PROGRESS REPORT NUMBER TEN

STATE OF MICHIGAN

DEPARTMENT OF CONSERVATION
P. J. HOFFMASTER, Director

GEOLOGICAL SURVEY DIVISION
R. A. SMITH, State Geologist

Strategic Minerals Investigations in Marquette and Baraga Counties 1943

By

A. K. Snelgrove, W. A. Seaman, and V. L. Ayres

PREPARED IN COOPERATION WITH
THE MICHIGAN COLLEGE OF MINING AND TECHNOLOGY
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* As a wartime measure to conserve paper, the six maps of Lake Michigamme area and vicinity, Nos. 5 to 10, by W. A. Seaman (some of which are currently being added to or revised) are not being distributed with this report, of which they are a constituent part. However, copies may be obtained at a cost of 25 cents each by writing Geological Survey Division, Department of Conservation, Lansing, Michigan.

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NOTICE:
Special arrangements have been made to furnish Plates V to X inclusive through the Capitol City Blue Printers. These Plates can be obtained for 25 cents each or $1.50 for the set. In case the Plates are desired unfolded 10 cents should be added for additional mailing costs. Please make checks or money orders payable to the Capitol City Blue Printers, 577 Hollister Building, Lansing, Michigan.

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ABSTRACT

Geological prospecting in 1943 of the borders of some of the late pre-Cambrian granite masses of the Northern Peninsula of Michigan, for strategic minerals useful in the war, was directed chiefly to the western part of the Marquette Iron Range which was mapped in detail. Prospects were examined and reconnaissances made in other portions of Marquette and Baraga Counties which are less known geologically.

Spectrographic analyses were made on all samples collected, with special search for minor and rare elements of possible economic interest.

By use of ultraviolet light, scheelite, an ore of tungsten, previously reported occurring in magnetic iron ore northwest of Republic, was detected in a variety of deposits, none of which has so far proved commercial. The hydrothermally altered iron formations were first examined for scheelite; when this examination proved unprofitable, search for ferroalloy elements in general was undertaken, and a restudy started in field and laboratory of the broad problems of beneficiation of low-grade iron ores of the Marquette Range. Although maximum benefits to be derived from solution of difficulties in beneficiating iron ore are of long-term rather than immediate application, this field of research, from the geological as well as mineral dressing viewpoints, now appears to hold the greatest potential values for the mining industry of Northern Michigan.

The main contributions of this report are: 1. Original publication of the geological column of Lake Superior Region in general and of the Marquette Iron Range in particular, as interpreted by the late Professor A. E. Seaman and by W. A. Seaman; 2. New data on the structure and stratigraphy of the Lake Michigamme area; 3. A compilation of existing information on the Republic Trough of the Marquette Iron Range; 4. An addition to the literature on the geological features of the Ishpeming gold belt, in which lie possibilities for future development; 5. Preliminary results on beneficiation of low-grade iron ores; and 6. Spectrographic and other analytical data which should serve as a guide in further prospecting.

INTRODUCTION

Investigations of the geology of the pre-Cambrian area of the Northern Peninsula of Michigan are part of the functions of the Geological Survey Division of the Michigan Department of Conservation and of the Michigan College of Mining and Technology. Surveys of the region have been conducted by the Geological Survey since 1840, and since the founding of the College in 1885 surveys west of Marquette have been conducted in close cooperation by the two agencies.

For over 60 years it has been known that ore of at least one rare metal can be found in the contact zones at the periphery of the granite masses of the Northern Peninsula in the "wolframate of lime" (scheelite), an ore of tungsten, reported by State Geologist Rominger in 1881. Because advances in metallurgy and chemistry made rare elements of strategic importance in World War II, it logically followed that all areas where geological conditions are favorable for the existence of ores of those elements should be intensively studied, sampled, and mapped and use made of all modern tools of exploration such as the ultraviolet lamp.

The Michigan College of Mining and Technology and the Geological Survey Division recognized an opportunity for service in the war effort and the need to continue collaboration in the search for strategic minerals in the mineralized zones at the contact of the granite masses in Baraga and Marquette Counties; to explore and investigate all known occurrences of strategic minerals that contain tungsten, molybdenum, manganese, beryllium and ores of other needed rare metals; and to discover if possible other economic deposits and to make them available. Therefore, the programs of each agency were broadened to carry on the work.

Progress Report Number 10 is a record of the field work and laboratory investigations made in 1943—44.

In this progress report, each author is responsible for the opinions expressed in the sections which appear under his name; the interpretations advanced are not necessarily shared by his colleagues nor by the Geological Survey Division.

Location

Detailed mapping and prospecting were begun in June, 1943, in Township 47N, Range 30W, northwest of Republic, and later extended to Township 46N, Range 29W, and to Township 48N, Ranges 29 and 30W. Reconnaissances and examinations of mineral prospects were carried out in the gold-quartz belt north of Ishpeming, in the silver-lead-zinc district of Dead River Basin, in the Huron Mountain area, and in other parts of Marquette and Baraga Counties. In the Marquette Iron Range, systematic sampling was begun on iron formations in the search for minor and rare elements possibly of economic significance. The field work was continued until mid-November.

Personnel

The field personnel consisted of Professors A. K. Snelgrove, W. A. Seaman, and V. L. Ayres of the staff of the Department of Geological Engineering at the Michigan College of Mining and Technology. Miss D. Jeanne Seaman and Mr. W. B. Loring served ably as compassmen. Miss Seaman was also responsible for drafting most of the maps for publication. Mr. Charles E. Secor, caretaker of Michigan Gold Mining Company, rendered valuable assistance as guide to old prospects north of the Marquette Iron Range.

Professor N. H. Manderfield, head of the Department of Mineral Dressing at the Michigan College of Mining and Technology, spent considerable time in the field with the geologists, and collaborated on sampling of iron and other ores; his laboratory crushed samples, provided gold assays and other analytical data, and experimented on beneficiation of low-grade iron ores. Beneficiation tests were made by Professor Frank J. Tolonen. Spectrographic analyses and special quantitative determinations were made by Professor Bart Park of the Department of Chemistry at the college.

References to Earlier Work

Since the discovery a century ago of iron on the Marquette Range, the geology and ore deposits of Marquette County, and to a lesser extent of Baraga County, have been the subject of numerous reports. Only those which have some relevance to the present investigations are included in the following list of references:

Van Hise, C. R., and Bayley, W. S., The Marquette Iron-Bearing District of Michigan: United States Geological Survey Monograph 28, 1897. Chapter I gives a history of geological exploration in the district and a summary of previously published literature.

Van Hise, C. R., and Leith, C. K., The Geology of the Lake Superior Region: United States Geological Survey Monograph 52, 1911, Chapter XI, pp. 250—290, The Marquette Iron District of Michigan including the Swanzy, Dead River and Perch Lake areas. The Swanzy and Dead River areas are in Marquette County and the Perch Lake area is in Baraga County at the west end of the Marquette Basin.

Allen, R. C., The Iron Ore Reserves of Michigan: Michigan Geological Survey Publication 16, Geological Series 13, 1913. Gives location of workable slates, pp. 93—94, and refers to two areas of graphitic slate in Baraga County, p. 119.

——— ———., and Barrett, L. P., Contributions to Pre-Cambrian Geology of Northern Michigan and Wisconsin: Michigan Geological Survey Publication 18, Geological Series 15, 1915. This report contains a proposed revision of the Huronian Group, a discussion of the correlation and structure of the pre-Cambrian formations of the Gwinn District, and of the evidence of a Middle-Upper Huronian unconformity in the quartzite hills of Little Lake.

Smith, R. A., Non-metallic Minerals of Michigan: Michigan Geological Survey Publication 24, Geological Series 20, 1917, Part II. The marble and verde antique quarries of Marquette County are discussed.

Swanson, C. O., Report on a portion of the Marquette Range covered by the Michigan Geological Survey—1929: Michigan Geological Survey, Mimeograph report, 1930.

Zinn, Justin, Report on a portion of the Marquette Range between Humboldt and Lake Michigamme covered by the Michigan Geological Survey in 1930. Michigan Geological Survey, Mimeograph report, 1931.

——— ———., Correlation of the Upper Huronian in the Marquette and Crystal Falls District: Michigan Academy of Science Papers, volume 18, pp. 437—456, 1937.

Barrett, L. P., Huronian Slate in Baraga County: Pan-American Geologist, volume 47, number 1, pp. 68—69, 1932.

Royce, Stephen, Advances in Information on the Lake Superior Iron Deposits: Lake Superior Mining Institute, Proceedings 24th Annual Meeting, volume 24, pp. 149—181, 1925.

——— ———., Geology of the Lake Superior Iron Deposits: Lake Superior Mining Institute, Proceedings 29th Annual Meeting, volume 29, pp. 68—107, 1936.

Lamey, C. A., Granite Intrusions in the Huronian Formation of Northern Michigan: Journal of Geology, volume 39, pp. 288—295, 1931.

——— ———., The Intrusive Relations of the Republic Granite: Journal of Geology, volume 41, pp. 487—500, 1933.

——— ———., Some Metamorphic Effects of the Republic Granite: Journal of Geology, volume 42, pp. 248—263, 1934.

——— ———., The Palmer Gneiss: Geological Society of America, Bulletin 46, pp. 1137—1163, 1935.

——— ———., Republic Granite or Basement Complex: Journal of Geology, volume 45, pp. 487—510, 1937.

In these articles Lamey contends that the granite of the Southern Complex in the southern part of Marquette County is for the most part of post-Huronian age, although rocks of Archean age are also present.

Dickey, R. M., The Granitic Sequence in the Southern Complex of Upper Michigan: Journal of Geology, volume 44, pp. 317—340, 1936. In this paper Dickey postulates three granite invasions—two of Laurentian and one of Keweenawan age.

——— ———., The Ford River Granite of the Southern Complex of Upper Michigan: Journal of Geology, volume 46, pp. 321—335, 1938. In this paper Dickey thought one of the previously named "Archean" granites was an intrusion during the Lower-Middle Huronian interval, and named it Ford River from a locality in Dickinson County, South of Marquette County.

Adler, J. L., Stratigraphic Zones in the Negaunee Iron Formation of Marquette County Michigan: Journal of Geology, volume 43, pp. 113—132, 1935. In this paper Adler subdivided the Negaunee Iron Formation of Marquette County.

Leith, C. K., Lund, R. J., and Leith, A., Pre-Cambrian Rocks of the Lake Superior Region with Revised Geologic Map: United States Geological Survey Professional Paper 184, 1935. In this paper the authors include the findings of the Michigan Geological Survey and unpublished data supplied by Mr. L. P. Barrett on Baraga County and on that part of Marquette County lying along and northeast of the Dead River Basin.

Creveling, J. G., The Peridotite of Presque Isle, Michigan, a study in serpentization: American Journal of Science, 5th Series, volume 12, pp. 515—521, 1926.

Richarz, S., Origin of Grunerite of the Lake Superior Region: American Journal of Science, 5th Series, volume 14, pp. 150—154, 1927.

——— ———., Note on Grunerite of the Lake Superior Region: American Mineralogist, volume 17, number 9, pp. 437—442, 1932.

Wienert, F., Formation of Martite and other iron oxides in sideritic ore of Marquette District, Michigan: Economic Geology, volume 28, number 1, pp. 63—74, 1933.

Slawson, C. B., High-iron Tourmaline from the Marquette Iron Range (Abstract): American Mineralogist, volume 21, number 3, p. 195, 1936.

Ayres, V. L., Differentiation in Xenolithic Lamprophyre Dikes at Marquette, Michigan: Journal of Geology, volume 47, number 6, pp. 561—582, 1939.

——— ———., Nontronite from the New Richmond Mine: American Mineralogist, volume 25, number 6, pp. 432—434, 1940.

Tyler, S. A., Marsden, R. W., Grout, F. F., and Thiel, G. A., Studies of the Lake Superior Pre-Cambrian by accessory-mineral methods: Geological Society of America, Bulletin, volume 51, pp. 1429—1538, 1940.

Four granitic intrusions are described, two in the Laurentian, one in the Late Huronian and one in the Keweenawan. Report is also made on studies of the Huronian sedimentary rocks.

Fairbairn, H. W., Deformation Lamellae in quartz from the Ajibik formation, Michigan: Geological Society of America, Bulletin, volume 52, number 8, pp. 1265—1277, 1941.

Additional specific references are quoted in footnotes in the body of this report.

Acknowledgments

This work profited from several visits in the field by Dr. R. A. Smith, State Geologist, and Mr. Franklin G. Pardee, Mining Engineer, Geological Survey Division, Department of Conservation, and from their continued advice and interest.

Thanks are due to Mr. O. W. Terry, Mining Engineer, Central Region, Bureau of Mines, United States Department of the Interior, for cooperation in sampling the Grummet gold prospect for tungsten and other metals, and to the owner of the Grummet property for permission to make this examination.

The Ford Motor Company, through Mr. W. E. Willmott, Land Department, kindly granted use of the roads and trails across their extensive lands. The Oliver Iron Mining Company, through Mr. R. H. B. Jones, Geologist, generously made available a "Mineralight" at a time when the party's ultraviolet equipment was being repaired. Both of these companies, together with the Cleveland-Cliffs Iron Company, furthered this investigation by furnishing their records of diamond drilling in the Republic Trough.

The writers are specially indebted to the Board of County Road Commissioners of Marquette County, and to Mr. W. A. Gray, Engineer, for much map information and the office use of aerial photographs.

Mine operators in the Marquette Iron Range were uniformly cooperative, and furnished all needed information, as well as the use of laboratory facilities when required.

It is a pleasure to acknowledge the assistance of Miss Phyllis S. Rankin, Librarian, Peter White Public Library and Marquette County Historical Society, Marquette, Michigan, in searching the literature on the Ishpeming gold belt.

This report is built, to no small degree, upon a foundation of work extending over many decades, and hitherto unpublished—the field notes and conclusions of the late Professor A. E. Seaman which have been used freely. Fortunately, Professor Seaman's intimate knowledge of Northern Michigan was shared by his son, one of the authors of this report, whose own previous work has also been drawn upon. Since 1930, Dr. V. L. Ayres has spent many summer months in the Marquette Iron Range; for this report he has assembled his own findings and those of his students and others on the Republic portion of the range.

The stimulus and support given to this project by President Grover C. Dillman of the Michigan College of Mining and Technology are much appreciated by the writers.

PROCEDURES

Field

The field work of this investigation consisted of three more or less distinct but supplementary types.

Areal geological mapping in Western Marquette County was performed almost entirely by W. A. Seaman. (See Plates I and II and V to X.) His description of mapping methods is on page 24. Simultaneously with mapping, sampling was done on all mineral exposures suspected of being of commercial interest.

The methods and types of *sampling,* as discussed on page 25, apply also to the second phase of the investigation, which was largely a reconnaissance and was concerned with detection of strategic minerals hitherto unsought or overlooked in the numerous mines and prospects of the two counties.

Many hundreds of samples were selected for analysis, care being taken to segregate all varieties of mineral assemblages present, with special regard for minor or rare elements, of possible economic significance now or in the future. This work led to a critical examination of low-grade iron ores and to the problem of their beneficiation.

Because tungsten was in much demand in 1943, and the ore mineral, scheelite, is most readily detected by the *use of the ultraviolet lamp*, much time was spent at night in examining dumps and outcrops. In addition, some ultraviolet "lamping" was done in the daytime, using a black cloth to cover the specimen and the instrument. Before crushing, all samples collected were examined carefully for fluorescence. The apparatus used in this work was the "Mineralight," manufactured by Ultra-Violet Products, Inc. Model V-42 proved much more efficient than the less powerful model M-12.

Laboratory

Preparation of Samples

In the laboratory each sample was weighed before crushing to about ¾ inch in a jaw crusher. On crushing rolls, the samples were reduced to —10 mesh. Very large samples were cut by cone-and-quarter before going to the crushing rolls. The —10 mesh material was then thoroughly mixed and a sample of approximately 100 grams was cut out by a Jones riffle for analysis. This portion was weighed and ground to —100 mesh (or —200 mesh if tungsten-bearing samples), mixed on mixing paper, and sent to the chemist. Rejects and hand samples are deposited at the Michigan College of Mining and Technology.

Spectrographic and Quantitative Analyses.

By Bart Park

Approximately 75 mg. of rock powder (—100 mesh) was placed in the cavity of a graphite electrode. Another graphite rod served as the other electrode. Exposures of one minute at 50 volts and 13 amperes were used. Plates were Eastman Process or Process Panchromatic depending upon the region studied.

The spectrograph used in this work was a large Littrow type with quartz optical system made by the Gaertner Scientific Corporation.

Quantitative estimates were made in a few samples by visual comparison of the appropriate lines with those of known standard samples which had been photographed on the same plate.

Bismuth	— Determined photometrically with thiourea.
Chromium	— Determined photometrically as chromate.
Copper	— Determined electrolytically.
Fluorine	— Determined photometrically by bleaching an oxidized titanium solution.
Molybdenum	— Determined photometrically with phenyl hydrazine.
Nickel	— Determined gravimetrically with dimethylglyozime.
Titanium	— Determined photometrically with hydrogen peroxide.
Tungsten	— Determined gravimetrically by cinchonine method.
Vanadium	— Determined photometrically with strychnine.

Lithium and Tin were estimated spectrographically.

A No. 7-089 Fisher Electrophotometer was used in all photometric work.

Beneficiation of Iron Ores.

By Frank J. Tolonen

As it is not possible to separate mineral grains unless they are free or have been liberated by crushing and grinding operations, any positive method of measuring the degree of liberation will also measure the utmost possibility of separation or concentration. The physical property most commonly used in ore beneficiation is specific gravity. Using an equimolar solution of thallous-formate and thallous-malonate in water, a heavy solution having a range of densities up to 4.9 can be secured. Using the solution at various dilutions or densities, it is possible to separate any sample into fractions on the basis of mineral content. Because of the high cost of these chemicals, laboratory testing by this means has been restricted to sizes under ½ inch. Larger pieces can be separated by means of galena, or ferro-silicon suspension in pails or other suitable apparatus.

