau am Obern See in Nord-Amerika [copper, Lake Superior district]: Zeitschr. Berg-, Hütten-u. Salinen-wesen preuss. St., vol. 25, pp. 203-221, map, 1877; vol. 27, pp. 77-97, 1879; vol. 28, pp. 210-236, 1880.

MÜLLER, ALBRECHT.

Ueber die Kupferminen am Obern See im Staate Michigan, Nord-Amerika: Naturf. Gesell. Basel Verh., vol. 1, pp. 411-438, 1857; abstract, Neues Jahrb., 1857, pp. 79-81, 589-590.

MURRAY, ALEXANDER.

[North shore of Lake Superior]: Canada Geol. Survey Rept. Progress for 1846-47, pp. 47-57, 1847.

NEBEL, MERLE L.

The basal phases of the Duluth gabbro near Gabamichigami Lake, Minnesota, and its contact effects: Econ. Geology, vol. 14, pp. 367-402, 4 pls., 3 figs., 1919.

NICHOLSON, HENRY ALLEYNE.

On the mining districts on the north shore of Lake Superior: North England Inst. Min. Eng. Trans., vol. 24, pp. 237-249, maps, 1875.

NISHIO, KEIJIRO.

Native copper and silver in the Nonesuch formation, Michigan: Econ. Geology, vol. 14, pp. 324-334, 1 pl., 1 fig., 1919.

NOGGERATH, JOHANN JACOB.

Gediegen Kupfer und Silber von Lake Superior: Neues Jahrb., 1848, p. 555.

NORWOOD, JOSEPH GRANVILLE.

Geological report of a survey of portions of Wisconsin and Minnesota, in Owen, D. D., Report of a geological survey of Wisconsin, Iowa, and Minnesota, pp. 209-418, Philadelphia, 1852.

ODENDALL, LEONHARD.

Die Kupfererzlagerstätten in Nordamerika (Inaug. Diss., Univ. Bonn., 63 pp., Koln, 1909.

OWEN, DAVID D.

On the age, character, and true geological position of the Lake Superior red sandstone formation, in Report of a geological survey of Wisconsin, Iowa, and Minnesota, pp. 187-193, Philadelphia, 1852.

PALACHE, CHARLES.

The crystallization of the calcite from the copper mines of Lake Superior: Michigan Geol. Survey, vol. 6, pt. 2, pp. 161-184, 1898.

Powellite crystals from Michigan: Am. Jour. Sci., 4th ser., vol. 7, pp. 367-369, 1899; Zeitschr. Kryst. Min., vol. 31, pp. 529-531, 1899.

(and Vassar, H. E.) Some minerals of Keweenaw copper deposits; pumpellyite, a new mineral; sericite; saponite: Am. Mineralogist, vol. 10, pp. 412-418, 1925.

PATTON, HORACE BUSHNELL.

Microscopic study of some Michigan rocks: Michigan Geol. Survey Rept. for 1891-92, pp. 184-186, 1893.

PECK, ALBERT B.

Mirabilite from the Isle Roy ale copper mine, Houghton, Mich.: Am. Mineralogist, vol. 2, pp. 62-63, 1917.

PENPIELD, SAMUEL LEWIS.

Crystals of analcite from the Phoenix mine, Lake Superior copper region: Am. Jour. Sci., 3d ser., vol. 30, pp. 112-113, 1885.

PETTIT, WILLIAM.

Remarks respecting the copper district of Lake Superior: Franklin Inst. Jour., 3d ser., vol. 13, pp. 338-345, map, 1847.

PHELPS, FRANK B.

The copper region of Michigan: Eng. Mag., vol. 4, pp. 47-63, 1892.

PIGGOT, AARON SNOWDEN.

History of the copper region of Lake Superior: Min. Mag., vol. 10, pp. 124-142, 1858. From his The chemistry and metallurgy of copper, pp. 216-254, Philadelphia, 1858.

POSSELT, C.

Die Kupfer-Distrikte des Obersee's Lake Superior: Neues Jahrb., 1856, pp. 1-10.

PUMPELLY, RAPHAEL.

The paragenesis and derivation of copper and its associates on Lake Superior: Am. Jour. Sci., 3d ser., vol. 2, pp. 188-198, 243-258, 347-355, 1871.

Copper district [Upper Peninsula]: Michigan Geol. Survey, vol. 1, pt. 2, 143 pp., 1873.

Metasomatic development of the copper-bearing rocks of Lake Superior: Am. Acad. Arts Sci. Proc, vol. 13, pp. 253-309, 1878.

Lithology of the Keweenawan system: Geology of Wisconsin, vol. 3, pp. 27-49, Wisconsin Geol. Survey, 1880.

(See also Brooks, Thomas Benton.)

RATH, GERHARD VOM.

Ein ausgezeichneter Kalkspathkrystall vom Oberen See in Nordamerika: Annalen der Physik, vol. 152, pp. 17-21, 1874.

Einige krystallographische Beobachtungen am Kupfer vom Obern See: Zeitschr. Kryst. Min., vol. 2, pp. 169-173, 1878.

READ, MATTHEW CANFIELD.

Copper mining in Michigan: Min. Mag., vol. 12, pp. 220-224, 1915.

RICE, CLAUDE T.

Copper mining at Lake Superior: Eng. and Min. Jour., vol. 94, pp. 119-124, 171-175, 217-220, 267-270, 307-310, 365-368, 405-407, 1912.

RICHARDS, JOSEPH W.

"Mohawkite" (ledouxite): Am. Jour. Sci., 4th ser., vol. 11, pp. 457-458, 1901.

RICKARD, THOMAS ARTHUR.

The copper mines of Lake Superior, 164 pp., New York, 1905; Eng. and Min. Jour., vol. 78, pp. 585-587, 625-627, 665-667, 705-706, 745-747, 785-787, 825-827, 905-907, 945-950, 985-987, 1904.

RIVOT, L. E.

Voyage au lac Supérieur: Annales des mines, 5th ser., vol. 7, pp. 173-328, 1855; translation, Min. Mag., vol. 6, pp. 28-37, 99-106, 207-213, 414-418, 1856; vol. 7, pp. 249-255, 359-367, 1856; vol. 9, pp. 60-65, 1857.

Sur le gisement du cuivre natif au lac Supérieur, États-Unis d'Amérique: Compt. Rend., vol. 40, pp. 1306-1390, 1855.

Ueber die Kupfererz-Lagerstätten am Obern See in den Nord-amerikanischen Freistaaten: Berg- u. hüttenm. Zeitung, vol. 15, pp. 261-263, 269-271, 277-279, 293-295, 314-315, 317-318, 325-328, 333-334, 341-343, 349-351, 357-359, 365-367, 381-382, 1856.

Notice sur le lac Supérieur: Annales des mines, 5th ser., vol. 10, pp. 365-474, 1856.

ROBINSON, W. I. (See Case, Ermine Cowles.)

ROGERS, HENRY DARWIN.

[On the geology and mineralogy of the southern shore of Lake Superior]: Boston Soc. Nat. Hist. Proc, vol. 2, pp. 124-125, 1846.

ROGERS, WILLIAM B.

[On the origin of the actual outlines of Lake Superior]; Am. Assoc. Adv. Sci. Proc. 1st meeting, pp. 79-80, 1848. Age of the sandstone: Boston Soc. Nat. Hist. Proc, vol. 7, pp. 394, 395, 1860.

ROMINGER, CARL LUDWIG.

Observations on the Ontonagon silver-mining district and the slate quarries of Huron Bay: Michigan Geol. Survey, vol. 3, pt. 1, pp. 151-166, 1876.

Paleozoic rocks [Upper Peninsula]: Michigan Geol. Survey, vol. 1, pt. 3, 105 pp., 1873.

Report of the State geologist for 1881-82: Michigan Geol. Survey Rept. for 1891-92, pp. 25-28, 1893; . . . for 1882-83: Idem, pp. 29-31.

Geological report on the Upper Peninsula of Michigan iron and copper regions: Michigan Geol. Survey, vol. 5, pt. 1, 179 pp., 1895.

RUGGLES, DANIEL.

Considerations respecting the copper mines of Lake Superior: Am. Jour. Sci., vol. 49, pp. 64-72, 1845.

RUTHVEN, A. G.

An ecological survey in the Porcupine Mountains and Isle Royale, Mich.: Michigan Geol. Survey Ann. Rept. for 1905, pp. 17-47, 1906.

(See also Allen, R. C.)

SANDERS, GEORGE N.

[Mineral region of Lake Superior]: 28th Cong., 2d sess., S. Ex. Doc. 117, pp. 3-9, 1845; 28th Cong., spec, sess., S. Ex. Doc. 175, pp. 8-14, 1845.

SAVAGE, THOMAS EDMUND.

(and Crooks, H. F.) Early Silurian rocks of the northern peninsula of Michigan: Am. Jour. Sci., 4th ser., vol. 45, pp. 59-64, 1918.

SAVICKI, WILLIAM V.

Geological survey of Michigan; report of field work for 1900: Michigan Miner, vol. 3, No. 3, pp. 9-11, 1901.

SCHALLER, WALDEMAR THEODORE.

The supposed vanadic acid from Lake Superior in copper oxide: Am. Jour. Sci., 4th ser., vol. 39, pp. 404-406, 1915.

SCHOOLCRAFT, HENRY ROWE.

Account of the native copper on the southern shore of Lake Superior: Am. Jour. Sci., vol. 3, pp. 201-216, 1821; translation in Struve, H. von, Beiträge zur Mineralogie und Geologie des nordlichen Amerikas, pp. 23-49, Hamburg, 1822.