The fractions obtained by these methods are thoroughly washed to remove the heavy solution, or suspension. They are then dried, weighed, and crushed for analysis. Next they are analyzed for the valuable constituents and also for impurities that affect their market value. From these results, by calculation and graphic analysis, it is possible to evaluate the sample for any conceivable economic situation.

There are other methods of fractionating samples on the basis of their specific gravity, such as the tube classifier and laboratory tables and jigs, but in these the size and shape of particles have to be considered. In all of these methods porosity, which is very important in partially leached ores, must be considered.

If the results are not satisfactory, microscopic examination of the ore becomes necessary as by this means it can easily be ascertained to what size the sample must be ground in order to effect the desired degree of liberation, or in other words to obtain concentrates that are marketable.

When dealing with magnetite, the magnetic tube tester was used for separating the sample. By varying the magnetic field and the fineness of grind it is possible to evaluate any sample quite readily. Here also microscopic study greatly reduces the amount of testing required for final results.

The specific results obtained on a number of iron ores which were investigated in connection with the present work are discussed under Iron, pages 56—59.

SUMMARY OF THE GEOLOGY OF THE MARQUETTE IRON RANGE

By W. A. Seaman

The geological record of that portion of the Marquette Iron Range which lies in Marquette County is more complete, and is better known, than the record in Baraga County. This discussion therefore deals chiefly with Marquette County.

Explanatory Notes on the Geological Column of the Marquette Range

The numbers in parentheses correspond to the numbers following each entry on the Geological Column in Table 1.

(1) Keewatin, Mona

The oldest known rocks on the Marquette Range are the Keewatin schists which are so abundant in and around the city of Marquette and also extend for a few miles westward. In most exposures less than 75 percent of the rock consists of Keewatin as many younger dikes of various ages are present. There are also numerous veins of quartz, carbonates, and chert or jasper formed during one or another of the later periods. Jasper veins, some well banded with fine hematite or magnetite, are commonly prominent near and parallel to the edges of basic dikes. Much of the Keewatin is an amphibole schist and may have been derived from basic lavas or tuffs.

(2) Laurentian or Marquette

The earliest dikes intrusive into the Keewatin are rhyolite, quartz porphyry, and other phases of the Laurentian granite. These dikes are commonly lenticular by reason of shearing, and parallel the east-west schistosity of the Keewatin. Northward these dikes become wider and more numerous, until north of the Dead River an area is exposed that is predominantly granite. This granite is quite uniform in texture and composition and is generally neither gneissoid nor porphyritic. Considerable calcic feldspar is present and hornblende is abundant. This hornblende granite is cut by numerous dikes which, starting with the oldest, are (a) amphibolite, (b) north-and-south striking acidic diorites with considerable alkalic felspar and a little hornblende, (c) north-and-south uralitic diabase dikes, (d) north-northeast-south-southwest uralitic gabbro dikes similar to the Clarksburg, (e) northwest-southeast peridotite dikes, and, lastly, (f) east-and-west olivine diabase and ophite dikes of Keweenawan age. The same granite, cut by a similar multitude of dikes, is well exposed on Middle Island Point, on nearby rocky islands, and for a few miles westward. This is the largest known area of Laurentian in the Lake Superior Region.

(3) Kitchi

The oldest known sediment on the range is a conglomerate having well rounded pebbles of the Keewatin schist and vein quartz and various phases of the Laurentian granite. This basal conglomerate is well exposed close along the north side of a dirt road across the southern part of Sec. 29, T48N, R25W., north of Enchantment Lake (called Mud Lake on the older maps). Intermittent exposures of this same conglomerate are found for several miles westward past Negaunee and for two or three miles eastward. South of the conglomerate is the thick overlying graywacke and considerable slate, both of which, being derived largely from the underlying Keewatin, are often mistaken for it. Next above are thin quartzite beds and then more graywacke and slate. This series, sometimes referred to as the "Mud Lake" or the "Great" graywacke, is several hundred feet thick and extends over a good deal of the Marquette Range. It thins out east of Enchantment Lake, due partly to erosion before the next series was deposited, but thickens and widens to the westward where it is commonly faulted in with the Keewatin and with the base of the overlying Mesnard. Still farther westward to the limits of the range it is, in general, quite thoroughly granitized and has usually been mapped as granite or granite gneiss. East of Negaunee it was classed as Lower Mesnard, but west of Ishpeming it was called Kitchi and considered a phase of the Keewatin. After the Kitchi sediments were deposited, they were subjected to some, if not considerable, crustal movements before the rocks of the next series were laid down.

By W. A. Seaman

GEOLOGICAL COLUMN, MARQUETTE IRON RANGE

ERAS	PERIODS, etc.		GENERAL DESCRIPTION	Paragraph in text			Terms used in U. S. G. S. Monograph and some other publications
CENOZOIC	RECENT		Gravel, sand, clay, etc.	20			
CENOZOIC			Post-Glacial tilting	20			
CENOZOIC	PLEISTOCENE		Glaciation and glacial drift	20			
		Laramide (?)	Faulting and mineralization	19			
MESOZOIC			Not represented on Marquette Range	18			
PALEOZOIC	SILURIAN		Limestones, etc.	17c			Potsdam, Lake Superior
PALEOZOIC	ORDOVICIAN		Limestones, etc.	17c			Potsdam, Lake Superior
PALEOZOIC	CAMBRIAN	Upper Keweenawan	Cong, sandstone, shale	17b			Potsdam, Lake Superior
PALEOZOIC	CAMBRIAN	Upper Keweenawan	Olivine diabase, etc., dikes	17a		KEWEENAWAN	Keweenawan
		Superior	Pegmatites, granitization and mineralization	16		KEWEENAWAN	Killarney, "Algoman" Republic, "Laurentian"
PROTEROZOIC	SIBLEY		Peridotite, etc., intrusions	15		KEWEENAWAN	"Keweenawan", "Archean"
PROTEROZOIC	MICHIGAMME		Graywacke, slate, schist, etc.	14	HURONIAN	UPPER	Michigamme
PROTEROZOIC	MICHIGAMME		Clarksburg basic volcanics	13	HURONIAN	UPPER	Clarksburg
PROTEROZOIC	IRON	Upper	Bijiki Iron Formation, slate, etc.	12	HURONIAN	UPPER	Bijiki, Ishpeming
PROTEROZOIC	IRON	Upper	Goodrich cong, qtzite, slate, etc.	11	HURONIAN	UPPER	Goodrich, Ishpeming
PROTEROZOIC	IRON		Ishpeming basic volcanics	10	HURONIAN	UPPER	
PROTEROZOIC	IRON	Middle	Negaunee Iron Formation	9	HURONIAN	MIDDLE	Negaunee
PROTEROZOIC	IRON	Middle	Grwke, slate, etc.	9	HURONIAN	MIDDLE	
PROTEROZOIC	IRON		Hemlock basic volcanics	8	HURONIAN	MIDDLE	Siamo
PROTEROZOIC	IRON	Lower	Grwke, schist, slate, etc.	7	HURONIAN	MIDDLE	
PROTEROZOIC	IRON	Lower	Ajibik cong, qtzite, gneiss, etc.	7	HURONIAN	MIDDLE	Ajibik
			Champion deformation & long erosion interval	6	HURONIAN	MIDDLE	Algoman?
EOZOIC	KONA	Upper	Qtzite, slate, dolomite, gneiss, etc.	5	HURONIAN	LOWER	Kona, Wewe
EOZOIC	KONA		Kona basic volcanics	5	HURONIAN	LOWER	
EOZOIC	KONA	Lower	Qtzite, slate, dolomite, gneiss, etc.	5	HURONIAN	LOWER	Kona, "Mesnard"
EOZOIC	MESNARD		Qtzite, slate, schist, gneiss, etc.	4	HURONIAN	LOWER	Mesnard
EOZOIC	MESNARD		Cong, grwke, slate, gneiss, etc.	4	HURONIAN	LOWER	Mesnard
EOZOIC	KITCHI		Qtzite, slate, schist, gneiss, etc.	3	HURONIAN	ARCHEAN	"Mesnard", "Wewe" or Kitchi (Keewatin)
EOZOIC	KITCHI		Cong, grwke, slate, schist, gneiss	3	HURONIAN	ARCHEAN	"Mesnard", "Wewe" or Kitchi (Keewatin)
			Marquette granite, rhyolite, qtz porphyry, etc.	2		ARCHEAN	Laurentian
AZOIC	KEEWATIN		Schists from basic volcanics	1		ARCHEAN	Mona

TABLE 1

(4) Mesnard

(4a) The conglomerate at the base of the Mesnard lies unconformably upon, and contains pebbles of, the various phases of the underlying Kitchi, in addition to which are pebbles from a stratified cherty formation that may represent an eroded Kitchi bed not locally observed. Pebbles of Keewatin and Laurentian vary considerably in abundance. This conglomerate is well exposed in its relations along the north edge of the quartzite bluffs on Sec. 32, T48N, R26W, from one to one and a half miles east of Teal Lake. It has sometimes been called the "Quartz" conglomerate from the local abundance of vein quartz pebbles, and in many of its exposures in the eastern part of the range it has been confused with the conglomerate at the base of the Kitchi.

(4b) Above the Mesnard conglomerate lies 100 feet of slate interbedded with graywacke and thin quartzite, much of the latter sericitic, which grades up through sericitic quartzite into a white vitreous quartzite much veined with chert. This vitreous quartzite (named after Mt. Mesnard near Marquette) is about 300 feet thick and is well exposed along the lake shore near the State Police barracks at Marquette, in a syncline near the quarry near Harvey, and also forms a prominent cliff along the north edge of Lake Enchantment. It also lines the road-cut on the concrete highway east of Teal Lake, where it is unconformably overlain by the Ajibik. This quartzite has been almost entirely removed by erosion west of Negaunee, and on the south side of the Marquette Trough has been quite thoroughly granitized, commonly appearing as granitic gneiss, "granite porphyry," and other granitic rocks.

(4c) The Mesnard quartzite grades up through sericitic quartzite into a prominent belt of slate that is well exposed in the quartzite ridges east of Teal Lake, and in the syncline just north of the quarry south of Marquette near Harvey.

(5) Kona

(5a) A thin conglomerate with poorly sorted, sub-angular pebbles of quartzite and chert has been found in a few places overlying the Mesnard slate. Overlying this a dark sericitic quartzite rapidly grades up into a vitreous, or in places dolomitic, quartzite, about 75 feet thick, which has a banded cherty top, grading up into a cherty slate about 50 feet thick. This cherty slate is usually intricately folded and the cherty top of the underlying quartzite is generally much brecciated. These formations are well exposed from near Negaunee to Marquette along the north side of the trough. The "cherty top" quartzite was originally mapped as part of the Mesnard series. Conformably overlying the cherty slate is 200 to 300 feet of cherty dolomite, usually rather pinkish but weathering white. The chert is in thin laminae parallel to the bedding and in narrow veinlets across it. This dolomite is prominently exposed from Marquette southwestward to Goose Lake; the thickness is greatly exaggerated by close folding and repetitional thrust faulting. A dome-like structure, rendered conspicuous by differential weathering, has been attributed to algal remains but as this structure has been noted only where the dolomite has been crumpled against dikes, or in the axes of close folds (as in the exposure near the quarry at Harvey), it seems likely that it is a structural feature. A red slate, nearly 20 feet in thickness, overlies the dolomite.

(5b) Overlying the Lower Kona is a thin, usually pinkish, dolomitic and in part cherty quartzite, above which is less than 50 feet of slate, then about 200 feet of dolomite, seemingly less silicious than the lower one. Because of intricate folding and faulting this upper dolomite often cannot be readily distinguished from the lower one. The uppermost of the Kona formations is the emergent slate designated the Wewe in the monographs. It is of unknown thickness. Southwestward and westward from Goose Lake to the vicinity of Palmer are numerous remnants of the Kona series, although much of it is thoroughly granitized. These, with the underlying formations, constitute much of what has been called the Palmer gneiss.

(6) Champion Revolution*

After the Mesnard and Kona series were formed large-scale crustal movements occurred. The older rocks were greatly disturbed, probably and then deeply eroded before the rocks of the metamorphosed, perhaps more or less granitized,

* This term is here introduced for the first time.

next series were laid down. Near the east end of Teal Lake, the entire Kona series and much of the Mesnard were removed by erosion before the deposition of the next formations. West of Ishpeming are long stretches where practically all of the Mesnard was removed; to the south of Ishpeming less of the older rock was eroded, although most of the Kona is missing or unrecognized westward from Palmer.

In the Lake Michigamme area, this Champion Revolution is of such a magnitude near Champion, and the older rocks were so highly metamorphosed and intricately folded before the Ajibik was laid down, that it is difficult to recognize them.

(7) Ajibik

The Ajibik starts with a basal conglomerate, generally quite thin, with well rounded pebbles of the older rocks, especially the Mesnard quartzite. This conglomerate lies unconformably on various older formations from the Wewe to the Keewatin. Above the conglomerate is 50 feet of quartzitic slate, commonly crumpled, then from 50 to 100 feet of vitreous quartzite, usually followed by a slate as much as 100 feet thick and generally quite ferruginous near the top. The Ajibik quartzite is the best known and most easily identified member of this series though it is often confused with the older Mesnard. It is much less veined with chert than the Mesnard, is apt to be more pinkish and in many places has, near the top, ¼ inch black to brownish-red spots. This quartzite is well exposed all along the rim of the Marquette basin though it is quite thoroughly granitized along much of the southern side, and in places west of Ishpeming, along the northern rim.

(8) Hemlock

Deposition of the Ajibik series was halted by volcanic outbursts southwest of, and elsewhere beyond the limits of, the Marquette Range. Ash from one or more of these Hemlock volcanoes mingled with the ferruginous slates above the Ajibik quartzite. Some of these ash layers, 2 or 3 feet in thickness, may be seen south of Negaunee and also south of Republic. Still farther south some iron formation had been laid down, but in Marquette County, which was probably nearer the main shore line, the water may not have been deep or quiet enough for deposition of an iron formation, and ferruginous slates were formed instead. The Ajibik slates, ash layers, and the graywackes and slates of the next younger series have been loosely grouped together under the term "Siamo."

(9) Negaunee

(9a and b) After the brief interruption caused by the Hemlock volcanic activity and change in sea level, deposition was resumed. Near shore, quartzite or graywacke (and in some places conglomerate) was formed. Zones in the limonitic quartzite or graywacke exposed in low ridges north of the Maas Mine, Negaunee, have many brown sandy concretions several inches in diameter. Above this concretionary quartzite is a considerable thickness of slate that becomes more ferruginous toward the top. This slate and the underlying concretionary quartzite vary in thickness in different parts of the district from a few feet to over 200 feet. Above this comes the main or Negaunee Iron Formation which has an orginal unfaulted thickness of about 400 feet. The original material was either: thinly bedded chert and iron carbonate, or, less commonly on the Marquette Range, a hydrous ferrous iron silicate (greenalite). The many other phases of the iron formation have been derived from one or the other of these.

(9c) The cherty iron carbonate near the top of the iron formation was largely oxidized to ferruginous cherts with thin layers of "limonite" or soft, red, earthy hematite. Later metamorphism converted these ferruginous cherts to banded specular hematite and jasper, well known and exposed throughout the range as "jaspilite." The hematite bands in the jaspilite often contain considerable fine magnetite.

(9d) The less abundant greenalite was oxidized to a sandy or granular-appearing ferruginous rock, like some of the softer "taconyte" on the Mesabi and other ranges.

(9e) Where the oxidized, jaspilite phase of the iron formation was more intensely metamorphosed, the banded magnetite and granular quartz phase was produced. The soft taconytic phase was likewise changed to the magnetic type

of taconyte. These highly metamorphosed phases are found in proximity to the areas of most intensive granitization, the banded magnetite being common in the vicinity of the Magnetic, Michigamme, Spurr, and other mines closest to the areas of maximum granitization.

(9f) When the original cherty siderite or greenalite was subjected before oxidation to the extreme metamorphic conditions that accompanied the later granitization, they were changed to the iron silicate grunerite (or cummingtonite) with varying amounts of magnetite and quartz. Gruneritic rocks are abundant in the lower part of the iron formation in areas where granitization progressed furthest. They are especially abundant in the same areas where the upper part of the iron formation has been changed to banded magnetite and granular quartz.

(9g) The iron ore was formed by one or more of these processes: by mechanical concentration, by removal of silica, and by addition of iron, either from other parts of the iron formation or from other sources. Mechanical concentration was important in the formation of some of the thin, rich, ore bodies mined from the base of the conglomerate directly overlying the iron formation, though in some places the silicious pebbles had been partly or completely removed and the resultant space either lined or sometimes completely filled with iron oxide. The ore on the range commonly lies in pitching troughs formed either by folding of the iron formation and underlying slate, or it lies where one or both sides of the trough consists of dike, fault blocks of suitable strata, gouge or other impervious material. The ore may be soft earthy "limonite," soft red to nearly black hematite, or metamorphosed hard blue to black hematite or magnetite. Different types of ore may be found within a short distance, as in Jackson Pit, Negaunee, where the jaspilite dipping down against the north side of a narrow basic dike has been locally replaced by nearly black hematite, whereas a few feet away on the other side of the dike the crumpled jaspilite has been replaced by "limonite." The original unconcentrated iron formation contains scarcely half enough iron to be used as an ore at present.

(10) Ishpeming

The term Ishpeming was originally used to include the conglomerate, quartzite, and slates above the Negaunee, but is here restricted to the volcanics accompanying the local upheaval that stopped the deposition of the Negaunee Iron Formation. This volcanic activity seemed to have started in the vicinity of Ishpeming and continued intermittently for some time, culminating in the later widespread eruptions in Clarksburg time near Champion. Good exposures of the Ishpeming intrusives are abundant in the uralitic diabase or "diorite" knobs around Ishpeming and Negaunee.