On the number, value, and position of the copper mines on the southern shore of Lake Superior: 17th Cong., 2d sess., S. Doc. 5, 33 pp., 1822.

Bericht über das gediegene Kupfer das sich an der Südküste des Ober-Sees in Nord-Amerika in grossen Massen findet: Annalen der Physik (Gilbert), vol. 70, pp. 337-348, 1822.

Notice of a recently discovered copper mine on Lake Superior, with several other localities of minerals: Am. Jour. Sci., vol. 7, pp. 43-49, 1823.

Remarks on native silver from Michigan: New York Lyc. Nat. Hist. Annals, vol. 1, pp. 247-248, 1825.

Observations on the geology and mineralogy of the region embracing the sources of the Mississippi River and the Great Lakes basin, during the expedition of 1820: Summary narrative of an exploratory expedition to the sources of the Mississippi River in 1820, resumed and completed by the discovery of its origin in Itasca Lake in 1832, pp. 303-362, Philadelphia, 1854.

SEAMAN, A. E.

A new locality for Silurian limestone in northern Michigan: Am. Jour. Sci., 3d ser., vol. 48, p. 173, 1894.

Geology of Mineral Range: First annual review of copper-mining industry of Lake Superior, pp. 49-60, 1899.

(See also Lane, A. C.)

SELWYN, ALFRED R. C.

Notes of a geological reconnaissance from Lake Superior to Fort Garry: Canada Geol. Survey Rept. Progress for 1872-73, pp. 8-18, 1873.

SHARPLESS, F. F. (See Lane, A. C.)

SHEPARD, CHARLES U.

On the copper and silver of Keweenaw Point, Lake Superior: Assoc. Am. Geologists Proc. 6th meeting, pp. 60-61, New Haven, 1845.

SHEPARD, FORREST.

Remarks on a boulder mass of native copper from the southern shore of Lake Superior: Am. Jour. Sci., 2d ser., vol. 4, pp. 115-116, 1847.

SMITH, R. A.

Mineral resources of Michigan: Michigan Geol. Survey Pub. 32 (Geol. ser. 26), 145 pp., 1922.

(See also Barrett, L. P., and Allen, R. C.)

SMYTH, HENRY LLOYD.

On the origin of the copper deposits of Keweenaw Point [abstract]: Science, new ser., vol. 3, pp. 251-252, 1896.

SOPER, E. K. (See Grout, F. F.)

SPENCER, JOSEPH WILLIAM WINTHROP.

On the Nipigon or copper-bearing rocks of Lake Superior: Canadian Naturalist, new ser., vol. 8, pp. 55-81, 1876.

SPERR, F. W.

Failures of the rule of following the hanging in the development of Lake Superior copper mines [with discussion]: Lake Superior Min. Inst. Proc., vol. 17, pp. 238-246, 1912.

SPURR, J. E.

The copper ores of Lake Superior: Eng. and Min. Jour., vol. 110, pp. 355-357, 1 fig., 1920.

STEVENS, HORACE JARED.

General information of the geology and mines of the Lake Superior copper district: Am. Inst. Min. Eng. Bimonthly Bull., vol. 1, pp. 208-222, map, 1905.

Mines of the Lake Superior copper district: Lake Superior Min. Inst. Proc, vol. 12, pp. 8-24, 1907.

STEVENS, HORACE JARED—Continued.

Copper Handbook, 1900-1911.

First annual review of Lake Superior copper-mining industry, 1899.

STEVENS, WILLIAM H.

The prospects of the Lake Superior mining region: Min. Mag., vol. 2, pp. 149-153, 1854.

STOCKTON, JOHN.

[Mineral lands of Lake Superior region]: 28th Cong., spec. sess., S. Ex. Doc. 175, pp. 2-4, 1845.

STRENG, A.

(and Kloos, J. H.) Über die krystallinischen Gesteine von Minnesota in Nord-Amerika: Neues Jahrb., 1877, pp. 31-56, 113-138, 225-242.

STRONG, MOSES. (See Chamberlin, T. C.)

SWEET, E. T.

Notes on the geology of northern Wisconsin: Wisconsin Acad. Sci. Trans., vol. 3, pp. 40-55, 1876.

Geology of the western Lake Superior district: Wisconsin Geol. Survey, vol. 3, pp. 303-362, with an atlas map, 1880.

SWINEFORD, A. P.

History and review of the copper, iron, silver, slate, and other material interests of the south shore of Lake Superior, 280 pp., Marquette, Mich., 1876.

TAYLOR, F. B.

A reconnaissance of the abandoned shore lines of the south coast of Lake Superior: Am. Geologist, vol. 13, pp. 365-383, map, 1894.

Changes of level in the region of the Great Lakes in recent geological time: Am. Jour. Sci., 3d ser., vol. 49, pp. 69-71, 1895.

TESCHEMACHER, JAMES ENGLEBERT.

On the vanadium minerals from Lake Superior: Am. Jour. Sci., 2d ser., vol. 11, pp. 233-234, 1851.

THOMSON, ELLIS.

A reexamination of keweenawite: Toronto Univ. Studies, Geol. ser. 20, pp. 35-38, 1925.

THWAITES, FREDRIK TURVILLE.

(and Hotchkiss, W. O.) Map of Wisconsin showing geology and roads, 1911, Wisconsin Geol. Survey, 1912.

Sandstone of the Wisconsin coast of Lake Superior: Wisconsin Geol. Survey Bull. 25 (Sci. ser. 8), 117 pp., map, 1912.

U. S. GEOLOGICAL SURVEY.

World Atlas of commercial geology, pt. 1, Distribution of mineral production, 72 pp., 72 pls. (maps), 1921.

VAN HISE, CHARLES RICHARD.

An attempt to harmonize some apparently conflicting views of Lake Superior stratigraphy: Am. Jour. Sci., 3d ser., vol. 41, pp. 117-137, 1891.

The Huronian volcanics south of Lake Superior [abstract]: Geol. Soc. America Bull., vol. 4, pp. 435-436, 1893.

Sketch of the pre-Cambrian geology south of Lake Superior, with references to illustrative localities: Internat. Geol. Cong., 5th sess., Washington, 1891, Compt. Rend., pp. 489-512, maps, 1893.

Excursion to Lake Superior; Pre-Cambrian geology of the Lake Superior district: Idem, pp. 110-150.

A central Wisconsin base-level: Science, new ser., vol. 4, pp. 57-59, 1896.

A northern Michigan base-level: Idem, pp. 217-220.

(and Leith, C. K.) The geology of the Lake Superior region: U. S. Geol. Survey Mon. 52, 641 pp., maps, 1911; abstract, Washington Acad. Sci. Jour., vol. 1, pp. 157-160, 1911.

Geological work in the Lake Superior region: Lake Superior Min. Inst. Proc, vol. 7, pp. 62-69, 1902.

WADSWORTH, MARSHMAN EDWARD.

Notes on the geology of the iron and copper districts of Lake Superior: Harvard Coll. Mus. Comp. Zoology Bull., vol. 7 (Geol. ser. 1), pp. 1-157, 1880; in part, with title On the jasper and iron ore of the Marquette region: Am. Jour. Sci., 3d ser., vol. 22, pp. 403-408, 1880.

On the age of the copper-bearing rocks of Lake Superior [abstract]: Am. Assoc. Adv. Sci. Proc, vol. 29, pp. 429-430, 1881; Eng. and Min. Jour., vol. 32, p. 270, 1881.

On the filling of amygdaloidal cavities and veins in the Keweenaw Point district of Lake Superior; a reply to

Prof. James D. Dana: Boston Soc. Nat. Hist. Proc., vol. 21, pp. 91-103, 1881.

Keweenaw Point geology: Science, vol. 1, pp. 248-249, 1883.

United States geologists, sandstones, and the Keweenaw series: Idem, p. 307.

On the relation of the Keweenawan series to the eastern sandstone in the vicinity of Torch Lake, Mich.: Boston Soc Nat. Hist. Proc, vol. 23, pp. 172-180, 1885; abstract, Science, vol. 3, p. 553, 1884.

On a supposed fossil from the copper-bearing rocks of Lake Superior: Boston Soc. Nat. Hist. Proc, vol. 23, pp. 208-212, 1886.

The South Trap Range of the Keweenawan series: Am. Jour. Sci., 3d ser., vol. 42, pp. 417-419, 1891.

Report of the State geologist for 1888-89: Michigan Geol. Survey Rept. for 1891-92, pp. 39-44, 1893; . . . for 1899-90: Idem, pp. 45-49; . . . for 1890-91: Idem, pp. 51-57; . . . for 1891-92: Idem, pp. 59-73.

A sketch of the geology of the Marquette and Keweenawan districts, in Ralph, Julian, Along the south shore of Lake Superior, pp. 63-82, copyrighted by C. B. Hibbard, of the Duluth, South Shore & Atlantic Ry., 1890; 2d ed., pp. 75-99, 1891.

The relations of the Eastern sandstone of Keweenaw Point to the Lower Silurian limestones: Science, vol. 18, p. 25, 1891; Am. Jour. Sci., 3d ser., vol. 42, pp. 170-171, 1891.

Subdivisions of the Azoic or Archean in northern Michigan: Science, vol. 20, p. 355, 1892; Am. Jour. Sci., 3d ser., vol. 45, pp. 72-73, 1892.

A sketch of the geology of the iron, gold, and copper districts of Michigan [abstract]: Geol. Mag., dec 3, vol. 9, pp. 571-572, 1892.

A sketch of the geology of the iron, gold, and copper districts of Michigan: Michigan Geol. Survey Rept. for 1891-92; pp. 75-174, 1893.

The copper deposits of Michigan: Geol. Mag., dec. 4, vol. 3, pp. 20-23, 1896.