(11) Goodrich

Following the uplift around Ishpeming, a thick conglomerate with poorly sorted, subangular pebbles, overlain by a quartzite of considerable thickness, was formed. The pebbles in this conglomerate are almost entirely from the iron formation immediately beneath it, though locally there are pebbles from older formations where the thrusting that probably accompanied the Ishpeming intrusions perhaps brought the older rocks within reach of erosion. No place is known where erosion at this time cut deeply into the underlying iron formation. This locally thick Goodrich conglomerate and quartzite thins out to the south and west, and is rather inconspicuous near the western limits of the Marquette Range. On most of the other ranges the iron formation emerged very little, if at all, and the Goodrich, which may be 200 feet thick near Ishpeming, is represented in many places by from 10 to 50 feet of slate in which there may be a thin conglomerate bed.

(12) Bijiki

The Goodrich is succeeded in some places by a few feet of slate or interbedded slate and quartzite and then by iron formation. In other places, the Goodrich is immediately succeeded by the Upper Iron Formation. This Bijiki formation (named after the Pesheekee River) is generally leaner than the Middle or Negaunee Iron Formation, the original carbonate having been somewhat nearer to ankerite than siderite. It has been oxidized and metamorphosed in the same manner as described for the Negaunee formation. The Bijiki attained a thickness of about 50 feet (exclusive of the slates) before deposition was stopped by the upheaval that accompanied the Clarksburg volcanics. In some areas, particularly on the south side of the Marquette basin, part of this iron formation had considerable volcanic ash mixed with it.

In other areas, emergence and oscillation resulted in the formation of interbedded quartzite and slates. Several mines, especially northeast and north of Champion and westward from Michigamme, formerly produced ore from the Bijiki formation. Much of the ore was limonitic, though all the other types that occur in the Negaunee have also been found in the Bijiki.

(13) Clarksburg

Gabbro and diabase dikes are particularly numerous in the Lake Michigamme area but also extend as far east as Marquette and westward and southward to the limits of the range. Clarksburg sills are abundant around Champion and Michigamme and at least as far south as Republic. These sills and dikes have been almost completely uralitized or otherwise metamorphosed. The edges of the larger dikes are commonly sheared and many of the narrower ones are now chlorite and amphibole or biotite schists. Others have had abundant chloritoid, tourmaline, and large garnets formed in them. Many are cut by pegmatites. The Clarksburg tuff ranges from coarse material near Champion, where some of the angular blocks are several feet in diameter, to fine tuff in the vicinity of Clarksburg, or to fine ash farther away. Many of the dikes and sills are over 100 feet thick and the tuff may be over 500 feet thick between Champion and Clarksburg.

(14) Michigamme

Partly contemporaneous with, but mostly succeeding, the extensive Clarksburg volcanics are the graywackes and slates of the Michigamme series. In the lower part are concretionary graywackes, mica-graywacke schist, and staurolitic mica schist with several thin interbedded layers of tuffaceous material. Higher up are slates containing progressively less basic material. The total thickness of the Michigamme series may be 1,000 feet, but that thickness is not likely attained in the Lake Michigamme area where th thickness may be less than 500 feet. It is inte mittently exposed in a multitude of rolls acros a distance of about 4 miles and in this area th underlying Goodrich, Bijiki, and even the Ne gaunee Iron Formation are exposed in some lo calities and probably lie quite close to the sur face in other places. Although these exposure of the iron formations may be the tops of anti clines, probably in some areas near Lake Michi gamme the ore in the troughs may not be too deep for profitable mining.

(15) Sibley

Following the Michigamme sedimentation came crustal movements throughout the Lake Superior Region. In Marquette County, these were accompanied by the intrusion of masses of quite basic rock, notably the peridotite at Presque Isle and along the south edge of the Gold Range northwest of Ishpeming. Many narrow dikes of peridotite are common on Middle Island Point and are less abundant as far south as South Marquette. In Houghton, Ontonagon, and Gogebic Counties, the Bessemer sandstone (or quartzite) and overlying lava flows that are cut by felsite and then by olivine diabase dikes belong to the lower part of this series, which has long been known as the South Trap series. However since 1931 at the Michigan College of Mining and Technology T. L. Tanton's term "Sibley"* has been used instead of South Trap because on Sibley Peninsula east of Thunder Bay on the north shore of Lake Superior the exposures are better and more continuous, the dip is flat, the exposures are not faulted causing repetition of section, and on Sibley Peninsula vulcanism was not excessive. Vulcanism is not necessarily characteristic of the series in most of the Lake Superior Region.

(16) Superior or Republic

After the Sibley peridotite intrusion, a major geological revolution took place accompanied by great changes in land and sea level throughout the Lake Superior Region, by granitization, and by mineralization of the older rocks over

* Tanton, T. L., Fort William and Port Arthur, and Thunder Cape Map-areas, Thunder Bay District, Ontario: Geological Survey of Canada, Memoir 167, 1931.

large areas. Most of the numerous pegmatites in the region are of this age. Vast changes were effected in the structure and character of the older rocks, and many were altered almost beyond recognition. Notable among these changes were further crumpling of the iron formation and much of its metamorphism; the development of staurolite and garnet in some phases of the Michigamme formation, and of chloritoid, uralite, tourmaline, and garnet in the Clarksburg intrusives. Also of this age are some of the gold-tungsten-molybdenum-bearing veins and the beryllium- and andalusite-bearing pegmatites.

(17) Paleozoic

(17a) Following the Superior revolution a great number of east-and-west olivine diabase and ophite dikes (Keweenawan) were intruded in the Marquette Range. In these dikes both the olivine and the augite are quite fresh, in contrast to their almost completely altered state in the pre-Superior intrusives.

(17b) The Keweenawan intrusives were succeeded by the deposition of a sandstone, exposures of which are mostly restricted to low areas near Lake Superior.

(17c) The Cambrian sandstone is succeeded by limestones, etc. of Ordovician and Silurian age to the southeast of the Marquette Range.

(18) Mesozoic

From the time when the Paleozoic limestones were laid down until comparatively late geological time, the Marquette Range was presumably mostly land, and erosion instead of deposition was probably taking place; hence there is no rock record of later Paleozoic or Mesozoic time. Although erosion was probably long continued in the district, it was likely not deep as the land elevation was probably no more and perhaps much less than at present. A great deal of the topography usually attributed to deep erosion has been produced by late faulting.

(19) Laramide (?)

Post-Paleozoic faulting thrust up the fresher peridotite from deep below on the northeastern part of Presque Isle, near Marquette. The Cambrian sandstone and conglomerate that lie along the lake shore to the southward are badly disturbed against this fault zone. This faulting was not accompanied by any known intrusives in Marquette County, but that some mineralization occurred at that time is proved by silver, galena, and chalcopyrite, in and near the fault. About 40 miles northwest of Michigamme the fossiliferous Ordovician, Silurian, and Devonian limestones are closely folded, faulted, and recrystallized; it seems probable that some of the faulting on the Marquette Range that affects the youngest rocks in the vicinity may also be post-Devonian, although the limited distribution of Paleozoic rocks in most of the Marquette Range area makes the age of the younger faulting difficult to determine.

(20) Pleistocene and Recent

The latest important geological events on the Marquette Range were continental glaciation, subsequent tilting of the land, and post-glacial deposition. The mantle of glacial material is in many places more than 100 feet thick, and in many areas almost hopelessly hides the underlying formations and veins from the geological worker and the prospector. Scouring by the glaciers also removed most of the chances of finding profitable placer deposits.

Mineral Deposits of the Marquette Iron Range

Table 2 presents a synopsis of the mineral deposits of various parts of the Marquette Iron Range. (See pocket)

LAKE MICHIGAMME AREA

By W. A. Seaman

Geological History

The geological histories of the Lake Michigamme area and the Marquette Range coincide as a whole except for a few local details. The paragraph numbers are the same as those used in the general descriptions in the preceding section and in the Geological Column, Table 1.

(1) Very little *Keewatin* was recognized in the Lake Michigamme area and, in mapping, it was included with the highly metamorphosed pre-Ajibik sediments. A few outcrops of chlorite and amphibole schist, seemingly overlain to the south by a conglomerate containing fragments of this schist, in the southern part of Sec. 21, T48N, R29W, are believed to be Keewatin.

(2) No *Laurentian* granite was identified though some small exposures of granitic material, not proved to be granitized sediments, may be remnants of the old granite. They are shown on the detailed maps of Secs. 20, 21, T48N, R30W. Most of the large areas shown as "Laurentian granite" on older maps, north of Lake Michigamme and south of Beacon Hill, have been identified as more or less granitized Ajibik or pre-Ajibik sediments in the latest detailed mapping.

(3) Closely folded and often quite thoroughly granitized sediments, striking about north and south in the Lake Michigamme area, have been tentatively classed as *Kitchi*. A common type is a rather thick graywacke or impure quartzite that was seen and sampled in all phases transitional to a hornblende biotite schist, and finally into a more or less gneissoid rock with a mineralogical composition ranging from a quartz monzonite to a grano-diorite. It occurs in tight folds striking from north and south to north 30° east, on the north side of the lake, and from north to north 30° west near Beacon Hill. The dips are usually nearly vertical to steep westward with both limbs of the folds dipping in the same direction, though one limb may dip more steeply than the other. In spite of the great repetition by close folding and some thrust faulting, it is thought that this great graywacke series is considerably thicker here than it is near the east end of the Marquette Range.

(4) The *Mesnard* quartzite in the Lake Michigamme area occurs most frequently as sericitized quartzite, granitic gneiss, or the so-called "granite porphyry". The strike and the dip are generally about the same as those of the Kitchi. The series seems to be somewhat thicker and more widespread south of Beacon Hill, apparently only remnants of it being left north of the lake. In this report the Mesnard is grouped with the other pre-Ajibik formations except in some detailed work such as that done south of Beacon Hill.

(5) In the Lake Michigamme area the *Kona* was not definitely recognized in place. That it was not entirely removed during pre-Ajibik erosion is shown by the occurrence of sizeable fragments in the Clarksburg tuff at Champion. It is thought that some of the contorted gneiss exposed in the axes of some partly eroded anticlines of Ajibik near Beacon Hill, and also some of the intricately folded gneiss that lies close to and apparently above some of the Mesnard south of there, may be highly metamorphosed Kona.

(6) A period of intensive deformation apparently intervened between the deposition of the pre-Ajibik sediments and the formation of the Ajibik quartzite; the deformation produced a series of close folds striking about north and south. The higher metamorphism of the pre-Ajibik, as compared to metamorphism of later formations, may have occurred partly at that time. These north and south folds were affected by the post-Michigamme deformation which superimposed east-and-west striking folds and thrust faults upon the structures of the older rocks, resulting in the notably rough and knobby topography, especially north of the lake.

(7) The *Ajibik* quartzite in the Lake Michigamme area is in many places the oldest easily recognizable sediment. The general strike is about east and west on the north side of the lake, and more nearly northeast in the Beacon Hill area. The general dip is toward the lake, usually at high angles. Near Beacon Hill the quartzite

is closely folded with both limbs, except near the crests of anticlines, dipping northeastward, one limb somewhat steeper than the other. The quartzite is overlain by graywacke and by slate, some of which is ferruginous.

North of the lake only the lower part of the quartzite is appreciably granitized, but in the Beacon Hill area a progressive change is noted from only slight granitization to higher degrees of metamorphism, especially to the southeastward. In general, the changes are:

(a) Vitreous quartzite, in many places slightly sericitized.

(b) Yellowish sericitized quartzite with a few feldspar crystals up to 4 or 5 mm. developed.

(c) Yellowish sericitized quartzite with more abundant and larger feldspars and with enlargement of the quartz grains visible with a hand lens.

(d) A whiter quartzite with notably enlarged quartz and still more abundant feldspar.

(e) Granitic gneiss with mica and frequently large feldspars, predominantly alkalic.

(f) Gneissoid granitic rock that gradually and progressively becomes more granitic and less gneissoid, or

(g) "Porphyritic" granitic rock, sometimes only slightly gneissoid and with the larger feldspars orientated roughly parallel to the strike of the formation.

No "contact" or line of demarcation can be found between any of the phases, nor between either of the last phases and the more massive appearing granitic rock that has been called granite and variously classified as Killarney, Republic, Superior, "Algoman," or "Laurentian."

All of the types described are cut by numerous pegmatites, most of which approximately parallel the general strike and dip of the metamorphosed sediments.

(8) *Hemlock* volcanics were not identified in the Lake Michigamme area but some biotite schist and graywacke zones in the "Siamo" between the Ajibik quartzite and the Negaunee Iron Formation may mark the Hemlock horizon.

(9) Most of the exposed *Negaunee Iron Formation* in the Lake Michigamme area is gruneritic in the lower parts, and grades upward into either the magnetite-granular quartz phase or to jaspilite. The formation is conformable with the underlying Ajibik and hence the dips, north of the lake and near Beacon Hill, are generally steep. The formation is cut by numerous basic dikes and by later pegmatites.

West of Lake Michigamme, jaspilite in several places lies rather flat. These exposures may be near the crests of anticlines and it is presumed that the Negaunee Iron Formation underlies the Bijiki and Michigamme throughout most of the area. Troughs and rolls in the iron formation, containing good ore, may lie fairly close to surface in places. The ore previously mined in this district has been from the steeply dipping iron formation close below the Goodrich and has been mostly hard ore. It seems likely that considerable good soft ore may be found in some of the less intensely folded and metamorphosed areas such as those west of Lake Michigamme.

(10) Any *Ishpeming* volcanics, if present in the area, were not separated from the Clarksburg in the mapping.

(11) The *Goodrich* is represented in the Lake Michigamme area by several feet of conglomerate succeeded by a rather thick quartzite that is commonly dark green to nearly black from chloritic material and magnetite. Most of the pebbles in the conglomerate are sub-angular fragments of the underlying iron formation, with subordinate slaty material. In no place has erosion cut deeply into the underlying Negaunee Iron Formation. It is thought that much of the iron formation material in the Goodrich may have been derived from rapid erosion where folding or faulting had locally elevated the iron formation immediately preceding Goodrich time. The strike and the dip of the Goodrich seem to be about the same as the strike and dip of the immediately underlying formation except for quite short distances in a few places, where a local fold of the iron formation was partly eroded. The Goodrich formation appears to thin out to the westward.

Slate and sericite schist beds, especially near the southern side of the trough, have been noted. Chloritoid, sometimes in plates larger than 30 mm. across, is locally abundant in the Goodrich, especially close to the areas of maximum granitization.

(12) In some places, especially on the north-

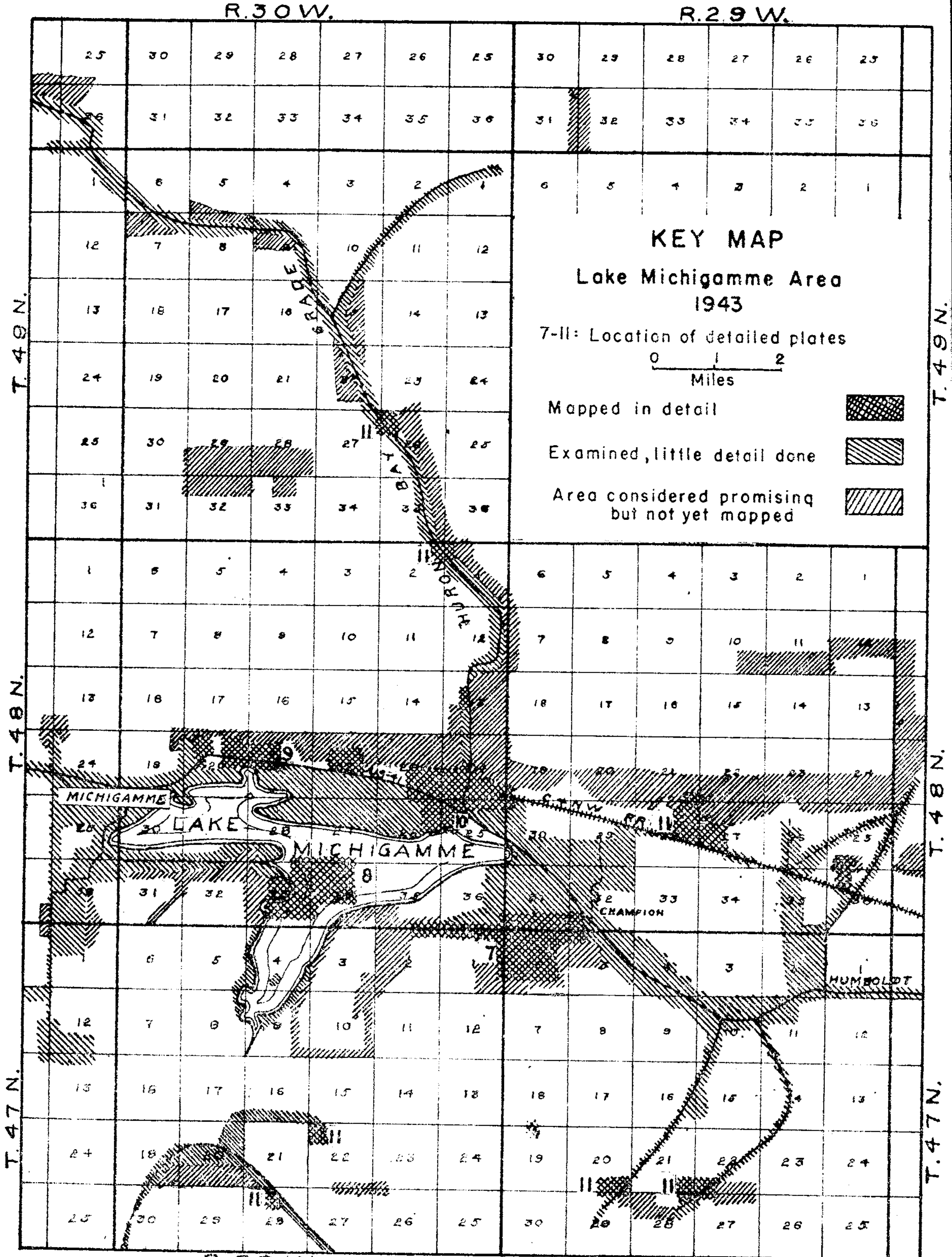
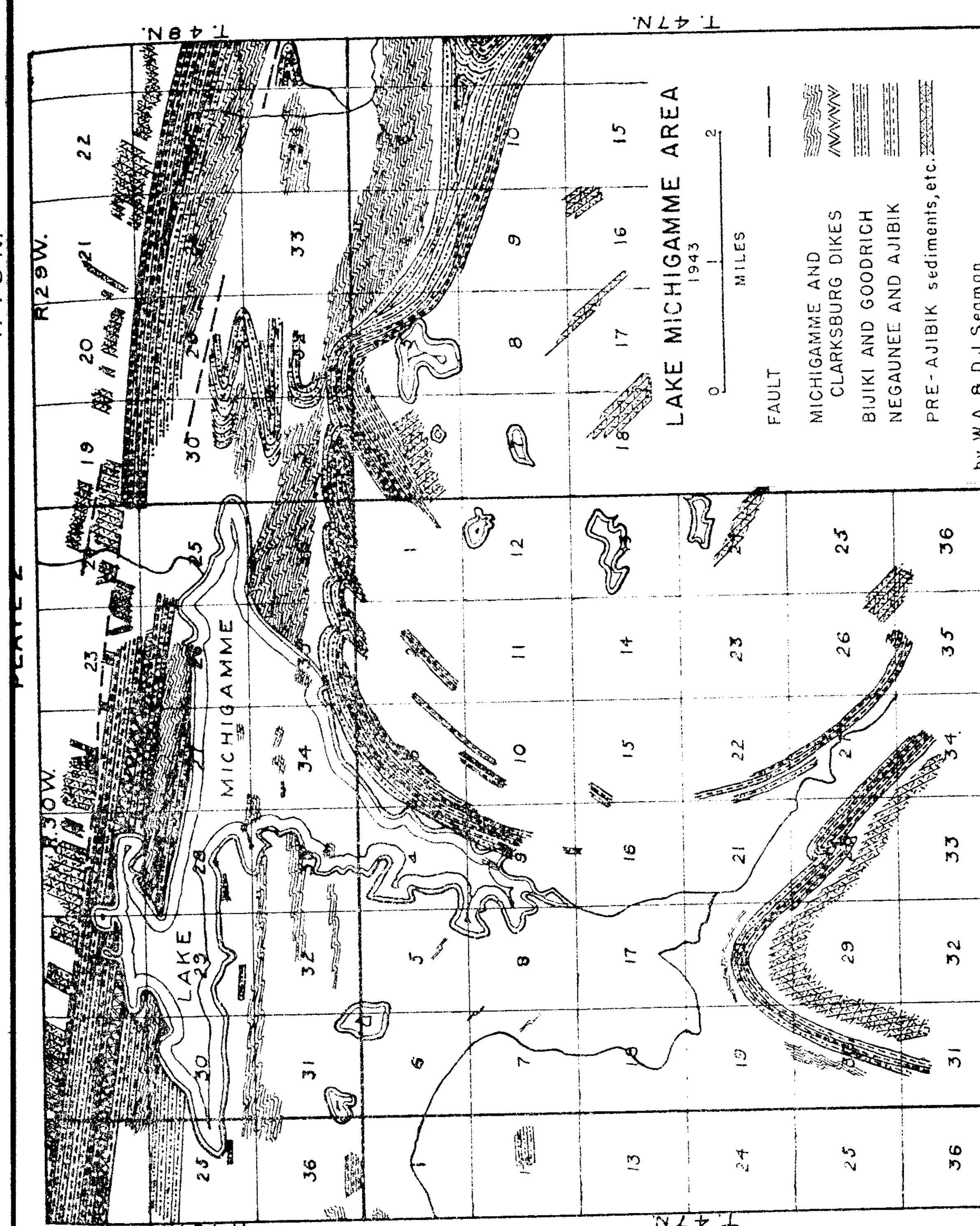


PLATE 1

Key Map of the Lake Michigamme Area
(Correction: Detailed plates 7—11 are renumbered 6—10 respectively)



General Geological Map of the Lake Michigamme Area ern limb of the basin, the Goodrich quartzite grades directly into the overlying *Bijiki Iron Formation.* In other localities, especially nearer the southern side, a considerable thickness of black slate, commonly with thin interbedded black quartzite, separates the Goodrich from the Bijiki. The iron-bearing part of the Bijiki appears to be considerably less than 100 feet thick and varies from the gruneritic phase at the bottom to ferruginous chert near the top, though in limited areas part of it may be the magnetite-granular quartz or other phases similar to those in the Negaunee. Toward the eastern part of the Lake Michigamme area considerable basic volcanic ash is interbedded with some of the Bijiki. Like the other formations in the area, the Bijiki is much folded and considerably faulted, and is cut by some basic dikes and a few pegmatites. Most of the ore mined from the Bijiki was the iron hydrate ("limonite") though there is some hematite in it and a little manganese.

(13) *Clarksburg* dikes are abundant and strike about east and west in the western part of the area, and from northeasterly to nearly north in the central and eastern part. They are mostly uralitized gabbro or diabase and vary in width from a few inches to over 100 feet. Large garnets, chloritoid, and sometimes tourmaline and other minerals are locally abundant along the contacts, especially where the dikes are closest to the zones of greatest granitization. Many of the dikes are sheared and somewhat mineralized along the edges. Spectrographically many show beryllium and nickel and fewer reveal silver, molybdenum, and other rare metals.

Tuffs, reaching a thickness of several hundred feet, are abundant in the eastern part of the area. The coarest tuff seen was just northeast of the Beacon Hill map area, where fragments as much as several feet in diameter occur in a matrix of basic ash and sand. Fragments of all the older formations, from the Mesnard quartzite up, have been identified. The tuff appears thicker nearer the south side of the trough. Thin layers are interbedded with the lower part of the Michigamme schists west of the lake, and considerable tuffaceous material is intermingled with some of the Bijiki east of Champion.

(14) No break that could be mapped was found between the Clarksburg tuff and the *Michigamme* formation—the two are interbedded in places. Portions of the map area that are designated as "Clarksburg-Michigamme" include the tuffs, the smaller Clarksburg dikes and the Michigamme graywackes and schists with their interbedded tuffs. Only the large dikes are shown bearing a distinctive legend.

The Michigamme formation is well exposed west of the lake from which it takes its name. It consists of graywacke with interbedded slate or mica schist, and tuff layers; concretionary graywacke; and staurolitic mica schist grading into fine mica schist or slate. Garnets are locally abundant in each of these phases. The formation west of the lake, and on islands near the west side, is in a series of folds striking about east and west, and varying from gentle rolls to closed folds, some of which are overturned. Each of the phases of the formation may be seen repeatedly in any north to south section, but the structure and succession have not yet been worked out in sufficient detail to give accurate thicknesses. It is believed that there may be only one, and probably not more than two, of the concretionary graywacke zones; and that perhaps each exposure of the wider staurolitic schist belt may be of the same zone. The cleavage is about vertical, but the bedding, though often quite steep, varies from vertical to horizontal. The total thickness of the Michigamme series, including interbedded tuff, is estimated to be several hundred feet but probably less than 1,000 feet.

The staurolite crystals are commonly X-twins about 10 to 15 mm. long. Occasional narrow belts show crystals 50 mm. in length. They vary greatly in abundance along the strike. In the concretionary zones the graywacke nodules range in size from very small to about 6 x 12 x 24 inches (15 x 30 x 60 cm.) and have their longest dimension downward along the bedding and their shortest dimension perpendicular to it. Many nodules have a one inch (25 mm.) zone of small garnets surrounding a central portion which may be either hollow or filled with quartz or other minerals.

(15) No rocks of *Sibley* age were identified in the area though one rather fresh-looking, columnar-jointed, diabase striking east and west on Sec. 20, T48N, R30W may be of this age. It somewhat resembles the Sibley (or South Trap) series of diabases that are in adjacent Baraga County, but it is exposed for only part of its width on the hanging side at the base of a cliff of highly metamorphosed sediments, and is so contaminated with fragments of the wall rock that its identification is still open to question.

(16) Pegmatites are abundant in all of the formations, from the pre-Ajibik sediments to the Michigamme, inclusive. In general they are more abundant in the older formations.

In the pre-Ajibik they are quite variable, even along the strike of the same dike. They range from coarse feldspathic pegmatites with broad feldspars and large quartz and muscovite crystals to graphic granites, or to feldspar-poor pegmatites and quartz veins. They generally either parallel the strike of the sediments, which is ordinarily about north and south, or else strike about east and west, parallel to the strike of the younger rocks. Many of them are very irregular in strike, dip, and width. It may be that all the pegmatites in the pre-Ajibik are not of the same age, but many of them can be followed into later formations. Most of these pegmatites do not seem to have more than spectrographic amounts of strategic minerals, although one wide vein in Sec. 28, T48N, R29W, showed an encouraging amount of molybdenite. This feldspar-poor pegmatite is exposed for a distance of 125 feet along the strike, and for a width of 50 feet from the northern contact. The southern edge is covered by overburden. Spectrographically it showed silver as well as molybdenum near the northern edge.

In the Ajibik sediments most of the pegmatites approximately parallel the strike, although narrower branches were observed at nearly all strikes for short distances. The majority of the pegmatites in the Ajibik have abundant fairly coarse feldspar with subordinate mica. Andalusite, beryl, and apatite, although observed, are comparatively rare.

It was difficult to find pegmatites in place in the poorly exposed Negaunee Iron Formation and in the Goodrich, but material on the waste-rock pile around the mines shows considerable pegmatite, some of which has quite coarse muscovite, apatite and andalusite. Some of this pegmatitic material showed contacts with the iron formation.

The Michigamme formation is intruded by many pegmatites—a few of them have considerable feldspar, many are very poor in feldspar, and some have so little that they were classed as quartz veins in the tabulation of analyses. Few of the pegmatites can be followed for more than a few hundred feet before they pinch out; many reappear in parallel position a few feet to one side. The same echelon arrangement has also been noted in section, as the pegmatites neither strike nor dip quite parallel to the schistosity of the Michigamme country rock. Occasionally narrow stringers of dike or vein connect through the schist from one long lens of pegmatite to another, either in plan or in section. Some of these pegmatite and vein zones are over 100 feet wide, with varying proportions of wall rock included. In general the veins pinch out to the eastward and in the few low vertical sections available they seem to widen downward, two or three narrow veins joining downward into one vein that is wider than the total of the narrower veins above.

Some feldspar-poor pegmatites have locally abundant andalusite in long crystals 10 to 30 mm. or more in diameter. Occasionally, as on a rocky island in the SE 1/4 of Sec. 28, T48N, R30W, the vein dikes, from 2 to 3 feet wide, are almost solid fine-grained andalusite. In other places a feldspar-poor pegmatite may be followed along the strike into a zone, rich in fine-grained andalusite, which gradually narrows but continues for some distance in the schist as a silicate zone without well defined boundaries.

Most of these pegmatitic zones in the Michigamme formation show, at least spectrographically, beryllium and molybdenum, especially near their southern side. The wall rock, especially along the southern side and narrow horses of the Michigamme schist in the veins, usually shows beryllium, molybdenum, and nickel spectrographically.

(17 to 20) Except for a few fresh-appearing, columnar, east-and-west diabase dikes that appear to cut all formations, including the latest pegmatites, there seems to be no definite geological record of events in the Lake Michigamme

area until Glacial time. Glacial scouring and plucking have modified the hills and glacial debris and Recent deposits have buried much of the older formations in the valleys and lowlands to a depth that prevents direct field observations over more than 90 percent of the area.

Table 1 gives the detailed succession on the Marquette Range. As the differences in character and thickness of some of the formations on this range are as great as those between the Marquette Range and other ranges, it is considered advisable to give the succession in each of three well-spaced sections in order to make this clear. (Table 3, in pocket)

Some of the thicknesses given are considerably less than those often reported, due to the common exaggeration of true thickness so often encountered in areas of steep dips. For example, a horizontal width of a mile of Ajibik sediments near Beacon Hill with a nearly uniform dip of 80° to the northwest does not represent 5,000 feet of thickness, because when the structure is worked out in detail the repetition by close folding and thrust faulting becomes evident and the true thickness is found to be only about a tenth of the apparent thickness.

It is known that in some sections, and it may be true in many others, the figures given in the literature for the thickness may be about right but the decimal point is in the wrong place. This is quite apt to be true for areas where the dips are steeper, as the repetition by close folding and thrust faulting may be very great although not readily apparent.

For purposes of comparison two other sections are given in Table 3: one from adjacent Baraga County and on through into Houghton County; the other one on the more distant north shore of Lake Superior, including a considerable area of rather flat lying rocks where the original character, true unfaulted succession, and unmodified thickness can be more readily determined.

Mapping Methods

In this survey, lines were run with a dial compass and distances determined by pacing.

The thread and standard of the dial compass were set correctly for the latitude. Tables of corrections were made and used which took care of the longitude, time equation, and refraction. They also took care of any imperfection in centering the thread.

Pacing was converted in all plotting to the standard of 2,000 paces to the mile, or 1 pace equal to 2.64 feet. The pacing was carefully done and the error probably held to less than 1%.

Traverses were kept as close to the outcrops to be mapped as was practical. Triangulation methods were used to establish position on islands in Lake Michigamme, on some of the high bluffs difficult to scale, and elsewhere when it was not considered feasible to carry a traverse the entire distance.

Mapping was done in cross-section notebooks ruled about 6 lines to the inch, a scale of 10 paces to the small square or 60 paces to the inch being generally used. Some details were mapped at scales of 1, 2, or 5 paces to the small square. A small amount of reconnaissance work was mapped at scales of 120 or more paces to the inch.

Most of the mapping was transferred from the notebooks to cross-section sheets and plotted, first to a uniform scale of 100 paces to the inch (20 inches to the mile), and later, if the detail permitted, was replotted to a scale of 10 inches to the mile so that more territory could be shown on a map of convenient size. Finally, general maps were made on a scale of 2 inches to the mile. On these last small scale maps, some of the topography, roads, streams, and lakes in areas not surveyed in detail were plotted from aerial photos obtained through the Michigan Geological Survey and from maps furnished by the Marquette County Road Commission. Considerable geological information on these small scale maps, outside the areas mapped in detail this year, is from previous college, private, and commercial work done by A. E. Seaman, W. A. Seaman, and C. A. Lamey.

Section corners and quarterposts which were not traversed to are shown on all the maps in the position in which they would be if the sections were all exactly a mile square and the lines run true. Where traverses were actually run and detailed mapping done, the position of the corners and quarterposts found are shown in the position as determined by the traverses in all maps except those to the scale of 2 inches to the mile.

The dip needle was resorted to only where certain geological boundaries or horizons could not be traced otherwise through heavy overburden. In the closely folded, highly metamorphosed areas where there were many basic intrusives, the dip needle was seldom of much help except in locating the main or Negaunee Iron Formation.

Sampling Methods

One or more of the following five types of samples were taken, depending upon the character and structure of the formation, its accessibility, and the time and opportunity available.

(1) Channel Sample. Every inch of the vein or formation was taken in equal amount across the entire specified width or distance.

(2) Skip Channel Sample. An approximately equal-sized portion was taken at about uniform intervals. This type of sampling was used when the bed or vein was quite thick but apparently rather uniform in character, or where insufficient exposures made more precise sampling impractical. It was also used for wide veins and thick beds where transportation difficulties necessitated reduction in the weight and volume of the sample. Three types of skip channel samples were taken, from "10 percent" skip channels for the widest and most nearly uniform veins to the "50 percent" skip channels that were more frequently used.

(2a) 10 Percent Skip Channel. At every 10 units of distance a unit width sample was taken.

(2b) 25 Percent Skip Channel. One fourth of the channeled material was taken, the portions being of about equal size and spaced nearly uniformly.

(2c) 50 Percent Skip Channel. About half of the material was taken or alternate equal portions.

(3) Selected Average Sample. The material was all carefully examined with a hand lens and that which was deemed representative and average was taken. This method was applied particularly to the material in old stock piles and waste rock dumps, to wide massive dikes that showed no change of character for a considerable distance, and in some reconnaissance work where lack of time or opportunity precluded the use of other methods.

(4) Hand specimens were intended to be selected average samples and were usually hand trimmed to a uniform size of about 3 x 4½ inches.

(5) Grab Sample. Taken on reconnaissance trips where bulk and weight of the samples had to be taken into consideration, or when lack of time or opportunity rendered other methods of sampling impractical. Grab samples, not being considered at all reliable, are not included in the summary of analyses, nor tabulated with the results on page 27.

Analyses and Assays

The following are the elements most generally tested for and reported spectrographically, those in the right hand column being less often asked for.

Beryllium	Boron
Chromium	Lead
Cobalt	Lithium
Copper	Manganese
Gold	Strontium
Molybdenum	Tin
Nickel	Tungsten
Silver	Vanadium
	Zinc

Tables 4 and 5 present the geological and geographical distribution of samples, together with spectrographic determinations.

Occurrence of Strategic Metals and Minerals Lake Michigamme Area

This section is based upon hand-lens work in the field up to November 18, 1943, and on spectrographic determinations of 135 samples.