The origin and mode of occurrence of the Lake Superior copper deposits: Am. Inst. Min. Eng. Trans., vol. 27, pp. 669-696, 1898.

WEED, WALTER HARVEY.

The copper mines of the United States in 1905: U. S. Geol. Survey Bull. 285, pp. 93-124, 1906.

The Copper Handbook, vol. 11, 1912-13.

The Mines Handbook and Copper Handbook, vols. 12-15, 1916-1922.

WHITNEY, JOSIAH DWIGHT.

Report of work in the Upper Peninsula of Michigan: Gen. Land Office Rept. for 1847 (30th Cong., 1st sess., S. Ex. Doc 2), pp. 221-230, 1847.

Description and analysis of three minerals from Lake Superior: Boston Jour. Nat. Hist., vol. 5, pp. 486-489, 1847.

WHITNEY, JOSIAH DWIGHT—Continued.

[On jacksonite, a new mineral from the Lake Superior region]: Boston Soc. Nat. Hist. Proc, vol. 3, pp. 5-6, 1848.

[On the composition of chloritoid or chlorite spar and masonite; and on oxide of copper from Copper Harbor, Lake Superior]: Boston Soc. Nat. Hist. Proc, vol. 3, pp. 100-103, 1849.

[Report of field work in the Lake Superior land district]: 30th Cong., 2d sess., S. Ex. Doc. 2, pp. 154-159, 1849.

Notes on the topography, soil, geology, etc., of the district between Portage Lake and the Ontonagon: 31st Cong., 1st sess., S. Ex. Doc. 1, pt. 3, and H. Ex. Doc. 5, pt. 3, pp. 649-701, 1849.

Field notes for 1847 [in the Lake Superior region]: Idem, pp. 713-758.

[On the mineral lands of the Lake Superior region]: Boston Soc. Nat. Hist. Proc, vol. 3, pp. 210-212, 1850.

Catalog of the rocks, minerals, etc., collected on the district between Portage and Montreal River during the years 1847 and 1848: Smithsonian Inst. Ann. Rept., vol. 9, for 1854, pp. 387-392, 1855.

Remarks on some points connected with the geology of the north shore of Lake Superior: Am. Assoc Adv. Sci. Proc. for 1855, pp. 202-209, 1856.

Notes on the geological position of the Lake Superior sandstone: Min. Mag., 2d ser., vol. 1, pp, 435-446, 1860.

(See also Foster, John Wells.)

WELLS, ROGER C.

Chemistry of deposition of native copper from ascending solutions: U. S. Geol. Survey Bull. 778, 1925.

WHITTLESEY, CHARLES.

Copper regions of Lake Superior, 64 pp., 1846.

Description of part of Wisconsin south of Lake Superior, with maps, in Owen, D. D., Report of a geological survey of Wisconsin, Iowa, and Minnesota, pp. 425-470, 1852.

Drift etchings, Lake Superior: Annals Sci,, vol. 2, pp. 57-59, Cleveland, 1854.

On the origin of the Azoic rocks of Michigan and Wisconsin: Am. Assoc. Adv. Sci. Proc, vol. 13, pp. 301-308, 1860.

Ancient mining on the shores of Lake Superior: Smithsonian Inst. Contr. Knowledge, vol. 13, art. 4 (155), 29 pp., 1863.

The Penokie mineral range, Wis.: Boston Soc Nat. Hist. Proc, vol. 9, pp. 235-244, 1863.

Physical geology of Lake Superior: Am. Assoc Adv. Sci. Proc, vol. 24, pp. 60-72, 1876.

On the origin of mineral veins: Am. Assoc. Adv. Sci. Proc., vol. 25, pp. 213-216, 1877.

On the Iron River silver district: Eng. and Min. Jour., vol. 23, pp. 254-255, 278-279, 1877.

Preglacial channel of Eagle River, Mich, [abstract]: Am. Assoc. Adv. Sci. Proc, vol. 31, p. 352, 1883.

The preglacial channel of Eagle River, Keweenaw Point, Lake Superior: Am. Jour. Sci., 3d ser., vol. 29, pp. 392-397, 1885.

WILLIAMS, CHARLES P.

(and Blandy, J. F.) ... the Copper Range of Lake Superior: Am. Jour. Sci., 2d ser., vol. 34, pp. 112-120, 1862.

WINCHELL, ALEXANDER.

Notice of a small collection of fossils from the Potsdam sandstone of Wisconsin and the Lake Superior sandstone of Michigan: Am. Jour. Sci., 2d ser., vol. 37, pp. 226-232, 1864.

The soils and subsoils of Michigan, 30 pp., Lansing, 1865.

Map of the State of Michigan colored to show the geo logical formations, 15 by 18 inches, 1864(?); notice, Neues Jahrb., 1868, pp. 99-101.

WINCHELL, ALEXANDER—Continued.

Notes on some post-Tertiary phenomena in Michigan [abstract]: Am. Naturalist, vol. 4, pp. 504-505, 1870.

Report on the progress of the State Geological Survey of Michigan, 64 pp., Lansing, 1871.

Michigan; being condensed popular sketches of the topography, climate, and geology of the State [extracted from Walling's Atlas of Michigan], 121 pp., maps, Claremont, N. H., 1873.

The diagonal system in the physical features of Michigan: Am. Jour. Sci., 3d ser., vol. 6, pp. 36-40, 1873.

Syllabus of a course of lectures on geology to be delivered in the Syracuse University during the winter term of 1874-75, 32 pp., Syracuse, 1875.

WINCHELL, ALEXANDER NEWTON.

Use of "ophitic" and related terms in petrography: Geol. Soc America Bull., vol. 20, pp. 661-667, 1908.

(and others). Handbook of mining in the Lake Superior region, prepared for Lake Superior meeting of Am. Inst. Min. and Met. Eng., August, 1920, 260 pp., illus. (incl. maps), Minneapolis, 1920.

WINCHELL, HORACE VAUGHAN.

Historical sketch of the discovery of mineral deposits in the Lake Superior region: Lake Superior Min. Inst. Proc, vol. 2, pp. 33-78, 1894; Minnesota Geol. Survey Ann. Rept., vol. 23, pp. 116-155, 1895.

WINCHELL, NEWTON HORACE.

Sketch of the work of the season of 1878: Minnesota Geol. Survey Seventh Ann. Rept., pp. 9-25, 1879.

The cupriferous series at Duluth: Minnesota Geol. Survey Eighth Ann. Rept., pp. 22-26, 1880.

Preliminary list of rocks: Minnesota Geol. Survey Ninth Ann. Rept., pp. 10-114, 1881.

Typical thin sections of the rocks of the cupriferous series in Minnesota: Am. Assoc. Adv. Sci. Proc, vol. 30, pp. 160-166, 1882; Minnesota Geol. Survey Tenth Ann. Rept., pp. 137-143, 1882; abstract, Science, vol. 2, p. 441, 1881.

Irving and Chamberlin on the Lake Superior sandstone: Am. Geologist, vol. 1, pp. 44-57, 1888.

Steps of progressive research in the geology of the Lake Superior region prior to the late Wisconsin survey: Am. Geologist, vol. 16, pp. 12-20, 1895.

The Keweenawan according to the Wisconsin geologists: Idem, pp. 75-86.

A rational view of the Keweenawan: Idem, pp. 150-162.

The latest eruptives of the Lake Superior region: Idem, pp. 269-274.

Comparative taxonomy of the rocks of the Lake Superior region: Idem, pp. 331-337.

(and Grant, U. S.) Volcanic ash from the north shore of Lake Superior: Am. Geologist, vol. 18, pp. 211-213, 1896.

Thomsonite and lintonite from the north shore of Lake Superior: Am. Geologist, vol. 22, pp. 347-349, 1898.

Common zeolites of the Minnesota shore of Lake Superior: Am. Geologist, vol. 23, pp. 176-177, 1899.

Adularia and other secondary minerals of copper-bearing rocks: Idem, pp. 317-318.

General index of the annual reports of the Minnesota Survey: Minnesota Geol. Survey Twenty-fourth Ann. Rept., pp. 179-284, 1899.

The Keweenawan at Lake of the Woods in Minnesota [abstract]: Science, new ser., vol. 23, p. 289, 1906; Am. Assoc. Adv. Sci. Proc, vol. 55, p. 378, 1906.

WOODS, THOMAS S.

The porphyry intrusions of the Michigan copper district: Eng. and Min. Jour., vol. 107, pp. 299-302, 3 figs., 1919.

WRIGHT, CHARLES E.

First annual report of the commissioner of mineral statistics of the State of Michigan, for 1877-78 and previous years, 229 pp., Marquette, 1879.

Report of the State geologist from May 1, 1885, to January 1, 1888: Michigan Geol. Survey Rept. for 1891-92, pp. 33-37, 1893.

WRIGHT, FRED EUGENE.

Report of progress in the Porcupines: Michigan Geol. Survey Rept. for 1903, pp. 33-44, 1905.

Notes on the rocks and minerals of Michigan, to accompany the loan collection issued by the Michigan College of Mines, prepared by the department of geology, 105 pp., map, Houghton, 1905.

The intrusive rocks of Mount Bohemia, Mich.: Michigan Geol. Survey Rept. for 1908, pp. 355-402, map, 1909; abstract, Science, new ser., vol. 27, p. 768, 1907.

(and Lane, A. C.) Preliminary geological map of the Porcupine Mountains and vicinity: Michigan Geol. Survey Rept. for 1908, pl. 1, 1909.

WRIGHT, JAMES NEY.

The development of the copper industry of northern Michigan: Michigan Polit. Sci. Assoc. Pubs., vol. 3, No. 5, Ann Arbor, 1899.