Beryllium is seemingly widespread in parts of Marquette and Baraga Counties, even outside of the Lake Michigamme area. It has been found in the following associations, although not necessarily as the mineral beryl:

(1) In beryl crystals in feldspar-poor pegmatites and quartz vein-dikes associated with a little feldspar, muscovite, some andalusite, and in places molybdenite. These pegmatites are intrusive into the Michigamme slates and graywackes and are to be correlated with the Superior

TABLE 4

TABULATION OF SAMPLES ACCORDING TO STRATIGRAPHIC OCCURENCE, LAKE MICHIGAMME AREA

By W. A. Seaman

Formations	Few if any dikes or veins:	Pegmatites cutting horizon indicated	Feldspar poor	Quartz veins	Basic dikes	Sheared dikes
Michigamme Schist and Graywacke & Clarksburg Tuff and Ash Layers	47-31-1 #1, 2, 3 48-29-32 #2, 3 48-30-28 #1, 1a, 4, 5, 6, 7, 9, 10, 11, 12 48-30-30 #1, 2, 3 48-30-33 #2, 4, 6, 8 48-30-34 #1, 2, 3, 5, 6, 8 48-31-25 #1	47-30-4 #1, 2	48-30-28 #2, 3, 8 48-30-33 #1, 5, 6 48-30-34 #6, 7, 10	48-29-32 #1, 1A 48-30-29 #1 48-30-30 #4 48-30-33 #3, 7, 9 48-30-34 #1F, #4, 6, 7, 9, 10, 11, 12, 13, 14		
Basic Dikes	48-29-31 #26	47-29-6 #13, 14, 41	47-30-22 #4	47-29-6 #10		
Bijiki Slate	48-29-32 #4 48-29-35 #3					
Bijiki Iron Formation & Ore	48-29-29 #1, 2, 3, 4, 5, 6, 7, 8, 9 48-29-29 #1 48-29-35 #1, 2 48-30-26 #1, 2			47-29-5 #1, 2, 3, 4		
Goodrich Qtzite & Cg	48-29-31 #13, 15 48-29-32 #7, 8				48-29-32 #9	
Negaunee Iron Formation & Ore	47-30-30 #4, 5, 6 48-29-31 #8, 10, 11, 12, 15 19, 20, 21, 22 48-29-32 #5, 6, 10		48-29-31 #15	48-29-31 #15, 16	48-29-31 #7, 14, 15 48-29-32 #9, 11	48-30-20 #1
"Siamo" Graywacke and Slate	47-29-6 #15, 16 48-29-25 #2, 3 48-29-31 #17, 18, 23 48-30-20 #2 48-30-23 #14, 14a	48-29-31 #24, 25		48-29-25 #4, 5	48-30-23 #15	48-29-31 #17, 18 48-30-20 #3, 15a
Ajibik Quartzite	47-29-6 #1, 2, 5, 6, 17, 18 20, 21, 22, 42 47-30-20 #13 48-29-31 #1, 2, 3, 4, 5, 6, 9 48-30-20 #4	47-29-6 #4, 13, 14 30, 35, 41 47-30-1 #2 48-29-31 #1A		47-29-6 #10 47-30-1 #1 47-30-20 #2 48-29-25 #1	47-29-6 #11	47-29-6 #3, 7, 9, 12, 19, 23, 34 48-29-31 #6
Pre-Ajibik Complex including granitized Mesnard and Kitchi	47-29-6 #24, 25, 26, 27, 28, 36, 37 48-29-21 #2, 3, 4, 5, 7 48-29-27 #1 48-29-28 #1, 2, 4, 8, 9 48-30-20 #9, 11, 15, 17, 18 48-30-21 #1, 2, 3, 5 48-30-22 #1, 2, 3, 4 48-30-23 #3, 5, 6, 11 48-30-24 #1, 3, 5	47-29-6 #32, 38, 29, 40 47-29-5 #1 48-29-21 #1 48-29-27 #2 48-29-28 #3, 7 48-30-13 #2 48-30-20 #12 48-30-21 #1, 2, 3, 4, 6, 8, 9 48-30-23 #1, 2, 7, 10, 12, 18	47-30-22 #4 48-29-28 #10 48-30-20 #13 48-30-21 #1	47-29-6 #29 47-30-22 #1, 2 48-30-13 #1 48-30-20 #14 48-30-21 #7 48-30-23 #9	47-29-6 #31 48-29-28 #5 48-30-20 #5, 6, 7, 8, 15 48-30-23 #3, 8 48-30-24 #2	47-29-6 #33 47-30-22 #3 48-29-21 #6 48-29-28 #6 48-30-20 #10 48-30-23 #4, 5 48-30-24 #4

TABLE 5

STRATIGRAPHIC DISTRIBUTION OF ELEMENTS, LAKE MICHIGAMME AREA.

By W. A. Seaman

	FORMATIONS & NUMBER OF SAMPLES ANALYZED		Ag	Be	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sn	V	Zn	B,Li,Sr	Blank
Pegmatites in	Michigamme schist & Clarksburg tuff, etc.	17	—	9	—	—	1	—	—	2	3	—	1	—	8	2
	Goodrich, Iron formation, "Siamo," etc.	3	—	1	—	—	1	—	2	—	—	—	—	—	—	0
	Ajibik	3	—	—	—	—	—	—	1	—	1	—	—	—	1	0
	Pre-Ajibik	18	1	—	—	—	—	—	2	—	5	—	—	—	3	10
Quartz Veins in	Michigamme-Clarksburg	17	—	2	—	1	1	—	1	1	—	—	—	—	1	12
	Bijiki-Goodrich	6	—	—	—	—	—	—	—	—	—	—	1	—	—	5
	Negaunee I. F.	2	—	—	—	—	—	—	—	—	—	—	—	—	1	1
	"Siamo"	2	—	—	—	—	—	—	1	—	1	—	—	—	—	0
	Ajibik	4	—	—	—	—	1	—	—	1	2	—	—	—	—	2
	Pre-Ajibik	3	—	—	—	—	—	—	—	—	—	—	1	—	—	2
Formations without veins	Basic Dikes (Mostly sheared Clarksburg)	16	2	6	1	1	—	—	—	11	—	—	7	—	—	1
	Michigamme-Clarksburg	23	—	15	—	6	—	—	3	16	—	1	4	—	—	1
	Bijiki	6	—	1	—	—	—	1	—	3	1	—	—	1	—	1
	Goodrich	2	—	—	—	—	—	—	—	—	—	—	1	—	—	1
	Negaunee I. F.	8	—	—	—	—	—	3	—	—	—	1	1	—	—	5
	"Siamo"	8	—	2	—	—	1	—	2	2	1	—	3	—	1	1
	Ajibik	5	—	—	—	—	—	—	—	—	1	—	—	—	1	3
	Pre-Ajibik	5	—	3	—	—	—	—	1	—	—	—	—	—	—	1
	Totals	148	3	39	1	8	5	4	13	36	15	2	24	1	16	48

(Killarney or Republic) granite. Beryl crystals have not yet been found in the Lake Michigamme area as large as those in similar veins near Republic (see page 43), nor does the beryl seem to be abundant in the portions of the veins exposed. In general the beryllium-bearing veins are poorly exposed, outcropping only at intervals in the low parts of the shore and islands in Lake Michigamme and the edges of valleys in some of the neighboring hills.

(2) In the schistose graywacke or slaty wall rock of the beryllium-bearing veins as determined spectrographically though no beryl was noticed in the field.

(3) In granitized quartzite, graywacke, and slate of Mesnard and Ajibik age, near pegmatite dikes. No beryl crystals were observed.

(4) Along the sheared edges of uralitic diabase and other basic dikes (mostly of Clarksburg age) that have been intruded and metamorphosed by the Superior granite. No beryl crystals were seen in these dikes.

(5) In the matrix of the Clarksburg tuff in synclinal folds where no pegmatites were visible and where the small quartz gash-veins present were entirely barren.

Chromium was found spectrographically only in thin beds of basic tuff, interbedded with graywacke and slate, where these are cut by veinlets of quartz and rhombohedral carbonate, near the axis of a syncline in the Michigamme, on an island in Lake Michigamme. It was shown in 6 spectrographic analyses. The occurrence gives no promise of commercial quantities.

Cobalt was noted in only one spectrographic report and was from a narrow sheared zone along the edge of a uralitic diabase dike near Beacon Hill. Nickel and vanadium showed in the same analysis. The occurrence was unexpected but of no apparent value or promise.

Copper in insignificant amount was frequently encountered in veins and along the sheared edges of basic dikes. It was even rarer than might have been expected. Disseminated chalcopyrite was frequently seen but the "richest" exposure noted was a two-inch vein that might have assayed as much as 3 pounds to the ton. Nothing approaching commercial ore was seen or is expected in the area that has been covered in detail.

Iron Ore as "limonite," hematite, and magnetite was seen in many places but no detailed work was done on it as it was a large problem in itself and outside the direct scope of the summer's work. It might be worth noting however that the boundaries of the iron formations as usually mapped do not fully coincide with some of the mapping done this summer. A more thorough mapping of the iron formations may reveal additional places to look for ore.

Hard ore. There are likely places between Champion and Michigamme where further detailed exploration may reveal commercial ore. West of Lake Michigamme the iron formation is probably not buried so deep locally under the Michigamme formation that it cannot be mined profitably. One locality was visited at which a jaspilitic phase of the Negaunee Iron Formation was exposed at surface intermittently over several acres. Although this appeared to be near the axis of an anticline, it was considered likely that ore might be encountered at moderate depth either north or south of the area. The Goodrich was observed to outcrop at another place south of the west part of Lake Michigamme. The Michigamme formation seems to be in comparatively gentle folds in a good deal of the territory west of the lake and is not likely to be nearly as thick as generally supposed; therefore, it may be that some *soft ore* might be found in some of the shallower troughs. A fairly rich limonitic phase of the Bijiki Iron Formation crops out in a nearly horizontal position and has also been exposed in several shallow pits west of the south end of Lake Michigamme.

Several samples of different phases of the iron formation were taken to the Mineral Dressing Department of the Michigan College of Mining and Technology. They were examined and tested to see if they could be beneficiated. The results are discussed on pages 56—59.

Lead was noticed in some of the spectrographic analyses and in a few veins an insignificant amount of galena was seen under a hand lens. In none of the area that was mapped in detail was any encouraging amount found.

Manganese was reported spectrographically in many samples, but none was seen under a hand lens in the field except in the waste rock dumps of some of the iron mines where pyrolusite, manganite, psilomelane, and rhodochrosite were found in limited amounts. Manganese is usually present in the iron formation in small amounts, but any commercial quantity would not likely be found except in pockets in the ore zone which could not be examined in the outcrop.

Molybdenum, occurring in the mineral molybdenite, was seen in several veins and was also reported spectrographically in much the same occurrence as beryllium, though it was sometimes found without beryllium. The best showing is along the north edge of a wide quartz vein, northeast of Champion, where the north three feet have quite an amount of molybdenite disseminated through it and small segregations are also present near the contact. The southern edge of this vein was not exposed—all that could be seen of it was the northern 50 feet in one place and near the northern edge for about 125 feet westward. The main part of the vein has not yet been sampled but it is not believed that the molybdenite is as abundant in it as it is along the northern edge. This occurrence merits further investigation.

Nickel was noted in many of the spectrographic reports, although no nickel minerals were positively identified in the field. What may be a little pentlandite was seen in some of the shear zones along the edges of basic dikes with pyrite and chalcopyrite. It was reported in the samples showing silver, in some specimens of the veins and wall rock of the beryllium-bearing veins, and occasionally in the iron formation, especially the Bijiki, where it was shattered and veined. No important amounts have been found nor are expected in the area so far mapped in detail.

Silver minerals were not noticed in the field, but silver was reported spectrographically from two locations. In each case it was from the sheared edge of basic dikes cutting thoroughly granitized sediments and in turn cut by nearby pegmatites, and seeming very close to thrust fault zones that appeared to be later than the granite. The occurrence of the silver seems much like that in the Garden River district in Ontario east of Sault Ste. Marie. There is no evidence that the silver in these veins is likely to be commercial. The age of the silver mineralization may be the same as in the Copper Country where the mineralization appears to be closely associated with the late (Laramide ?) faulting.

Tin was reported from only two samples. One was a veined mica schist that appeared to be in the axis of a synclinal fold in the Michigamme formation, on an island in Lake Michigamme. The other was from a highly metamorphosed garnet-magnetite phase of the Negaunee Iron Formation where closely folded, just south of Champion. Neither occurrence seems of much promise but the locations will be revisited and re-examined when conditions permit. Tin will also be watched for more closely in the future.

Vanadium is widespread in very small amounts. None of the quantitative analyses to date have shown more than a few hundredths of one per cent. It occurs in various slates, mica schist, fine-grained graywacke, the iron formations, and in the basic dikes. It is hoped that enough may somewhere be found in the iron ore bodies to permit of its extraction as a profitable by-product.

Zinc has not yet been found in the Lake Michigamme area in quantities sufficient to even show in a hand specimen. It has been reported spectrographically from very few places, the most interesting perhaps being in the Bijiki Iron Formation from the Marine Mine pit, north of Champion.

Andalusite occurs in groups of crystals 1 x 3 inches and in rough prisms commonly two or more inches in diameter and has been seen as large as 6 x 12 inches. It is found in feldspar-poor pegmatites and quartz vein-dikes of Superior (Killarney or Republic granite) age. These veins usually run about east and west and generally dip quite steeply. Some beryl is found in the same veins, and some apatite also in greenish crystals as much as 1 x 3 inches in size. Some of these andalusite-bearing veins are quite wide, but the andalusite is seldom in zones more than two or three feet wide in the veins, and may be along one wall or near the middle. It is also in coarsely crystalline silicate zones in the wall rock, and in silicate zones from a few inches to three feet wide, roughly paralleling the strike and cleavage of the schist. Some narrow silicate zones pass into veins when followed along the strike. The andalusite in these veins and silicate zones is commonly a pale lilac color and quite fresh. Some is rather reddish and is so fresh that the cleavage faces, though notably less perfect than those in feldspar, make it appear quite like the feldspar in the same pegmatites. Smaller andalusite, in many places quite badly altered, has been found in graywacke and quartzite of Mesnard and especially Ajibik age where metamorphism has been quite intense. The andalusite veins, like the beryllium-bearing veins, are not well exposed and much more work remains to be done in locating and examining them. It is hoped that some of the andalusite may be commercially exploited.

Chlorite, especially "Aphrosiderite," occurs quite extensively in and along the edges of some of the large Clarksburg basic dikes, notably where they cut the iron formation and are greatly metamorphosed (probably by the nearby Superior granite). One or more companies making composition roofing have been interested in this material which seems quite abundant. The difficulty in using it appears to be due to inability to separate the hard garnet dodecahedrons from their matrix of chlorite. The material is difficult to crush—even where the garnets seem to be lacking, enough are in the rock to wreck rolls and other crushing equipment.

Feldspar of commercial quality has not yet been found in the Lake Michigamme area though a few of the pegmatites give promise, especially some in the granitic hills north of Champion and Lake Michigamme.

Garnet, as mentioned under chlorite, may be more of a liability than an asset though someone may figure out a use for the rather fresh garnets that occur in dodecahedrons that are 2 to 3 inches and some 4 inches across the flats. Also fresh red trapezohedrons and dodecahedrons of garnet an inch or so in diameter are common in belts several feet wide or thick in several of the formations near the iron formation and in the iron formation itself. In some of these zones the garnet seems to make up as much as 50 percent of the rock by volume.

Graphite is abundant at many places in the various slates of the iron formation, from the slate below the main iron formation to the slate above the upper one. It is also with grunerite and magnetite in some of the highly metamorphosed phases of the iron formation, especially the upper phase. Although the graphite is the main constituent in many of the slates, it is in a very finely divided state approximating what is known to the trade as "amorphous" graphite. It was formerly mined by open cut near the southeast corner of Sec. 9, T49N, R33W in Baraga County and treated in a plant at L'Anse. Several other localities having graphite of similar quality and probably equal abundance are now more readily accessible elsewhere, especially near Champion.

Muscovite and sericite are common; the muscovite is in plates commonly less than ½ inch in diameter and not likely to be commercial except in a few pegmatites north of the middle of township 48 north where it is hoped to find not only commercial mica but also feldspar.

Beds of quite pure muscovite or sericite have been developed in some phases of the slates interbedded with the Goodrich in places. Some of these beds are over 90 percent pure muscovite. Their extent is not yet known but it is hoped that future work may prove them of value.

A sample submitted to the U. S. Bureau of Mines was found to consist essentially of muscovite with which are associated minor amounts of rutile and feldspar. Wet ground to —325 mesh, this material is being investigated as a possible paint extender.

Quartz is, of course, common in veins, and is the most abundant gangue mineral in the district. Most of the veins are too small to be worked but it is hoped that some of the wider ones, such as the 50-foot wide vein northeast of Champion that has molybdenite along its edge, may be of commercial use. Practically all quartzites in the district are either originally too impure or have been too thoroughly granitized to be of any use for the production of silica.

No quartz crystals of commercial grade have been noted.

Staurolite is found in certain zones in the Michigamme graywacke in crystals (usually X-twinned) more than an inch in length, but no osity, is known at present.
use for them, other than as an interesting curi-

REPUBLIC AREA

By V. L. Ayres

Abstract

The Republic Trough is a northwest-trending syncline of Middle and Upper Huronian sediments outside of which is a crystalline complex consisting mostly of porphyritic granite and greenstones. The older literature assigned the granite to the Archean but more recently it has been called post-Huronian by Lamey and post-Lower, pre-Middle Huronian by Dickey. The writer presents further evidence indicative of post-Huronian age, considering the porphyritic granite as a replacement of older granites and sediments which had become highly plastic but not molten.

Geology and Petrography

United States Geological Survey Monograph 28, published in 1897, contains in addition to a bibliography of previous geological work, a chapter by H. L. Smyth on the geology of the Republic District. The crystalline complex is considered as a basement upon which the Huronian sediments were laid down.* Herein use is made of Smyth's localities and additional localities are described.