GEOGRAPHY

Location.—The copper district of Michigan is in the extreme northern part of the northern peninsula, in Keweenaw, Houghton, and Ontonagon Counties. Its mines all lie within a narrow belt from 2 to 4 miles wide and more than 100 miles long.

Topography.—The most prominent topographic feature of the copper country is a broad flat-topped ridge or narrow plateau extending in a northeasterly direction through the district and falling off to a lowland both to the north and to the south. The northern portion projects into Lake Superior as Keweenaw Point. This plateau rises to a general level of 500 to 600 feet above Lake Superior, with ridges such as the Greenstone and Bohemia Ranges, in Keweenaw County, rising still higher. In the south end of the district the Porcupine Mountains form a prominent feature north of the main ridge.

Weather conditions at Houghton, Mich., 1901–1924

	Temperature (°F.)							Relative humidity (per cent)		Cloudiness (tenths of sky)			Precipitation (inches)			
	Means			Extremes										Greatest in 24 hours		
				Highest		Lowest										
	Maximum	Minimum	Mean monthly	Degrees	Date	Degrees	Date	7 a. m.	Noon	7 a. m.	Noon.	During daylight	Total	Quantity	Date	Total unmelted snow
January	22	7	15	50	1906	−31	1915	78	76	8. 6	7. 9	8. 1	2. 47	0. 95	1901	27. 3
February	22	5	14	54	1906	−19	1905	78	76	7. 8	7. 7	7. 2	1. 65	1. 56	1922	17. 3
March	33	16	24	78	1910	−22	1917	80	71	6. 7	6. 4	6. 0	1. 99	1. 54	1917	14. 3
April	46	29	38	88	1901	−10	1923	78	65	5. 9	5. 9	5. 5	2. 14	1. 91	1914	6. 7
May	59	40	49	94	1921	22	1909	77	61	5. 6	4. 8	5. 1	2. 85	2. 65	1918	. 7
June	70	49	60	101	1901	34	1913	81	65	5. 0	4. 8	5. 0	2. 69	2. 14	1905	0
July	74	56	65	103	1917	41	1905	80	69	4. 5	5. 0	5. 6	2. 23	2. 30	1921	0
August	72	54	63	96	1916	37	1915	83	66	5. 1	4. 7	5. 1	2. 38	1. 74	1906	0
September	65	48	57	94	1913	31	1912	89	71	5. 6	5. 7	5. 8	3. 23	3. 70	1905	. 2
October	54	39	46	87	1908	18	1905	86	69	6. 4	3. 9	5. 2	2. 68	2. 31	1903	2. 7
November	39	28	34	67	1903	3	1914	84	78	8. 2	7. 9	8. 1	2. 98	2. 93	1919	16. 8
December	27	15	21	58	1923	−16	1916	83	80	8. 6	9. 0	8. 5	2. 78	1. 88	1917	28. 0
Year	48	32	40	103	July, 1917	−31	Jan., 1915	81	71	6. 5	6. 3	6. 3	30. 26	3. 70	Sept., 1905	110. 1

The main ridge or plateau is cut through by several low transverse gaps or valleys. The deepest are the Portage Lake and Ontonagon River valleys, but there are many others of similar type.

The drainage is mainly outward from the central ridge, and most of the streams are small. The largest is Ontonagon River, which rises south of the main ridge and flows northward through the Ontonagon Gap. As most of the streams have small basins, they are subject to marked variations in flow. In dry summers and continuously cold winters the flow in many of the streams is very small, but while the snow is rapidly melting in the spring there is a large flow.

Climate.—The following statements of the climatic conditions are taken from the summary for 1924 prepared by Howard B. Cowdrick, meteorologist of the Houghton station of the Weather Bureau, United States Department of Agriculture. The Houghton station is in the Portage Lake valley, 82 feet above lake level, and the average conditions on the Copper Range Plateau both north and south of it are somewhat more severe. The waters of Lake Superior on three sides of the region greatly temper the climate. Killing frost in the autumn is later than at many stations much farther south, and although the spring opens late, there are almost never periods of high temperature followed by injurious freezing weather. For the last 23 years the average date of the last killing frost in spring has fallen in May and that of the first in autumn has fallen in October, and the average interval between them has been 149 days. The summer climate, with its long sunny days and cool nights, is almost perfect. The winters are cold but not unpleasant. A great amount of snow falls, but it is usually dry, and because of expertness developed through many years of experience in handling it, the railroads and electric lines are not seriously inconvenienced. Sleet is almost unknown.

Weather conditions at Houghton, Mich., 1901–1924—Continued

	Number of days for conditions specified													Wind				
										Temperature					Maximum velocity for 5 minutes			
										Maximum		Minimum						
	Wind 40 miles an hour or more [a]	Clear	Partly cloudy	Cloudy	Precipitation, 0.01 inch or more	Precipitation, 0.04 inch or more	Snow, melted, 0.01 inch or more	Thunderstorms	Dense fog	32° or lower	90° or higher	32° or lower	Zero or lower	Prevailing direction	Miles per hour	Direction	Year	Average hourly velocity
January	17	3	6	22	18	14	18	0	1	25	0	31	9	NW.	58	W.	1923	8. 3
February	16	5	7	16	18	14	18	0	0	23	0	28	10	NW.	63	W.	1923	8. 1
March	19	8	10	13	13	10	11	1	1	16	0	29	4	E.	54	W.	1918	9. 0
April	10	11	8	11	12	9	6	1	1	3	0	19	4	E.	50	NW.	1922	9. 1
May	12	10	11	9	12	9	1	3	2	0	5	4	0	E.	60	W.	1916	8. 8
June	10	11	11	8	11	8	0	4	2	0	23	0	0	E.	52	SW.	1918	8. 3
July	7	13	11	7	10	8	0	5	2	0	25	0	0	W.	52	NW.	1920	7. 6
August	3	10	12	9	11	8	0	4	3	0	7	0	0	W.	43	W.	1923	7. 6
September	9	9	9	12	13	9	0	3	3	0	7	0	0	W.	63	NW.	1919	8. 4
October	13	7	7	17	14	9	3	1	2	0	0	6	0	W.	52	W.	1921	8. 6
November	14	3	6	21	16	11	11	0	1	7	0	21	0	NW.	52	W.	1924	9. 5
December	17	2	5	24	19	14	18	0	0	21	0	30	3	NW.	58	W.	1922	9. 0
Year	146	94	102	169	158	218	81	22	18	94	67	167	25	E.	63	W.	1923	8. 8

Industries.—The chief industry of Keweenaw Point I is copper mining and smelting; of far less importance are lumbering and agriculture. In addition to these I there is some fishing and a little manufacturing.

Copper mining has been the most important industry for many years, and until the end of the World War, when copper mining nearly everywhere was curtailed, it had made a pretty steady growth.

Lumbering is of course decreasing in importance as the original timber is removed, but there is still much original hardwood timber standing, and lumbering will continue for some time. As the timber has been cut some of the land has been cleared for farming, and agriculture has been steadily expanding. Much of the soil is good, and although the seasons are short, especially on the higher lands of the Copper Range, the region is suited to certain types of agriculture, especially the growing of potatoes and root crops generally. Dairy products are also more than sufficient to supply local demands.

Transportation.—The district borders on Lake Superior, and Portage and Torch Lakes and the Portage Lake Canal bring lake transportation into its heart. Most of the heavy freight, such as fuel and much of the copper, therefore has the advantage of lake freight rates. Lake transportation usually opens by May 1 and closes in December.

The district is also connected with outside points by the Chicago, Milwaukee & St. Paul Railway and the Duluth, South Shore & Atlantic Railroad. It is also served by the Mineral Range Railroad and the Copper Range Railroad. The Keweenaw Central Railroad has served the northern part of the district in the past and would undoubtedly resume operation if conditions should justify. Several of the mines are connected with the mills and smelters by privately owned railroads.

An improved highway extends from Copper Harbor, near the end of Keweenaw Point, to Rockland, on Ontonagon River. This road, together with numerous branches, brings practically all parts of the district within a few miles of good highways, which are open to automobile traffic for about eight months of the year.

The north end of the Porcupine Mountain section also has improved highways, and the Chicago, Milwaukee & St. Paul Railway has a branch to the White Pine mine.

Power.—Practically all power for the district is generated from coal brought in by Lake steamers. Much of the power is used directly as steam power or as compressed air produced by steam power, but there is a steadily increasing use of electric power generated at central plants.

The only water-power plant in the district is that of the Victoria Copper Co. on the West Branch of Ontonagon River. A fall of 71 feet was utilized to produce compressed air directly, which operated all the machinery of the mine and mill. A dam to store water in Lake Gogebic helps to equalize the flow of the river, and the power available could be considerably increased by raising the dam. There is a fall on the East Branch of Ontonagon River that has not yet been utilized for developing power, and some power could also be generated on other small streams in the district. The irregular seasonal flow of the streams, however, would make storage dams necessary to develop power continuously.

PHYSIOGRAPHY

An account of the development of the physiographic features of the copper district requires consideration of a much wider area than the district itself. Such descriptions have been prepared by Martin[7] for the Lake Superior region, by Leverett[8] for the northern peninsula, and by Lane[9] for the copper district, and only a brief outline will be presented here.

The ridge or plateau known as the Copper Range represents an old mature erosion surface with monad-nocks rising above its general level and also valleys below that level. With the elevation of this old surface the softer rocks on each side of the present range were eroded to form the present lowlands, while the crystalline rocks were but little affected. (See pl. 53.) This was the condition of the region before the glacial epoch.

The glaciation had little to do in forming the major physiographic features, but it affected the minor features profoundly. When the ice swept over the region it scoured off the soil and the weathered outcrops of the rocks. It smoothed the outlines and probably widened and deepened the valleys somewhat, but it did not change the major rock features. In local protected areas the effect of preglacial weathering is preserved—for example, it can be well seen in a shaft on the Petherick vein, near Copper Falls, Keweenaw County.

The deposits laid down by the ice and the accompanying streams are prominent features of the detail of the physiography and are economically important both from the viewpoint of the farmer, because they form the soil, and from that of the miner, because they constitute a rock cover which affects the ease of both exploration and development. There are four principal types of glacial deposits on the Copper Range—the general till sheet or ground moraine; moraines formed around the margins of the ice tongues; deposits formed in glacial lakes; and deposits laid down by streams flowing from the ice.

The most extensive of these deposits is the ground moraine, which was left in greater or less amount everywhere as the ice melted. It covers practically all the range except a few steep ridges from which it has been removed or on which it could not accumulate.

Over much of the area it forms a rather shallow mantle, which is not continuous but fills minor depressions and covers the outcrops of the weaker rocks such as the amygdaloids.

The marginal moraines cover a much smaller area. The most prominent one, which outlines the ice lobe that moved down Keweenaw Bay, touches the Copper Range at Wheal Kate Mountain, near South Range, and follows it south westward to a point beyond Winona, where it turns southward around Keweenaw Bay. This moraine buries the rocks deeply and is a serious impediment to prospecting.

The lake deposits were formed in the lakes along the south margin of the ice. In their early stages these lakes drained into the basin of Mississippi River. Later, as the ice melted, lower outlets were opened to the east, and the lakes dropped to successively lower-levels. The most extensive of these lakes in the Copper-Range was Lake Duluth, which covered most of the area. At Calumet its highest shore line surrounds Centennial Heights, about 700 feet above the level of Lake Superior, and in the south end of the district only the higher summits projected as islands. This highest stage was followed by successively lower stages whose positions are marked by old beach lines. Since these were formed the land has been tilted so that there is a slight rise in altitude of each beach line from south to north, the amount of which has not been determined for the Copper Range.

In these lakes were formed extensive deposits of clay mixed with boulders, especially in the southern part of the range. These deposits have not buried the rocks as deeply as the marginal moraine, but in places they constitute a decided handicap to prospecting.

Since the glacial epoch erosion has modified the deposits somewhat, especially near streams, but in the main there has been little change. (See pl. 54.)

[7]Martin., Lawrence, U. S. Geol. Survey Mon, 52, p. 85, 1911.

[8] Leverett, Frank, Michigan Geol. Survey Pub. 7, Geol. ser. 5, 1911.

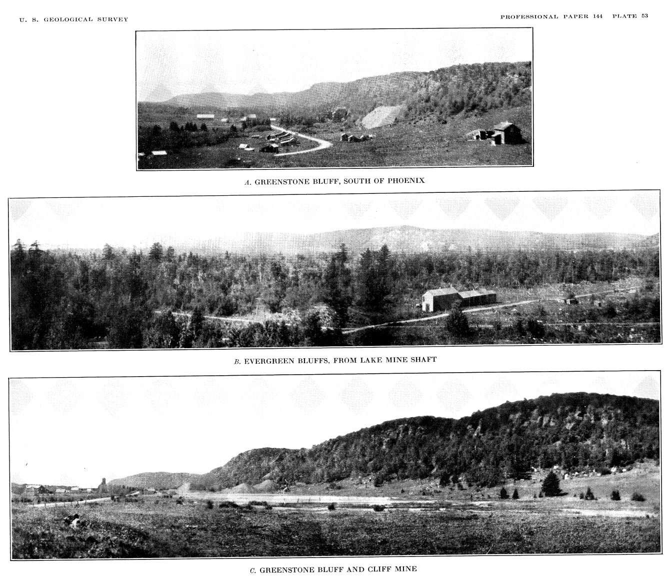
[9] Lane, A. C, Michigan Geol. Survey Pub. 6, Geol. ser, 4, p. 48, 1911.

BEDROCK GEOLOGY

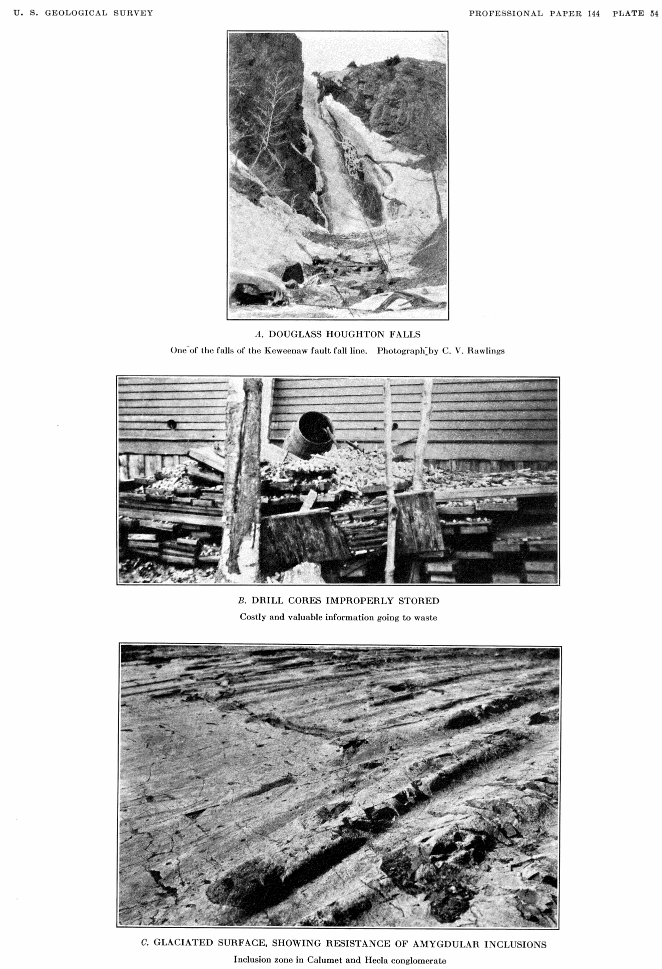
BROADER RELATIONS

Location and extent.—The native copper deposits of Lake Superior are inclosed in rocks of Keweenawan age. The area in which these rocks are exposed lies in the southern part of the pre-Cambrian shield of North America and forms a part of the Lake Superior basin. Along the south shore of the lake it extends from Keweenaw Point southwestward through northern Wisconsin into Minnesota. (See pl. 2.) The Keweenawan rocks border the north shore of the lake in Minnesota to the Canadian boundry, crop out on Isle Royal, and in Canada appear in the Black Bay and Thunder Bay districts and extend northward around Lake Nipigon. To the east of this almost continuous area they occur in scattered outcrops along the shore and on islands of Lake Superior.

Character of the rocks.—The Keweenawan series comprises coarse clastic sediments and intrusive and extrusive igneous rocks. Both the base and the upper part of the series were formed during periods of sedimentation. The igneous activity became dominant after a maximum of 1,500 feet of sediments had been deposited, when basaltic flows were poured out, one after another, with occasional short intervening periods of sedimentation. More rarely acidic eruptions occurred. The flows were probably fissure eruptions; how many there were is not known, but they are to be numbered in the hundreds. Igneous activity gradually ceased, the intervening periods of sedimentation becoming more frequent and longer. The upper part of the series is made up largely of a thick conglomerate overlain by a thick sandstone.



[PLATE 53. Ridges produced by resistant flows.]



[PLATE 54. *A*, Douglass Houghton Falls; *B*, Drill cores improperly stored; *C*, Glaciated surface showing resistance of amygdular inclusions.]

Intrusion probably though not certainly occurred during the Keweenawan epoch. On the north shore the great Duluth gabbro laccolith of Minnesota was intruded essentially along the unconformity at the base of the Keweenawan. Similar intrusive rocks occur south of the lake in Wisconsin, and it is thought that these are outcrops of the same great body extending beneath the lake, from one side of the Lake Superior synclinal basin to the other. Smaller intrusive bodies occur toward the base of the Keweenawan at intervals along Keweenaw Point. Both their petrographic character and their position in the series suggest that they are contemporaneous with and derived from the same magma as the Duluth gabbro. Other examples of intrusive rocks that are probably of Keweenawan age are the dikes in the Gogebic iron country and the Logan sills in Minnesota and Ontario.

STRATIGRAPHY

MAPS AND SECTIONS

The detailed geologic maps and sections (pls. 2-32) are based largely on data from diamond drilling and underground openings. Outcrops have of course been used as far as possible. As the region is largely covered with drift and the depth to bedrock is unknown except at the location of drill holes or other openings, it was decided to show the rock beds on the surface map as projected on their dip through the drift to the surface. Where there is no drift cover the outcrop as shown coincides with the actual bedrock outcrop. Where there is a drift covering a given contact in westward-dipping beds is shown farther east than its position on the bedrock surface by a distance that varies with the thickness of the drift and the dip of the beds. The dip is indicated on the map and shown on the sections, and the thickness of drift at the drill holes is shown on the sections, and it is also indicated on the map by a gap between the location of the hole and the position of the bedrock.

Near the Keweenaw fault, where the beds are in general considerably broken and in many places have low dips, the surface outcrop has not been shown. The structure so far as it is known is indicated in the sections.

On both maps and sections the character of the traps is shown by letters, as O for ophites, M for melaphyres. The character of amygdaloids, as fragmental, scoriaceous, or cellular, is shown by symbols.