Lamey in 1933** suggested the name "Republic Granite" for the "Southern Complex" of Archean connotation because he considered it post-Huronian.

Dickey*** in 1938 proposed to substitute "Ford River" for "Republic" for the "granite-porphyry" which he thought to be post-Lower Huronian and pre-Middle Huronian.

In presenting new evidence for the post-Huronian age of the porphyritic granite, this section of Progress Report No. 10 will first take up the sediments in stratigraphic order as found in the Republic district. It will then pass on to the basic intrusives and the granites nearby, then to the Ford River rocks, and to a summary of conclusions. Appended are comments on the pegmatitic minerals associated with the late granite.

* Van Hise, C. R., and Bayley, W. S., The Marquette Iron-Bearing District of Michigan: United States Geological Survey Monograph 28, p. 526, 1897.

** Lamey, Carl A., The Intrusive Relations of the Republic Granite: Journal of Geology, volume XLI, pp. 487—500, 1933.

*** Dickey, R. M., The Ford River Granite of the Southern Complex of Upper Michigan: Journal of Geology, volume XLVI, pp. 321—335, 1938.

The sedimentary column for the Republic trough is:

- Upper Huronian
  - Michigamme slate and graywacke, including at least one zone of iron formation (Greenwood or Bijiki)
  - Goodrich quartzite and conglomerate, including a detrital hard ore zone at the base
- Unconformity
- Middle Huronian
  - Negaunee Iron Formation
  - Ajibik quartzite and conglomerate

SEDIMENTARY ROCKS

Ajibik

The oldest of the sedimentary rocks not metamorphosed beyond recognition is the Ajibik at the base of the Middle Huronian—a quartzite and conglomerate grading in part into mica schist. Seven or eight localities are shown in the atlas which accompanies Smyth's report.

Smyth states, regarding the relationship to the underlying crystalline rocks, "In only one known locality in which it is found to rest in direct contact upon the Archean does it appear as a coarse conglomerate made up of recognizable fragments derived from the underlying granite and crystalline schists."* This locality is in the eastern part of the NW 1/4 of the NE 1/4 of Sec. 18, T46N, R29W. This is reviewed in great detail by Lamey** who claims that the pebbles and boulders are not of granite since they contain no feldspar, and that the matrix is not arkosic but "is actually cut by dike-like intrusions which have emanated from some larger granite mass, apparently the granite associated with the conglomerate," which he considers post-Huronian.

* United States Geological Survey Monograph 28, p. 528, 1897.

** Lamey, Carl A., Republic Granite or Basement Complex?: Journal of Geology, volume XLV, pp. 494—499, 1937.

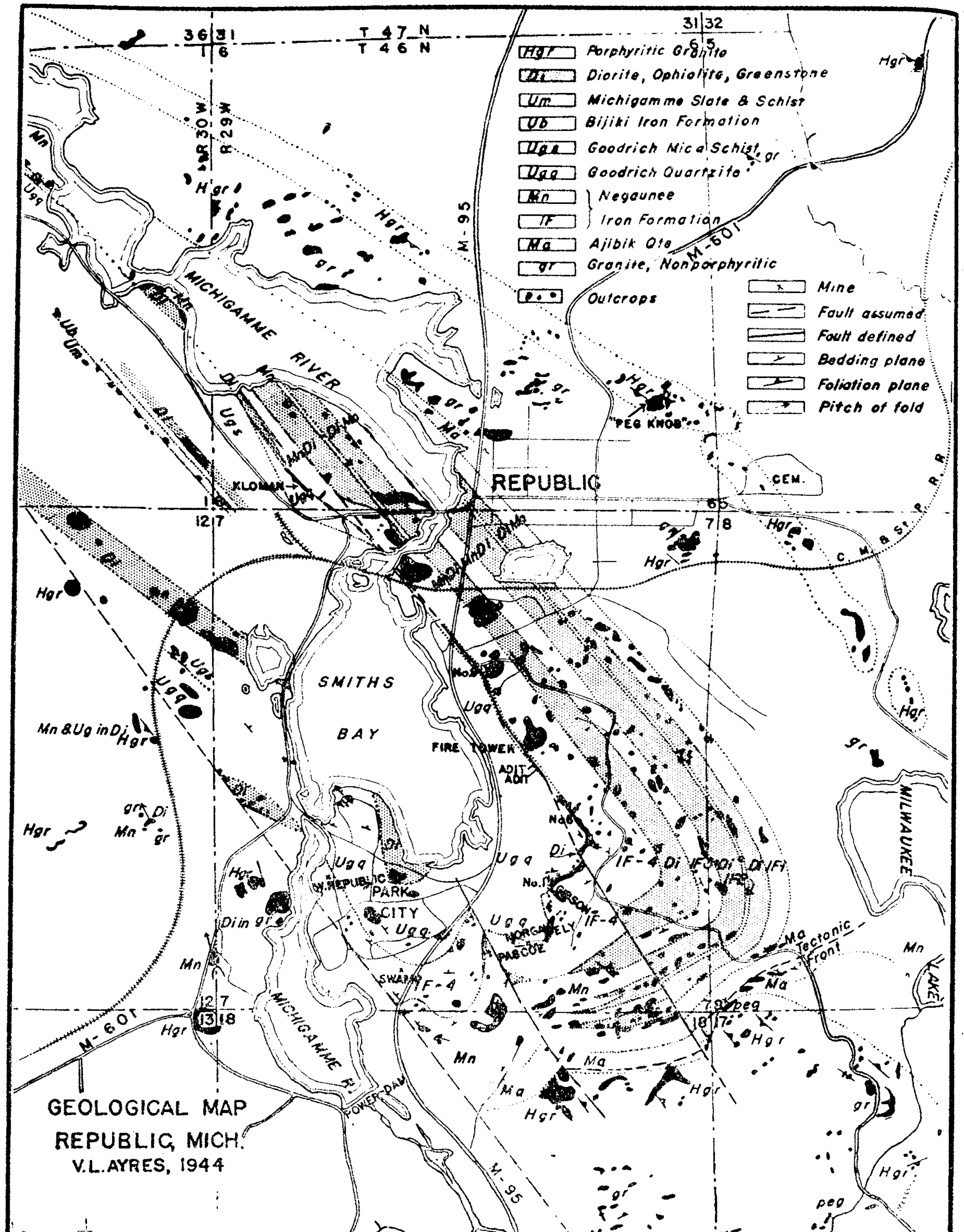


PLATE 3

Geological Map, Republic

Additional proof of the replacement rather than the unconformable nature of the contact between the granite and the Ajibik conglomerate was found by the writer in an outcrop 1,400 feet farther east-northeastward along the "tectonic front." (See Plate 3) Here a plaster of conglomeratic vitreous quartzite shows gradation southward within a single bed to a granite-like rock. A short distance farther southward the porphyritic granite crops out. The quartzite is considered Ajibik (basal Middle Huronian) rather than Mesnard (basal Lower Huronian) because considerable interbanded chert and grunerite are in the quartzite and mica schist along the tectonic front farther east-northeastward in Sec. 8, T46N, R29W. The outcrops are outside the Ajibik margin as mapped by Smyth, and they are separated by a marsh from the less metamorphosed Ajibik and Negaunee to the northwest.

Another "contact" mentioned by Smyth is in Sec. 20, T47N, R30W, (erroneously printed section "7") a short distance south of the Magnetic Mine and on the nose of the anticline west of the Republic Trough. He states, "Between the undoubted granite and the iron-bearing member (Negaunee) is a considerable interval occupied by banded gneisses and mica schists, which certainly include part of the horizon of the lower quartzite. . . . Some of the gneisses and schists have evidently been derived in place from the granite through shearing parallel to the contact; others seem clearly to be *metamorphosed sediments* in which it is possible to detect here and there traces of the large quartz pebbles. But between them there is a considerable interval of somewhat similar gneisses and schists the origin of which is wholly indeterminate. The facts here are quite in harmony with the view that the contact is an erosion contact, although they do not give it direct support." In the view of the writer, the "erosion contact" has been modified by a soda and by a potash flood. Some of the schists are made up of quartz, sodic plagioclase, and muscovite in a flaser-like pattern suggestive of original quartz pebbles. The introduction of quartz stringers and microcline-perthite into parts of this schist make it resemble a granite.

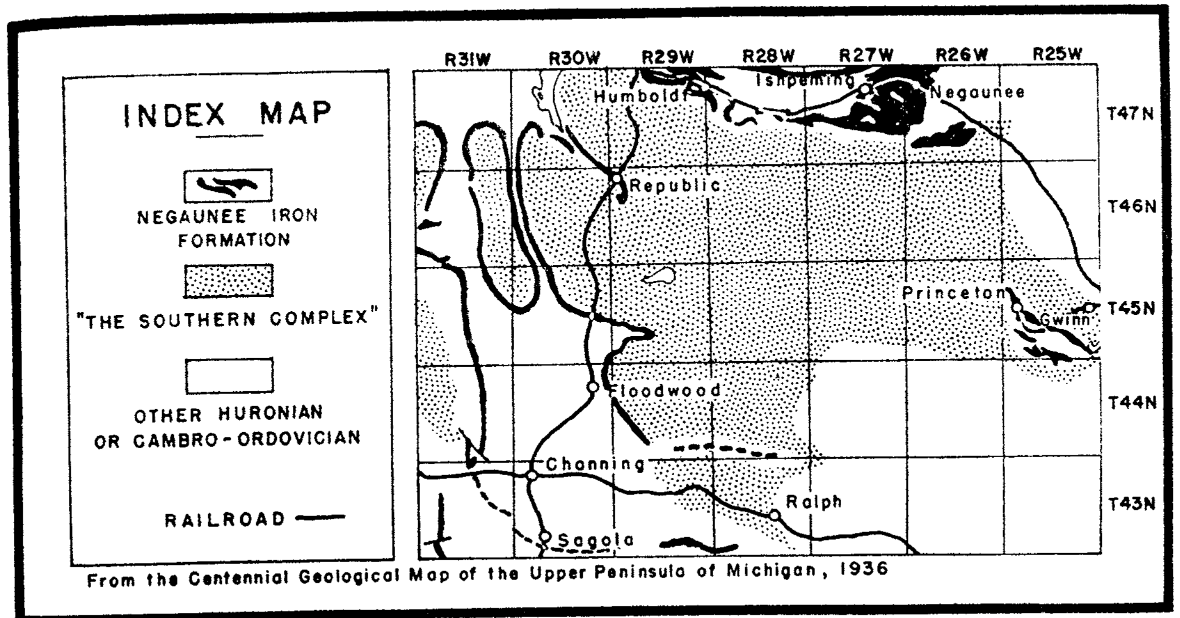


Figure 1.

Republic Granite Area

With the kind permission of the Ford Motor Company the Ajibik was examined in drill cores from the Riverside Mine (NE 1/4 of the NW

1/4 of Sec. 35, T47N, R30W) along the northeast side of the Republic Trough. It consists of mica schist, quartz-mica schist, and quartzite. The drill hole bottomed in "granite" but this was found to be a partial replacement of the quartzite by early sericite and later microcline.

Diamond drill records were also made available through the courtesy of the Oliver Iron Mining Company. These show in the vicinity of the Magnetic Mine 300 to 500 feet of vitreous, sheared or schistose quartzite and mica schist occupying the position of the Ajibik. At the contact, both the granite and the quartzite show shearing and quartz veining.

In the SE 1/4 of Sec. 27, T47N, R30W, drill holes were put down through both limbs of the syncline. On the southwest limb, 14 feet of "sheared granite or sheared quartzite" separate the granite from the overlying quartzite, of probable Goodrich age. On the northeast limb, across the Michigamme River, 214 feet of Ajibik separate iron formation from the underlying granite, the uppermost 5 feet of which is referred to as "recomposed" granite. "Granitization of sediments" had not been recognized in the district in 1911 and so was not mentioned in the logs; neverthess the granite contact is suggestive of such an interpretation.

Negaunee

Above the Ajibik is the Middle Huronian Negaunee Iron Formation. (See map, Figure 1) The lower part consists of grunerite and/or quartz and/or magnetite, and the upper part of jasper and hematite and/or magnetite. The upper part (jaspilite) is present only near the nose of the syncline at Republic. The presence of grunerite instead of original siderite is now generally accepted as proof of thermal metamorphism, and this mineral characterizes the lower Negaunee along the entire contact with the Republic granite. (See Plate 3) Garnet is also abundant in the Negaunee but only in the immediate vicinity of basic intrusives.

The transition from Ajibik to Negaunee is through admixture of the two types, without the slate which is found in part of the Marquette basin.

As yet it has not been possible to locate the drill cores taken from either side of the Standard Mine in Sec. 34, T46N, R29W, along the southwest limb. The logs suggest, however, that neither Ajibik nor Negaunee extends as far from the mine as would be indicated by Smyth's map, and that instead younger Goodrich rocks abut against the granite.

Additional outcrops of Negaunee, outside the boundaries of Smyth's map, call for some modification of the simple synclinal structure:

On the peninsula in Milwaukee Lake about 1,000 feet north of the south 1/4 post of Sec. 8, T46N, R29W, are several small shafts in lean iron ore. Iron formation and vein quartz with gold were also reported from drill holes in the swamp to the west. These indications point to an extension of the tectonic front referred to above, and to a fringe of Negaunee along the front. The Milwaukee Lake pits are a quarter mile east of the syncline and inside the granite boundaries of Smyth's map.

At the Suneson gold prospect farther west-southwest and about 750 feet from the corner of section 8, a grunerite schist presumably represents metamorphosed Negaunee. It is adjacent to the quartzite and quartz-mica schists referred to under Ajibik. Vein quartz, pegmatite, and an incipient porphyritic granite are also encountered at the prospect.

Another outcrop lies to the west of the main syncline, about 400 feet north of the southwest corner of section 7. It is a west-of-north-plunging anticline in highly metamorphosed gruneritic sediments. Its relationships are uncertain since a granite knob 300 feet in diameter lies between it and the Negaunee of the West Republic Mine to the northeast. It possibly has a connection with another outcrop 1,700 feet to the west of north, where iron-bearing sediments seem to have been entangled in a basic eruptive. Nine hundred feet beyond this in Smyth's "Archean" is still another outcrop of undoubted sediments entangled in the eruptive.

All these outcrops are explained more easily by a replacement than by a basement relationship of the granite.

Goodrich

Unconformable above the Negaunee is the Goodrich conglomerate and quartzite of the Upper Huronian. In the vicinity of Republic it is

a massive vitreous quartzite and overlying quartz-mica schist, with a detrital hard ore zone at the base. A drill record, kindly furnished by The Cleveland-Cliffs Iron Company, shows at one place 224 feet of vitreous quartzite and 144 feet of mica schist above the ore level, and 800 feet along the strike the quartzite has lensed out in favor of schists and basic intrusives. It would seem more than coincidence that the hard ore zone is present only where it is overlain by a couple of hundred feet of vitreous quartzite.

Bijiki

Above the Goodrich comes the Michigamme slate with at least one iron-rich zone near the base, the probable equivalent of the Bijiki or the Greenwood of the Marquette basin. It is 40 to 80 feet in thickness. It crops out about 120 feet northeast of the southwest corner of Sec. 6, T46N, R29W, and at intervals for a couple of thousand feet along the strike northwestward, on the northeast limb of the syncline. It consists of quartz, grunerite, and garnet, with layers highly folded and contorted, and with vertical plunge. It is about 650 feet horizontally from the base of the Goodrich (the beds are practically vertical) but this figure includes a 120-foot basic sill about 60 feet below the Bijiki horizon.

Michigamme

The youngest formation of the syncline is the Michigamme slate and graywacke, in part very schistose. Outcrops are rare. Banded slate and black phyllite parallel the Bijiki for 1,000 feet along its southwest (upper) side. The northwest end of the syncline flares out in this formation.

CRYSTALLINE ROCKS

Basic Intrusives

Intrusive into all the sediments are altered basic eruptives. They correspond to what Bucher calls "ophiolites"*—greenstones of variable composition and altered largely to amphibole and saussurite due to dynamic metamorphism. They have a world-wide association with geosynclines and radiolarian cherts (compare the chert of the Negaunee Iron Formation). Near the granite, as at the Suneson prospect, Sec. 8, T46N, R29W, they may be altered to biotite and garnet by thermal metamorphic action. Aplitic phases are not uncommon and occasionally a little microcline is to be found in pegmatitic facies.

As shown by Brooks in 1869* the Negaunee Iron Formation along the northeast side of Republic Mountain is divided into four sections by sill-like "diorites." In general the writer is in agreement with Brooks, although the sills do not wrap completely around the syncline as he shows; nor is their continuation northward across the Michigamme River the same as shown on his map. A fourth basic intrusive not mentioned by Brooks is the "soapstone" found in the hanging wall of parts of the Republic Mine, and in places extending down into the top of the jaspilite (IF-4). Reference to map, Plate 3, shows:

- Di-4 Soapstone
- IF-4 Jaspilite, 350 feet, tapering to northwestward
- Di-3 Diorite, 240 feet where nearest vertical
- IF-3 80 feet magnetite and quartz, minor hematite and grunerite
- Di-2 250 feet, tapering to northwestward
- IF-2 45 feet, grunerite, quartz, magnetite
- Di-1 160 feet
- IF-1 180 feet, grunerite, quartz, magnetite

Beyond the Kloman Mine to the northwest, IF-4 is split into three parts by the wedging in of other diorites, and in addition there is the one well up in the Goodrich. IF-4 just north of the river is cut obliquely by one of the diorites.

For the southwest limb of the syncline, complete data are unavailable as yet. One 225-foot sill in the Goodrich can be traced for at least 2,200 feet northwest of Smith's Bay. Farther northwest the position of the Middle Huronian rocks is occupied by similar basic eruptives with similar trend, and they are cut by granite with porphyritic bands. These basic eruptives are probably of the same age as the more definite ophiolites.