AGE AND RELATIONS

The rocks of Keweenaw Point are of Keweenawan and Cambrian age. On the Gogebic Iron Range, near by, the Keweenawan rests unconformably upon the upper Huronian, and Keweenawan dikes cut the earlier rocks. Overlying the upper Keweenawan, without apparent unconformity or abrupt change of character, is a sandstone which has been considered to be Upper Cambrian. This relation does not exist on Keweenaw Point, where the upper Keweenawan sandstone (called the Freda) is separated from the Upper Cambrian sandstone (the Jacobsville, "Eastern," or Lake Superior sandstone) by a great overthrust fault. In the valley of St. Croix River, in western Wisconsin, fossiliferous Upper Cambrian sandstone lies unconformably on middle Keweenawan beds. The Jacobsville sandstone may be likewise unconformable on the Keweenawan in the South Trap Range of Michigan, but there the relations are obscured by faulting, and the problem is complicated further by the doubt that exists regarding the equivalence of the Jacobsville ("Eastern") sandstone to the Upper Cambrian of the St. Croix Valley. This relation may mean simply that the Lake Superior basin was forming during Keweenawan time and in places the latest member was laid down unconformably on the earlier members, which had been already tilted, though there was no break in the general series.

In northern Wisconsin the Freda sandstone is overlain conformably by other sandstones of Keweenawan age, into which, indeed, it seems to grade imperceptibly. It would appear from this relation that the formations were laid down in one period of continuous deposition without interruption by diastrophic movements. Although the accepted usage of the United States Geological Survey is to group the Keweenawan with the pre-Cambrian, the fact that the apparently major unconformity lies below the Keweenawan series rather than above it has led some geologists to the view that the major division between the Cambrian and pre-Cambrian should be placed at the base of the Keweenawan. Thus, Lane groups the rocks of the Keweenawan as Cambrian.[10] The present work has contributed nothing of significance toward determining the relations, and it seems to be still an open question with good arguments on both sides.[10a]

[10]For a discussion of the age and relations of the Keweenawan see Van Hise, C. R., and Leith, C. K., The geology of the Lake Superior region: U. S. Geol. Survey Mon. 52, pp. 384, 389, 415, 416, 616, 620, 625, 1911; Lane, A. C., The Keweenawan series of Michigan: Michigan Geol. Survey Pub. 6 (Geol. ser. 4), pp. 41, 629, 630, 941-942, 1909.

[10a]Since this report was prepared C. R. Stauffer (Age of the red clastic series of Minnesota: Geol Soc. America Bull., vol. 38, pp. 469-478, 1927) has reported the finding of Middle Cambrian fossils near the top of the red sediments below the St. Croixan series in Minnesota. These rocks have in the past been correlated, somewhat uncertainly, with the Keweenawan.

GENERAL CHARACTER AND DISTRIBUTION

The Keweenawan series is divided in a general way into upper, middle, and lower Keweenawan, which are further subdivided into groups and formations.[11] The several workers in the district have classed the subdivisions somewhat differently, as indicated in the following table:

Classification of subdivisions of Keweenawan series

Name	Thickness (feet)	Classification		
		Irving	Van Hise and Leith	Lane and Gordon
Freda sandstone	900– (?)	Upper Keweenawan	Upper Keweenawan	Upper Keweenawan.
Nonesuch shale	350– 600			Lower Keweenawan.
Outer conglomerate	1, 000– 3, 500			
Lake Shore trap	400– 1, 800	Lower Keweenawan	Middle Keweenawan	
Great conglomerate	340– 2, 200			
Eagle River group	1, 417– 2, 300			
Ashbed group	1, 456– 2, 400			
Central Mine group	3. 823–25. 000			
Bohemian Range group	(?) – 9, 500		Lower Keweenawan	

The rocks consist of acidic and basic intrusive and extrusive rocks, shale, sandstone, conglomerate, ash, and tuff. The same rock types, both igneous and sedimentary, are characteristic of the Keweenawan of the entire Lake Superior region. The Keweenaw Point belt extends southwestward into northern Wisconsin and dips northwestward under Lake Superior. Rocks of the same types emerge on the north side of the Lake Superior syncline in Minnesota, Isle Royal, and Ontario. Lane believes that some of the specific horizons identified in the Michigan copper district can be recognized on Isle Royal.[12]

[11]Lane, A. C., op. cit., p. 20.

[12]Lane, A. C, Geological report on Isle Royale, Mich.: Michigan Geol. Survey, vol. 6, pt. 1, 1898.

SEDIMENTS

DISTRIBUTION

The sediments are decidedly subordinate in the lower groups on Keweenaw Point. They become increasingly abundant in the upper groups, however, constituting practically the entire thickness of the series above the Eagle River group.

GENERAL CHARACTER

The sediments are predominantly red in color, feldspathic, and poorly sorted; they show horseshoe-shaped ripple marks, cross-bedding, and mud cracks, and so far as known they have no fossils. Their characteristics indicate that they were deposited largely or entirely under terrestrial conditions.[13]

CONGLOMERATE

Under conglomerate, as here considered, are included rocks of two types—those that are composed predominantly of felsitic material and those that are composed of fragments of amygdaloid in a basic sand and have heretofore been called either amygdaloid conglomerate or scoriaceous amygdaloid. A bed of the second type immediately underlies or forms the lower part of the felsitic Calumet & Hecla conglomerate but is distinct from it in character and is far more extensive. The two types are distinct in composition and in source of material, and it seems desirable for certain purposes to regard them as separate units, though from purely stratigraphic considerations they might well be grouped together, as they commonly have been.

[13]Van Hise, C. R., and Leith, C. K., op. cit., p. 417. Lane, A. C., The Keweenawan series of Michigan: Michigan Geol. Survey Pub. 6, Geol. ser. 4, p. 32, 1909.

FELSITE CONGLOMERATE

Extent and thickness of beds.—Conglomerate of the felsitic type is the principal sedimentary rock in the copper district. Beds of it range in thickness from a few inches to 3,500 feet. Some have been traced for many miles along the strike; the Allouez conglomerate, for instance, is recognized for over 50 miles along the strike and has been identified by Lane across the lake on Isle Royal, though nowhere is it known to be more than 50 feet in thickness. The recognition and enumeration by Marvine[14] of 22 conglomerates numbered from the base of the series upward to the Great conglomerate constitutes the chief basis of correlation used in all the later geologic work in the district.

Vertical distribution.—The conglomerates form a relatively small proportion of the lower part of the series and a large proportion of the upper part. In the lower part many of the flows have no felsitic sediment between them, indicating that sedimentation at a given place, at least, was intermittent.

Character of material.—The felsitic conglomerates are siliceous in general composition, the most abundant rocks in them being felsite and quartz porphyry. In the north end of the district every bed contains many varieties of such rocks, from the densest felsite to very coarse quartz and feldspar porphyries and from highly siliceous rocks to rocks that are strongly feldspathic and rich in iron. In the south end of the district felsitic pebbles predominate and those of quartz porphyry are practically absent so far as observed. Amygdaloid pebbles are present in most of the felsite conglomerates, and locally such basic material may become plentiful, but fragments of trap are decidedly unusual. In the south end of the district pebbles of iron formation have been observed, and in the Calumet & Hecla conglomerate there are a few pebbles of hard white quartzite, which is not known elsewhere in the Keweenawan series. Except for the amygdaloid pebbles, which are of local derivation, all the constituents are physically and chemically resistant. Most of the pebbles are fairly well rounded; some, however, are sub angular and might be regarded as having been transported no great distance were it not that similar angularity is to be found among hard materials on beaches subject to strong wave action and can not be taken to indicate feeble abrasion.

[14]Marvine, A. R., Michigan Geol. Survey, vol. 1, pt. 2, 1873.

Character of beds.—The beds, as is true of conglomerates in general, are lenticular, thinning or thickening rather rapidly along the strike. Where thin they are usually of rather fine texture, consisting of sandstone or grit; the coarser material, the largest boulders in which are rarely over a foot in diameter, is usually present in rather thick beds, though the thick beds are not at all places composed of coarse material. The Wolverine sandstone included in the conglomerate of Marvine, for example, in places attains a considerable thickness, though usually retaining the texture of a sandstone or shale. Lenses of sandstone are present in much of the conglomerate. Cross-bedding, mud cracks, and ripple marks are common features. (See pl. 55.)

Character of underlying bed.—Commonly the felsitic conglomerate is underlain by a soft red or brownish basic sandstone, locally ripple-marked, and contains pebbles of amygdaloid that become increasingly abundant toward the base and were evidently derived from the underlying amygdaloid. This is what Lane has designated amygdaloidal conglomerate. Where the felsite conglomerate is underlain by the more basic fragmental material, amygdaloid pebbles are likely to be present in the felsitic layer and more noticeably toward its base but rarely in abundance. Much less commonly a felsite pebble may be found in the basic layer. On the whole there has been little commingling of the two kinds of material, and as a rule the boundary between the felsite and the basic layers is pretty distinct. Rarely does either the felsitic rock or the underlying basic conglomerate rest directly on trap without the intervention of a band of amygdaloid, though there is in many places evidence that some of the amygdaloid has been eroded.

Source of material.—The principal material of the felsite conglomerate is similar to that composing several masses of felsite and acidic porphyry, in part at least intrusive, that are exposed in the district. Lane has called attention to the similarity between certain pebbles in the Calumet & Hecla conglomerate and an intrusive rock near the Keweenaw fault east of Calumet. There are conglomerates of like character, however, that are older than any of the exposed masses of similar igneous rocks, and the exposed masses seem much too small to have furnished the large amount of material that the conglomerates contain. The variety of acidic igneous types is greater in the conglomerate beds than would be expected if they were derived wholly or mainly from the breakdown of any single igneous body. Furthermore, as already mentioned, pebbles of iron formation and of foreign quartzite are present sparingly in the conglomerate beds, and on Michipicoten Island similar conglomerates carry pebbles of granite and gneiss. Lane[15] and others have suggested that certain extensive flows of felsite, poured out on top of the basalt flows, immediately succumbed to erosion, thus forming a nearly contemporaneous conglomerate. Some of the pebbles of felsitic texture show flow structure which may be a result of surface flow; but it is not necessarily so, for similar structure is present in felsite that is known to be intrusive, and these pebbles showing flow structure are mingled with an abundance of others of such coarse porphyritic and holocrystalline texture as to make their derivation from effusive rocks unlikely.

Aldrich,[16] of the Wisconsin Geological Survey, believes that much of the material in the conglomerates of Wisconsin is derived from rhyolite flows. He describes conglomerates resting on rhyolite flows and made up in part of pebbles that are similar to the flows and are thought to have come from them. Nowhere in the Michigan copper region, however, is a conglomerate known to rest upon or be in contact with a felsitic mass that can be regarded as effusive.

It seems probable that the conglomerate pebbles were not of immediate local derivation but came from long-lived uplands composed mainly of felsite and quartz porphyry, and that the débris from these uplands, together with a small proportion of other material from different source, was spread intermittently on the adjacent piedmont plains occupied mainly by the basic flows.

Where such uplands were located is not known, for no remnants of formations that seem adequate to have furnished the material for the conglomerates have been found. They may have been outside the present limits of the Keweenawan and in the area now covered by the Jacobsville (“Eastern” or Cambrian) sandstone, or they may have been inside these limits and in the area now occupied by the Freda sandstone (upper Keweenawan). It seems probable that they came from the same direction as the flows and were spread over and carried down the gently sloping surfaces of the flows. Aldrich[17] and Hotchkiss18 believe that the source of the similar acidic and basic rocks in Wisconsin was in the interior of the Lake Superior basin, and there are reasons for supposing a similar source for the rocks in Michigan, as is pointed out in the discussion of igneous rocks on page 26.

[15]Lane, A. C., The Keweenawan series of Michigan: Michigan Geol. Survey Pub. 6 (Geol. ser. 4), p. 753, 1908.

[16]Aldrich, H. R., Magnetic surveying on the copper-bearing rocks of Wisconsin: Econ. Geology, vol. 18, p. 569, 1923.

[17]Idem, p. 571.

[18]Hotchkiss, W. O., Lake Superior geosyncline: Geol. Soc. America Bull., vol. 34 pp. 669-678, 1923.

Manner of deposition.—The upper surfaces of many of the lava flows are not eroded and are immediately overlain by other flows without the intervention of any sediment. Sedimentation therefore must have been intermittent. Two contrasting ways in which the intermittent deposition of the felsite conglomerates might have been accomplished have been imagined— that the conglomerates are marine deposits and were accumulated in a body of water that alternately advanced and retreated from the area during the period of lava accumulation; or that they are dominantly terrestrial deposits and were accumulated intermittently on a plain that was being flooded by lava.

The second hypothesis appears the more probable. There has been an increasing tendency among geologists, including workers in the Michigan region, to regard sediments of this general type as having accumulated on land or in very shallow water. Within the stratigraphic limits that embrace the conglomerates no sediments of undoubted marine origin are known, nor any that are more probably marine than the conglomerates themselves. The presence of ripple marks and mud cracks is strongly indicative of deposition in streams, puddles, or shallow sheets of water. Perhaps these Michigan conglomerates find their closest analogy in point of origin with the extensive Gila conglomerate of Arizona and western New Mexico and similar deposits of whose terrestrial origin there can be little doubt.

Emphasis should be placed on the fact that the red color of the conglomerates is not due mainly to weathering and oxidation, the causes most commonly assigned in explaining red sediments. The conglomerates are red because the pebbles in them are red. Comparison shows that the felsite and porphyry are but little redder than the red felsite and quartz porphyry masses, such as Mount Houghton, the Bare Hills, and the body east of Calumet. The pebbles in these conglomerates are almost as free from weathering as the freshest similar massive rock in glaciated outcrops. The color in both is due to minute plates of primary hematite. The cementing material of the conglomerates contains much iron oxide in grains not inclosed in rock. In the Great conglomerate the oxide is magnetite partly altered to hematite and limonite. In the Calumet & Hecla conglomerate little unaltered magnetite remains. It is probable that some of the limonite resulted from surface oxidation.

AMYGDALOIDAL CONGLOMERATE

Relation to felsite conglomerate.—The Calumet & Hecla felsite conglomerate is immediately underlain by a fragmental layer consisting chiefly of basaltic material—in part basic sand, in part pebbles or boulders of amygdaloid—resting upon the amygdaloidal upper part of a basaltic flow. To material of this type Lane has applied the name “amygdaloidal conglomerate.” Similar material underlies most of the felsite conglomerates and is present on numerous flows without accompanying felsitic material. Apparently Lane and others have regarded such basic fragmental stuff as a part of a single conglomerate formation, of which the overlying felsite portion is perhaps the more conspicuous and certainly the more important economically. For purposes of stratigraphic correlation this view leads to no difficulty, but as the acidic and basic portions are derived from different sources and as they also differ in distribution and persistence, it seems advisable, especially for the copper-bearing conglomerates, to make a separation between the amygdaloidal conglomerate and the felsite conglomerate.

For example, the copper of the Calumet & Hecla conglomerate lode is confined almost exclusively to the upper, felsite portion, the underlying basic portion being nowhere an ore; the felsite portion is of slight lateral extent, thinning out to sandstone and then pinching almost entirely, but the basic sedimentary portion continues on regardless of whether or not the felsite conglomerate is present. To designate the amygdaloidal conglomerate the Calumet & Hecla conglomerate without qualification at places where the felsite portion is absent might lead to a misunderstanding as to the possibility of finding ore at such places. In the sections and maps this and similar beds have been classed under the term “scoriaceous amygdaloids,” a term well established in the records of the district, though it is recognized that “amygdaloidal conglomerate” conveys a better idea of their probable mode of formation.

Origin.—These scoriaceous amygdaloids or amygdaloidal conglomerates have often been considered true “ash beds” or the accumulation of explosive volcanic material—bombs and volcanic ash. That some explosive material was produced in connection with the basic flows is entirely possible, but the evidence that it was of noteworthy amount is not clear, and the sedimentary origin seems adequate to account for the deposits as they are. The felsite sediments are characteristically underlain by amygdaloidal conglomerate. It is not uncommon to find some felsitic sediment resting on the amygdaloidal conglomerate where no well-defined and persistent felsite conglomerate is present. There are, however, many beds of amygdaloidal conglomerate with which no felsite is associated. Very commonly the amygdaloid of the underlying flow has been partly eroded, and in places it has been entirely removed so that the dark conglomerate rests directly on trap. It is clear, therefore, that the amygdaloidal conglomerates have been formed repeatedly at horizons where both erosion and sedimentation have taken place, and that they are products of erosion rather than of explosive eruption. The amygdaloidal conglomerates with which no felsite sediment is associated are similar to those that are accompanied by felsitic rock and doubtless are of similar origin.

It seems most likely that the amygdaloidal conglomerates represent the early stages of a period of erosion and sedimentation, when the sedimentary material was mainly derived near at hand from the readily eroded amygdaloids. Where the sedimentation persisted a long time, so that the basic lavas were extensively mantled with gravel and sand, felsitic debris from more distant sources mingled with that from the basic lava and became the dominant material of the sediment. Where the period was short only the basic material accumulated.

SANDSTONE AND SHALE

At the top of the Keweenawan series occur the Nonesuch shale and the Freda sandstone. The Nonesuch formation consists of black and red shales interstratified with layers of sandstone. The Freda sandstone is the uppermost formation of the Keweenawan series in Michigan. Its material indicates that it was derived mainly from basic igneous rocks, and Lane regards its source as having been predominantly in pre-Keweenawan rocks.[19]

ASH AND TUFF

Material that may be ash, though not abundant, is widely distributed. Many of the flows with brecciated tops contain small quantities of finely granulated material mingled with the coarse that may be ash, though it may be merely small fragments of the same origin as the larger. The Ashbed and similar beds are considered on page 33, under types of amygdaloids, but their probable mode of origin is outlined above, under amygdaloidal conglomerate. One siliceous layer, called the “Mesnard” epidote, is said to contain quantities of acidic ash[20] and is ascribed to a period of rhyolite eruption.

[19] Van Hise, C. R., and Leith, C. K., op cit., p. 414. Lane. A. C, Jour. Geology; vol. 15, p. 690, 1907.

[20] Lane, A. C,. The Keweenaw series of Michigan: Michigan Geol. Survey Pub. 6 (Geol. ser. 4), pp. 409, 565, 1909.

IGNEOUS ROCKS

The major part of the igneous rocks exposed on Keweenaw Point are basic lava flows, which make up most of the central portion of the Keweenawan series and whose outcrop forms the higher portion or backbone of Keweenaw Point. Intrusive rocks of the gabbro and “red rock” types, similar to the Duluth gabbro and “red rock,” and felsite and quartz porphyry intrusives, are present at several localities near the base of the series, and intrusives are also present high in the series in the

Porcupine Mountains. It is possible that some of the felsite bodies are surface flows.

EXTRUSIVE ROCKS

DISTRIBUTION

The basic lava flows in the central portion of the Keweenawan series extend as a belt 1 to 3 miles wide from the end of Keweenaw Point into Wisconsin. (See pl. 2.) A southern belt of flows, the South Trap Range, diverges from the main range near the Michigan-Wisconsin boundary and extends eastward toward Keweenaw Bay. In addition to these main belts there are a few small flows, the Lake Shore trap, in the prevailingly sedimentary rocks of the upper part of the Keweenawan series.