Presumably the ophiolites were intruded near the end of Michigamme time, while the geosyncline was most deeply buried, and before its up-

* Bucher, W. H., The Deformation of the Earth's Crust: Princeton University Press, pp. 268—269, 1933.

* Brooks, Major T. B., Atlas Accompanying Reports on Upper Peninsula: Geological Survey of Michigan, 1869—1873.

lift had started. Whether some of the greenstones of the area represent Keewatin, Timiskaming, or early Middle Huronian, cannot be stated at this time. But it can at least be asserted that there were even younger basic eruptives. One type which will be mentioned later as cutting the porphyritic granite is also amphibolitized. Another can be designated as porphyrite. It cuts the porphyritic granite in two areas—near the north 1/4 of Sec. 19, T46N, R29W, and in the northeast corner of Sec. 29, T47N, R29W, and adjacent sections. The youngest basic dikes are fresh diabases generally with a trend north of east.

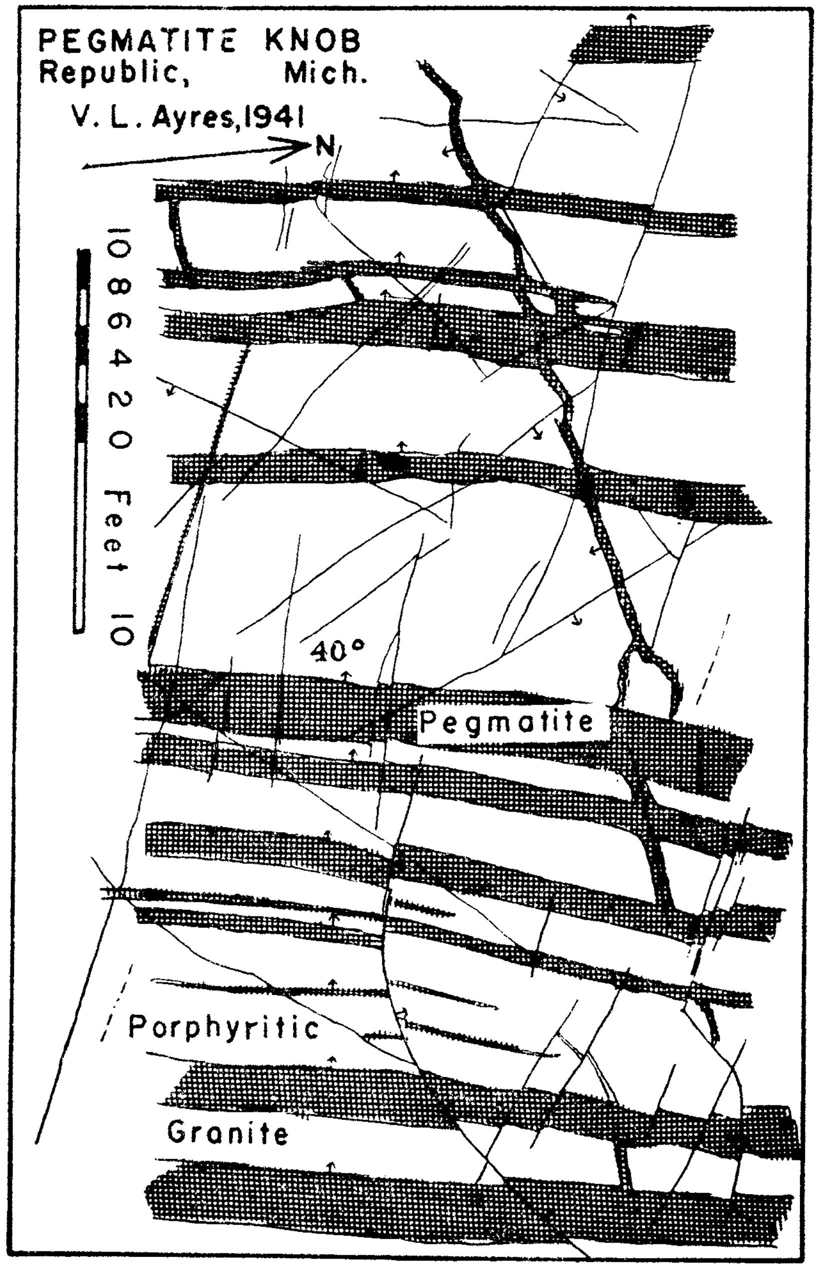


Figure 2

Geological Map, Pegmatite Knob

Granites

EXAMPLE No. 1

The first exposure to be considered is located just north of the limits of Republic village, about a hundred yards to the east of the old State highway, now No. 601. It is a bare rock knob and, as viewed from the south, is notable for the large number of parallel pegmatites dipping generally westward. Figure 2 is a map of the flatter part of the knob, showing the pegmatite and joint patterns.

The main rock is a porphyritic granite, light gray in color and weathering pink. Quartz runs 25 to 30 percent. Biotite runs 5 to 10 percent, mostly as webs marking the schistosity, but also as scattered half-inch orbs with garnet. The remainder is silicic feldspar, subhedral for the most part, but containing perhaps 15 percent of thin microcline phenocrysts. These show strong preferential orientation to N65°W with a minor maximum to N50°W. Platy parallelism, brought out by the biotite and the feldspars, strikes N65°W and dips 80° to 85° southward. Lineation in this plane pitches 50° southeastward—shown primarily by the phenocrysts and secondarily by slickensides along the south margin of the outcrop. A 20-inch belt near the south contains the biotite-garnet orbs to the near exclusion of phenocrysts.

The pegmatites consist of coarse quartz, microcline and biotite and have sharp contacts with the granite. The oldest ones strike N10°E and dip 40° west-northwestward, thus corresponding to the early cross-joints of a crusted pluton,* with the stretch direction plunging 50° southeastward like the phenocrysts. Vertical longitudinal joints are plentiful and rarely contain pegmatites but some of them offset the earlier cross-dikes. In such cases the direction of movement is such as would result if the south-southwest side hung back. This south-southwestward side is that which would be attached to the less heated sediments. Pegmatites also occupy several diagonal joints and these offset the cross-joints to produce elongation in the direction of stretch.

Whatever the condition of the porphyritic granite itself—and that would seem to have been plastic rather than molten—the pegmatitic joints behaved like part of a stretching crust over molten (or perhaps merely plastic) magma.

Along the northeast flank of this knob are several even-grained layers of granite with quartz and silicic plagioclase as essentials, muscovite and biotite as auxiliaries, and with slight alteration to the secondaries, sericite and calcite. Minute scattered grains of microcline and fluorite would indicate a start in the replacement process. The orbs of biotite-garnet found in other layers would also point toward inhomogeneity of the replaced material. Farther east the source of the biotite-garnet is to be seen in a "stew" made up of contorted greenstones or ophiolites in the finer grained porphyritic granite. The dark schlieren are tens of feet in length and, of course, are elongated in the direction of stretch. Although they are slit apart and bent, it is inconceivable that the basic xenoliths became actually molten; in fact it is questionable whether the lower-temperature granite itself was was most intense, the greenstones were changed into biotite-garnet-feldspar rock.

From the outcrop just discussed an intermittent belt, 200 yards wide, extends for a mile and a half along the strike southeastward. It consists of porphyritic and non-porphyritic granites and basic schlieren. In the other direction the belt bends to the west-northwest and passes the Riverside Mine (NW 1/4 of Sec. 35, T47N, R30W) where it granitizes the Ajibik quartzite.

EXAMPLE No. 2

The next area to be discussed is in the northeast corner of section 7, at the east end of Republic village, and 275 yards closer to the syncline than the belt just described. Figure 3 is a map of the outcrops. The porphyritic granite forms a belt along the southeast side, 80 feet in width, from which gently dipping tongues extend upward into the adjacent older granite to the northwest. Since they are thin and most of the contacts are gradational, their boundaries are largely a matter of personal opinion. The unmistakably older granite gneiss trends N40°E with a dip nearly vertical northwestward. Upon it has been imposed a flow cleavage with a general northwestward trend and a few augen feldspars by a different orogeny—the one which

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* Balk, R., Structural Behavior of Igneous Rocks: Geological Society of Am., Memoir 5, p. 27, 1937.

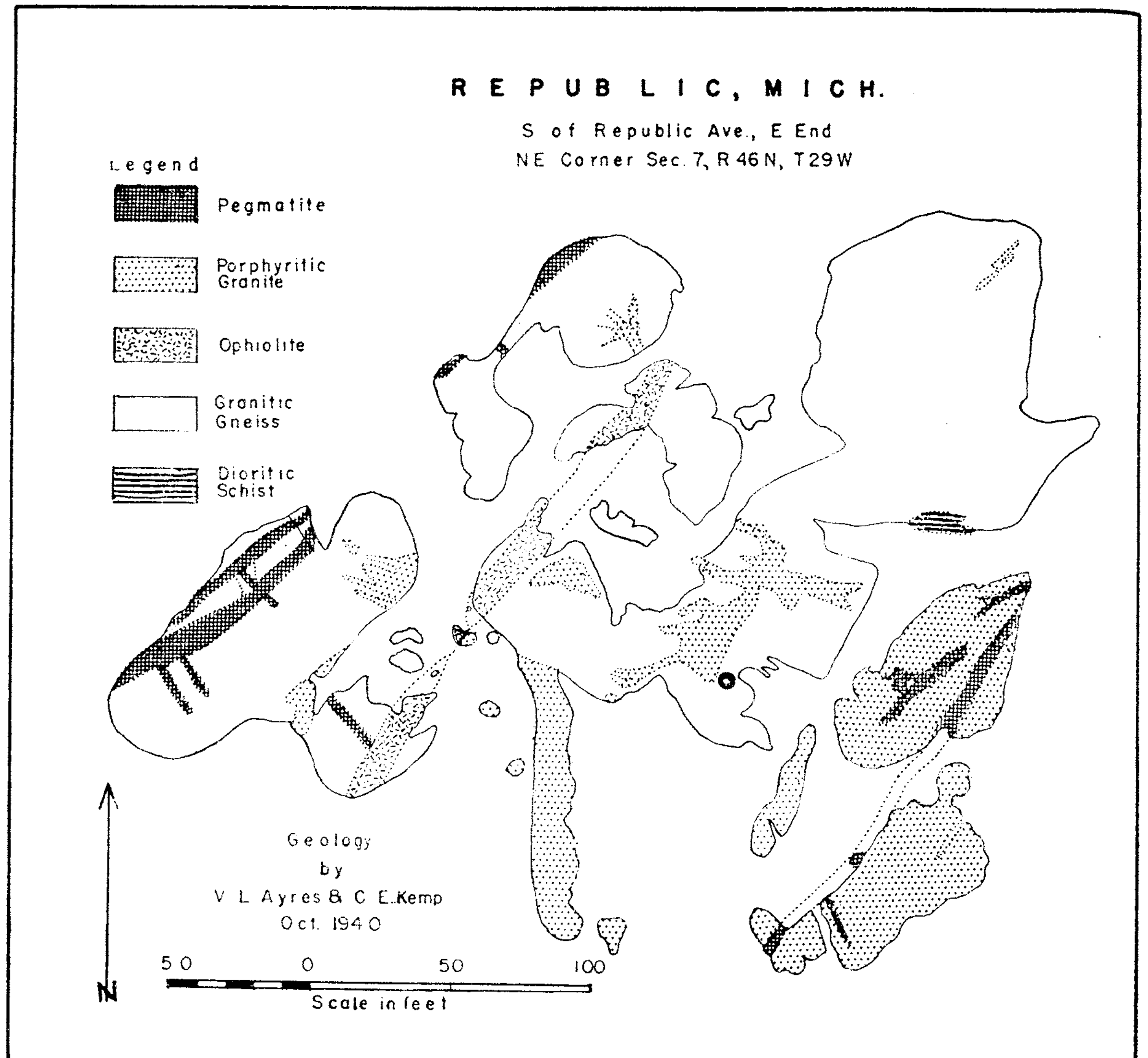


Figure 3

Geological Map, NE corner Sec. 7, T46N, R29W
(Note: Range and Township transposed in error in title)

lined up the feldspars in the porphyritic granite. The granite gneiss succumbed partially to the new stresses but did not change sufficiently to obliterate the bands and other shapes assumed by the alaskite-type granite whose injection had produced the gneiss.

The basic dike shown on the map lies between the two granites in age, for thin seams of the younger granite are found in the joints where tongues of porphyritic granite extend across the dike. It differs from the ophiolites only in direction.

The youngest dikes are cross-pegmatites similar to those from the first locality. Coarse microcline, quartz, and muscovite form their substance but a couple of samples of columbite were also found. A vein of barren quartz extends along the length of one. Older pegmatites, whose relationship is not clear, trend northwestward.

Another place where the product of the older orogeny is mixed with newer granitization is half a mile southeastward, north of Milwaukee Lake. Bands of granite, granite gneiss, and dioritic schist trend northeastward. Broken

blocks of these rocks are separated by porphyritic granite, the phenocrysts showing rude parallelism regardless of any interference from the blocks.

Example No. 3

The progressive change in the size of feldspars in the porphyritic granite is well shown along county road "FC" in the northwest corner of Sec. 33, T47N, R29W, two miles northeast of Republic. In a distance of 150 feet along the roadway the rock changes from a sharply banded microgranite with orthoclase to a porphyritic granite and abundant microcline as wide as 1½ inches. The gradation is marked by increasing number, size, and idiomorphism of the microcline crystals and by the grain size of the other constituents. Certain intermediate stages could be called augen gneiss. The strike is west-northwestward and the very coarse porphyritic granite can be traced for a mile in that direction.

Two dioritic intrusives (greenstones) are also present, one older and one younger than the phenocryst rock. Both are dynamically altered; the older one is more schistose.

The examples given typify the porphyritic granite for its four-mile-wide extent along the old State highway, now No. 601. Next the section along the new road M-95, north from Republic, will be considered.

Example No. 4

Non-porphyritic in the village, the granite along Michigan highway M-95 northward first becomes augened, then takes on more phenocrysts, but not for over a mile can it be called a true porphyritic granite. The dip which had been steep northeastward then becomes 60° to 75° southwestward with a strike about northwestward. Phenocrysts are progressively larger for about 3,300 feet, where 2 x 3 inch sizes are common. The strike here is N75°W and the dip 40° southward. These directions hold for half a mile, then the dip steepens and there are as many structural planes dipping northward as southward. In the final mile porphyrite and greenstone have confused the pattern of the porphyritic granite but it retains its large stout phenocrysts. The total width of four miles has without doubt been increased by faulting.

Example No. 5

Passing across the syncline of sediments, the porphyritic granite on the southwest side was next examined. The belts have a north-northwestward strike and a dip which at first is steep eastward but further along tends to flatten. In this northeast quarter of the near-oval or dome, less than half the rock is porphyritic granite, the rest being granite, diorite, mixed types, gneiss, ophiolites, etc. In Secs. 27 and 35, T47N, R30W, a granite seems to abut against the Goodrich and the relations have not been unraveled. It would seem that this is the granite that intruded the ophiolites, which in turn had absorbed the iron formation. If so, all of the post-Huronian granite is not porphyritic; if not, nothing has been detracted from the view of the age of the porphyritic granite.

Across the river from the West Republic Mine (200 to 400 feet) is a knob of older granite cut by an ophiolite. Fifty feet northwest of the knob the granite is porphyritic instead. The new was probably formed by partial replacement of the old. The abrupt change from iron ore to old granite will be mentioned again under "faults."

Example No. 6

One example has been chosen from the Gwinn district about 30 miles east-southeast of Republic. The area is shown on a map by R. C. Allen, Figure 9 of Mich. Geological & Biological Survey Publication 18, Geological Series 15, "Contributions to pre-Cambrian Geology." In the west part of Sec. 19, T45N, R25W, at the north end of a belt of Ajibik (?) arkose, the rock has been subjected to flow cleavage marked by mica films 1/16 inch apart and trending N67°E with a 65° southeast dip. At the north end are scattered feldspar metacrysts 3/8 to 1 inch long, with a N50°W trend—an *incipient porphyritic granitization*. The outcrop is in line with a N25°W streak in coarse porphyritic granite with strong parallelism, but half a mile of drift cover prevents tracing the intermediate stages. Pegmatite veins of quartz, with or without feldspar crystals, are frequent in the neighborhood of the metacrysts. The flow cleavage is older than the coarse feldspar; this is shown also 3 miles northwestward, at the Escanaba River crossing, where flow cleavage in granite strikes N70°E without cutting large idiomorphic feldspars of quite haphazard disposition.

At this point it is well to suggest that the arkose is probably Lower-Huronian Mesnard instead of Middle-Huronian Ajibik, because Lower-Huronian dolomite was found to crop out along the new roadway east of the iron formation at Princeton. The flow-cleavage of the arkose may thus be ascribed to a pre-Ajibik orogeny, with the porphyritic granitization much later.

Structural Directions

A comparison of the structural directions in the Republic syncline and the areas of porphyritic granite on either side is next considered. In order to the southwest they are:

Strike	Elongation axis
WNW	50° to ESE
NW	40° to NW
NNW	? to SSE

The primary elongation of the plastic granites would appear to be upward from the general southeastward; the syncline would also have this as a direction of secondary elongation but the pitch of the minor folds and the stretching of pebbles, etc. would be downward in the opposite direction, at right angles to the plunge of the primary elongation. (See Figures 4a and b.) Although the axes are not exactly parallel, the connection seems definite; the trough of sediments is over a mile wide at the nose, but 3 miles northwestward it is only half a mile wide. This cool, converging block would act as a more rigid septum and impress its boundaries on the more plastic material on either side. The formation of the syncline was post-Michigamme, after the geosyncline had started rising. Not before that time could a permanent set to the plastics exist. Therefore the porphyritic granite is post-Michigamme.