EXTENT OF BEDS

Several of the flows have been traced for 40 or 50 miles along the outcrop. The Greenstone flow, for example, which forms Greenstone Cliff, in Keweenaw County, is known from the end of Keweenaw Point to a locality south of Portage Lake; the "Big" trap, immediately above the "'St. Louis" conglomerate, extends from a point considerably south of Calumet well toward the end of Keweenaw Point; the Kearsarge flow has been traced for 40 miles. Doubtless there are numerous flows not so easily recognized and followed that persist for miles.

At several horizons there are series of relatively thin flows which can be traced, collectively, for long distances, though it is rarely possible to correlate the individual flows between distant outcrops. The Pewabic flows, in the northern part of the district, and the Evergreen and succeeding flows, in the southern part, are of this character.

Lane believes that he can recognize some of the individual flows of Keweenaw Point in the outcrops on Isle Royal, which lies 50 miles distant, near the north side of the Lake Superior basin.

THICKNESS

There is a notable variation in the thickness of the portion of the Keweenawan series composed predominantly of lava flows at different points along the range. The total thickness of the series is nowhere known, as it everywhere abuts against the Keweenaw fault.

In Keweenaw County the thickness between the Great conglomerate and the Keweenaw fault is about 15,000 feet. At Calumet about 11,000 feet is exposed between the Great conglomerate and the fault, but the fault apparently cuts the series at a much higher horizon here than in Keweenaw County. Near South Range about 11,000 feet is exposed, but here the fault cuts the series much lower than at Calumet. At Victoria probably not more than 8,000 feet is exposed between the Great conglomerate and the Keweenaw fault.

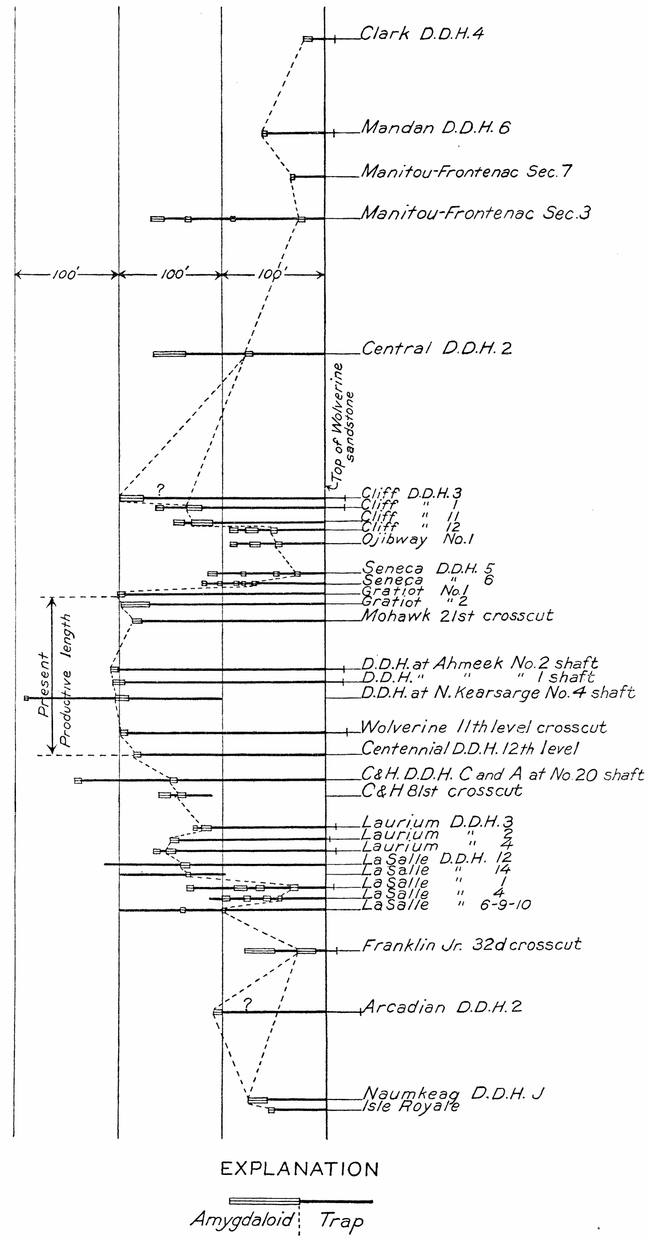


FIGURE 1.—Variation in thickness of Kearsarge flow

The beds that have been most definitely correlated through the district are the Great conglomerate (No. 22), the Allouez conglomerate (No. 15), and the No. 8 conglomerate. The correlation of No. 8 is not as certain as that of the other two. The No. 8 conglomerate at Portage Lake is correlated with the "St. Louis" conglomerate near Calumet and with the Bohemia conglomerate in Keweenaw County. These correlations are probable but not certain. Likewise No. 8 conglomerate in Ontonagon County is not positively known to be the extension of No. 8 at Portage Lake but is thought to be.

If these correlations are correct it is apparent from an examination of the plate showing correlation of sections that the greatest thickness between conglomerates No. 8 and No. 15 is at Calumet, where it is about 8,000 feet; at Franklin it is about 6,000 feet; at South Range it is little over 5,000 feet; and at Winona and farther south it is little more than 4,000 feet.

The greater thickening in the vicinity of Calumet seems to be due, in large part at least, to the presence of the "Big" trap above No. 8 conglomerate and to 1,000 to 1,500 feet of thin flows that seem to be largely absent at Portage Lake and farther south. A somewhat similar thinning seems to occur northward into Keweenaw County. There is a tendency to thinning southward higher in the series, as can be seen by inspection of the plate, but it is much less marked. Between the Allouez conglomerate (No. 15) and the Great conglomerate (No. 22) the greatest recorded thickness is about 4,000 feet at Eagle River. At Calumet the interval is about 3,000 feet. South of Calumet it is about 2,700 feet at Franklin Junior and about 2,400 feet at South Range.

The greatest cause for variation in this part of the section is the difference in thickness of the Greenstone flow.

The individual flows vary greatly in thickness from place to place. In general the more extensive flows are thick; the Greenstone flow has a maximum thickness of 1,300 feet in Keweenaw County; the "Big" trap exceeds 400 feet, and the Kearsarge flow (fig. 1) exceeds 200 feet. These great flows commonly thin rather gradually from their thicker portions, as is well shown by the Greenstone flow, which thins southward from Keweenaw County, where it forms the great Greenstone Cliff, to only moderate thickness at Calumet, and which can not be positively identified south of Portage Lake except by its relations to other beds. An inspection of Plate 2 will show the rather gradual thinning of other flows, though some thin rather abruptly, as the Mandan flow north of Delaware, in Keweenaw County, and the thick flow above No. 8 conglomerate near South Range.

Although certain flows can be traced for long distances, and in certain places and horizons all the individual flows throughout a considerable thickness can be closely correlated, at other places and horizons there is little certainty in the correlation of individual beds, even in sections but a short distance apart, though there may be and frequently is a good correlation of the general series of flows.

In certain portions of the series the flows over long distances are prevailingly much thinner or thicker than the general average. One persistent belt of thin flows lies above the "St. Louis" and No. 8 conglomerates; with the exception of the heavy trap that is immediately above the conglomerate in places the flows in this belt, for several hundred feet statigraphically, are thin, many being only 5 or 10 feet thick. To a less pronounced degree this is true of the belt above the "Mesnard" epidote. The flows for several hundred feet below the Allouez conglomerate or between the Allouez and Kearsarge conglomerates, on the other hand, average unusually thick, many of them reaching 100 to 200 feet or even more.

In addition to the broader variation in thickness of the flows over long distances discussed above and shown on the geologic maps and sections, there are local variations due largely to irregularities in the top of a flow or of the surface on which it rests. The surfaces of some of the flows are irregular and hummocky, showing differences in altitude of as much as 20 feet or even more. It is evident that the thickness of a flow measured from the tops of the hummocks would differ materially from the thickness measured from the bottoms of the depressions, especially if the flow should rest on one with equally irregular top and a depression in the upper flow lay over a hummock in the lower. In the flows with fragmental tops, in which most of the copper deposits occur, marked variations in thickness are the rule and make a close determination of the thickness of a flow from place to place impossible. In general it may be said that the flows having cellular or smooth tops are the most uniform in thickness and those having fragmental or rough tops the least uniform.

Sedimentary deposits commonly approach a plane. The base of a flow that rests on a conglomerate, sandstone, "scoriaceous" amygdaloid, or cellular amygdaloid will therefore be a nearly plane surface; a flow that rests on a fragmental amygdaloid will have an uneven base, and its thickness will vary accordingly.

COMPOSITION OF FLOWS

The great bulk of the flows of the Keweenawan series are basaltic, rather simple mineralogically, and monotonously similar in appearance. The district contains, however, numerous types of lava grading from typical olivine basalt through andesite to rhyolite.

The more basic flows are typical olivine basalts composed essentially of feldspar, pyroxene, olivine, and magnetite, the last two now largely altered to other minerals. In the flows of more andesitic composition olivine decreases and disappears and the proportion of feldspar to pyroxene increases. Biotite has been noted in the feldspathic flows but is not common or abundant. Toward the Michigan State line, north of Lake Gogebic, are feldspathic flows, with a very low proportion of dark mineral but without visible quartz phenocrysts, which approach rhyolite, and farther south, in Wisconsin, Aldrich[21] noted rhyolite porphyry flows, which also occur in the series north of Lake Superior.

The Keweenawan flows are of the "plateau" type. (See p. 25.) In the following tabulation of analyses two of the typical Keweenawan flows are compared in composition with plateau basalts from other localities as given by Washington[22] and with Daly's average basalt.