Considering the general direction of compression (northeast-southwestward) for the syncline, what can be expected at the granite contact southeast of the nose? No septum was here to interfere and a contemporaneous orogeny would leave the same strike to the planes of the plastic rock as it would to the axial plane of the syncline—northwestward. Actually the phenocrysts are in two main directions: 10° on either side of N45°W. The planar direction in the phenocrysts and its perpendicularity with the unconformity at the base of the Ajibik, then, are not at all disturbing factors from the viewpoint of replacement.

Ford River Granite near Floodwood

In 1938, Dickey recognized a granitic intrusion, unconformably below the Ajibik, which had incorporated quartzite in various stages of sericitization and granitization. To this post-Lower- pre-Middle-Huronian granite he gave the name Ford River.* It is in Secs. 19, 20, and 31, T44N, R29W, in Dickinson County.

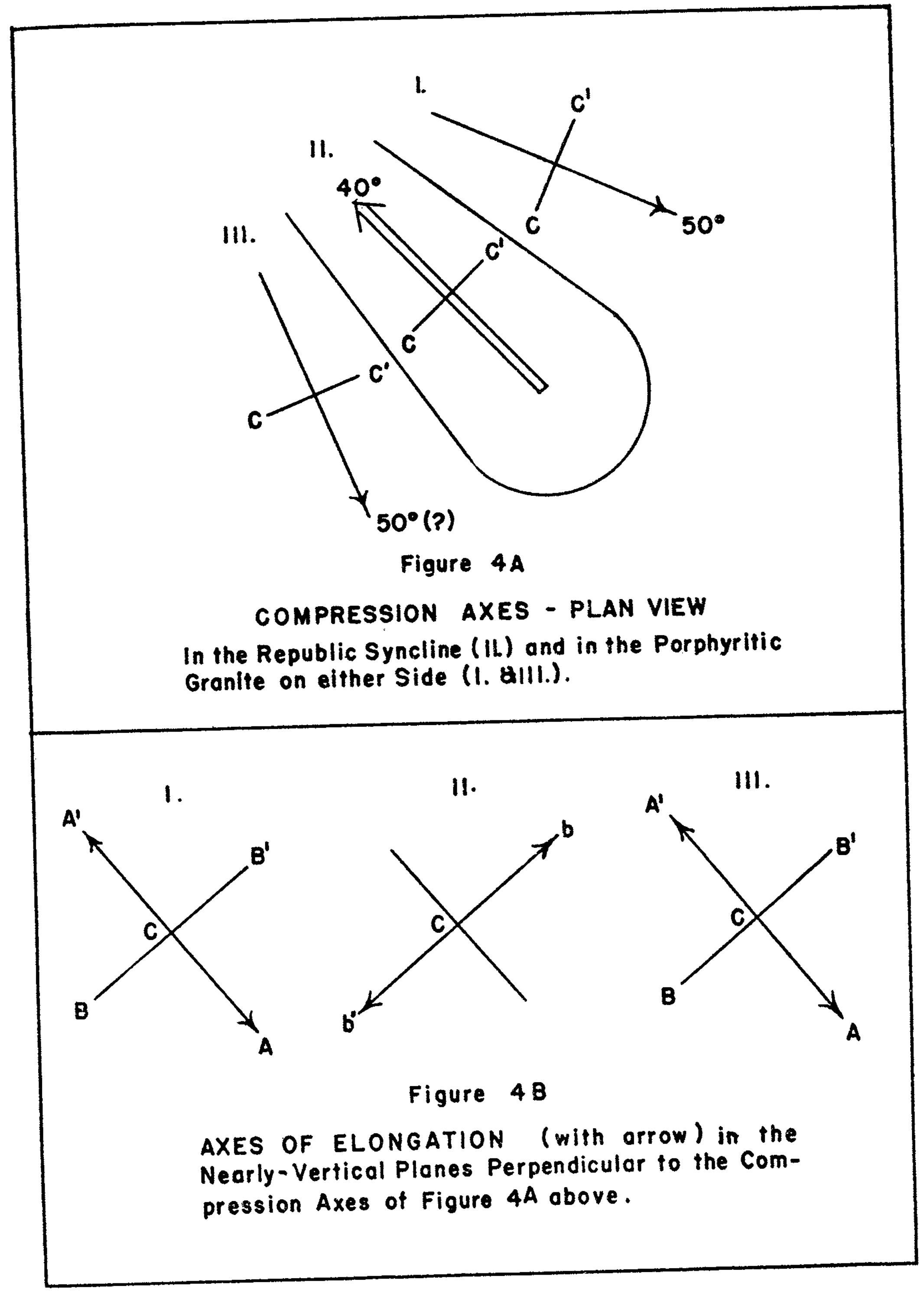
In the opinion of the writer, two phases of granite are present, an older even-grained, and a newer porphyritic. As around Republic, the porphyritic granite is merely a local replacement of older rock. The porphyritic granite is quite abundant in the north part of the area, but does not itself reach the unconformity. It is the older granite which contains the partly altered quartzite blocks and "ghosts." It also has certain seams reddened by the newer granite.

In the southern part of the Ford River district, non-porphyritic granite and pegmatite predominate. At the beaver house a very small area of porphyritic granite seems to have crowded aside a dioritic rock. Elsewhere in the vicinity the heterogeneity of the granite suggests that it was transformed from quartzite. The Ajibik has a relatively smooth 45° westward dip. Beneath and touching the Ajibik are the various types of granite (but not the porphyritic), the pegmatites, and the tight synclines of less altered quartzite, probably Lower-Huronian Mesnard.

It is in the central part of the area, however, that the best proof is found for considering the porphyritic granite younger than the unconformity. Dickey** admits that the Ajibik has been thermally metamorphosed, especially the gruneritic bed, but he does not mention that *all*

* Dickey, R. M., The Ford River Granite of the Southern Complex of Upper Michigan: Journal of Geology, vol. XLVI, p. 329, 1938.

** Op. cit., p. 330.



Figs. 4 A and B. Axes of Compression and Elongation, Republic Area

gradations between the Ajibik quartzite and porphyritic granite can be found. At his locality "E" is a 30-foot wide, east-west graben, capped with Ajibik in various types of assimilation, and containing fragments of Lower-Huronian dolomite. At the crest this is altered to biotite, quartz and calcite, with microcline metacrysts. Without the dolomite the transformation is apt to be to granite, through the stage of sericite with scattered microcline metacrysts. The ridge northeastward from the graben is porphyritic granite: the west face of the hill is older granite with quartzite "ghosts" which show along reddened cracks a more advanced alteration. All these would indicate that the porphyritic granite is younger than the Ajibik-Negaunee.

The name "Ford River" as used by Dickey is appropriate for the post-Lower- pre-Middle-Huronian granite, providing the porphyritic phase is excluded from its definition. The porphyritic granite belongs with the Republic,* which is post-Upper Huronian.

Other Granites

Where a granite dike terminates in greenstone (perhaps ophiolite) it has a special phase—fragments of silicic feldspar crystals are embedded in quartz. Examples occur in Secs. 34 and 35, T47N, R30W, southeast of the Standard Mine, and as far away as the northernmost outcrop along the new Highway M-95.

As mentioned previously, a belt of porphyritic granite, 4 miles wide, lies to the north of Republic. Farther north along County Road No. 601 is a lens of non-porphyritic material which shows lineal but no planar directions. In places it is nearly white but contains a small percentage of biotite in addition to quartz and feldspar. It is probably part of the post-Huronian unit.

Still farther north and just south of the sediments of the Marquette Trough, gneissic rocks are found. They are not typical porphyritic granite although they have assimilated Ajibik quartzite. Some of the rocks are mapped in detail in another part of this report.

Faults near Republic

Along the southwest edge of Republic Mountain, a tongue of Negaunee jaspilite is repeated by longitudinal faulting above the Goodrich contact.* This fault appears to pass northwestward across Kloman peninsula at the top of Di-4. (See map, Plate 3) In the opposite direction it extends about S30°E across the nosing sediments to the granite. Drag is well shown along the north line of section 18, 400 feet west of the northeast corner.

On the other limb of the syncline, north-northwest faulting seems just as certain but its position is less definite. In attempting to trace the fault a start can be made in the north central part of section 18 where the granite seems to descend to lower altitudes southwestward by step faults. No further outcrops occur along the southwest side until the granite knob is reached on the west side of the river, near the West Republic Mine. From here to the north-northwest, sediments, mostly Goodrich, and ophiolites are on the syncline side: old and new granites, dioritic rock, and enclosed iron formation lie to the southwest. A tentative fault trace has been placed on the map, Plate 3.

The tectonic front, so often referred to, consists of one or more faults separating the porphyritic granite from the syncline to the northwest. However, the pattern is rather indefinite.

Summary of Conclusions

That the porphyritic granite is post-Huronian, and not Archean or post-Lower, pre-Middle Huronian, seems born out by the following new data:

Ajibik in at least two localities was found to be granitized.

The Negaunee in one place is intermixed with the granite.

At two places, Negaunee was caught in ophiolites which are themselves older than the porphyritic granite.

The porphyritic granite has internal structures corresponding to those impressed upon Middle and Upper Huronian sediments.

Structures of this set have been implanted secondarily upon a granite which had an altogether different set.

A flow cleavage in arkose has been partially obliterated by introduction of metacrysts of feldspar in an incipient granitization.

The Ford River granite which has assimilated Lower Huronian, without affecting the Middle Huronian, is non-porphyritic.

The Republic granite which has metamorphosed the Ajibik is porphyritic.

Ophiolites which intersect Upper Huronian sediments seem to be older than the porphyritic granite.

Other Recent Opinions

Tyler and Marsden et al. in 1940* presented considerable data on the heavy mineral suites of the granites and other rocks of this district. They reached the conclusion that there are four granitic intrusions, two of which, the youngest and the oldest, can be distinguished by the nature of their zircons. The youngest, Keweenawan, is not represented at Republic. The oldest, part of the Laurentian, may be. The others, late Huronian and pre-Huronian (part of Laurentian), cannot be differentiated by their zircon (malacon), although they can thus be distinguished from the early Laurentian and the Keweenawan. The authors cited admit the possibility of a post-Lower, pre-Middle Huronian granite in the Gogebic Range, and of the post-Huronian, pre-Keweenawan age of the Republic granite, but do not restrict the two malacon granites to these two ages.

The porphyritic (Republic) granite is of the malacon type, and there are also even-grained granites of this type.

In the granitic debris of basal conglomerates, two of the types of zircons were found, but no specific reference is made to the porphyritic granite as occurring in such boulders. The total absence of true porphyritic granite in Huronian conglomerates was brought to the writer's attention by the late A. E. Seaman fifteen years ago. This is strong evidence for the post-Huronian age of the porphyritic type.

Spectrographic work on the granites and mixed rocks to determine any systematic variation of minor elements is now under way at the Michigan College of Mining and Technology; the results will be presented elsewhere.

Occurrence of Strategic Metals and Minerals, Republic Area

Beryllium

Beryl was first identified by the writer in 1940 in a prospect in the southwest corner of Sec. 8, T46N, R29W. It was in a quartz vein along the tectonic front, where the country rock is mica schist grading toward porphyritic granite. Beryl was abundant as a two-inch layer in the quartz for about 3 feet, at an overturning of the vein. The excavation was not carried further because the boundaries of the "forty" were very close. This is the only quartz vein of the many on the tectonic front which carried visible beryl. The beryl was opaque and yellowish green.

A second beryl locality was uncovered by a prospector in the SE 1/4 of the SW 1/4 of the NW 1/4 of Sec. 17, T46N, R29W, just half a mile south-southeast of the first. The beryl is a dull greenish-yellow and formed less than 0.1 percent of the rock. It was enclosed in coarse pegmatite consisting chiefly of microcline, quartz, and muscovite. It was as much as 3 feet wide and could be traced near the side of the hill for several scores of feet. The largest beryl crystal seen was 6 inches long by 3 inches wide, but most crystals were an inch or less across. A grab sample of nearly ten pounds yielded 0.02 percent Be, corresponding to a spectrographic trace. Well terminated, six-inch crystals of pink microcline, flattened parallel to (010) were not uncommon.

A third locality for beryl was found half a mile south-southeast of the second, in the SW 1/4 of the SE 1/4 of the SW 1/4 of the same section, on the William Perry farm. The pegmatite is located on the north face of a cliff, receding westward back from the face, for a total length of several hundred feet and a width of about seven feet. Of the total length only 25 feet near the east end contains beryl. In an area of 25 by 7 feet beryl runs about 0.5 percent. The exposure showed eight crystals between 2 and 4 inches thick and twelve between 1 and 2 inches. A short adit into the cliff face from ground level would reveal much concerning the continuation of the beryl pocket.

* Included in "Superior" by Seaman, Table 1.

* Van Hise, C. R., and Bayley, W. S., The Marquette Iron-Bearing District of Michigan: United States Geological Survey Monograph 28, Plate 34.

* Tyler, S. A., Marsden, R. W., Grout, F. F., and Thiel, G. A., Studies of the Lake Superior Pre-Cambrian by Accessory-mineral Methods: Geological Society of America, Bulletin, volume 51, pp. 1429—1538, 1940.

A fourth locality for beryl was found at 22,000 feet north along the new M-95 highway from Republic. The second pegmatite mentioned under feldspar (below) changed to vein quartz as it crossed the roadway. The lowest drill hole for the excavation passed through a nest of beryl in the quartz.

A spectrographic trace of beryllium was found in a 6 inch pegmatite containing a little fluorite in Sec. 35, T47N, R29W.

Bismuth

In the excavation for beryl and molybdenum at the extreme southwest corner of the Suneson property, Sec. 8, T46N, R29W, 0.04 percent Bi was shown in one sample. The bismuth-containing mineral has not been recognized.

Columbium

Two bean-sized specimens of columbite were found in pegmatites in the northeast corner of Sec. 7, T46N, R29W. They are crude crystals which were also identified by chemical and X-ray analyses. Their density is 5.9.

Another mineral from the feldspar quarry of Sec. 22, T47N, R29W, has not yet been identified. It looks much like blomstrandine, occurs in irregular 1/8 inch seams, spectrographically shows Cb (estimated at 0.4 percent) and microscopically consists of black "curds" in yellowish "whey," the "whey" being transparent yellow to opaque brown according to thickness and also varying from medium to very high index of refraction and from isotropic to birefringent. Not enough is birefringent to give any discernible X-ray pattern, however. Some of it sinks and some floats in a liquid of density 4.2, and all of it sinks in 4.0.

Gold

At the Suneson prospect near the southwest corner of Sec. 8, T46N, R29W, a quartz vein 2 to 4 feet thick has been excavated for gold. This quartz vein crosses obliquely the ridge of the tectonic front, passing across metamorphosed diorite, iron formation, porphyritic granite, and pegmatite. At the southeast end of the vein, the quartz was said to have yielded $4.00 a ton in gold (at $20.67 per ounce) although none of the samples taken by the writer showed gold spectrographically.

A core drilled in the swamp near the east border of the southwest forty of Sec. 8, T46N, R29W, by the late Martin Suneson is said to have passed through a six-inch streak of gold-bearing rock in the general hard iron ore formation. This was also in a quartz vein of the tectonic front.

Molybdenum

Molybdenite accompanies the beryl at the southwest corner of Sec. 8, T46N, R29W. In addition it was scattered through the exposed quartz vein (30 feet) and the adjacent schist. It was in flakes of finger nail size although the actual quantity was very small, about 0.01 percent. One grab sample assayed 0.17 percent Mo. Molybdenite was not found in the other beryl localities.

Molybdenite occurs in the first feldspar quarry mentioned below, in Sec. 22, T47N, R29W. A few flakes were also picked up in the feldspar quarry of Sec. 23, T46N, R30W.

Tungsten

A hybrid gneiss composed of granite and greenstone forms a quarter-dome along the new M-95 Highway near the northeast corner of Sec. 29, T47N, R29W. In one of the layers a bead-chain of scheelite (calcium tungstate) was disclosed by the "Mineralite." A "high-grade" grab sample of about 1/4 pound ran only 0.02 percent W. Other scattered "colors" were found along the east side of this highway, at 0.75 miles and 1.85 miles south of U. S. Highway 41, in sheared basic dikes or schlieren in the porphyritic granite. Another trace is present in a pegmatite on the west slope of Pegmatite Knob, SE 1/4, Sec. 6, T46N, R29W. (See Figure 2)

The coarsest scheelite which was observed, though nowhere in economic concentration, is in the iron formation of the Magnetic Mine,* NE 1/4 of NE 1/4 of SE 1/4 of Sec. 19, T47N, R30W, near the nose of an anticline. (See Plate 2) It is an open question whether the scheelite was an emanation from the ophiolite or from the granite, both of which rocks are equidistant from the exposures of iron formation containing

* Rominger, C., Geological Report on the Upper Peninsula of Michigan: Geological Survey of Michigan, volume 1, part 1, p. 27 (1881—1884), 1895.

tungsten. In favor of the ophiolite (diorite) are the associated minerals—almandite garnet with admixed magnetite, and a dark green amphibole whose pleochroism is X = yellow, Y = green, and Z = blue. These minerals are common in the ophiolites at the contact with iron formation, but are not found in the granite pegmatites. In California and Nevada, according to Lindgren,* scheelite occurs as pyrometasomatic deposits in limestone or dolomite intruded by granodiorite or quartz diorite. By analogy, if the scheelite of the Magnetic Mine were introduced by the ophiolite, the calcium might have been furnished by the original siderite of the iron formation. The siderite must have contained calcium and magnesium carbonates for, while the iron silicate, grunerite, is the common thermal metamorphic product of the unoxidized iron formation, actinolitic and cummingtonitic amphiboles are not uncommon. Another argument favoring the ophiolite as the source rock of the scheelite is that the dumps which contained tourmaline and granite did not show any "colors" of scheelite.

Scheelite from the Magnetic Mine shows fluorescent colors which indicate the presence of some molybdenum, also. In one specimen both pale blue and pale cream occur; on the Cannon-Murata "Scheelite Fluorescence Analyzer" these colors correspond to 0.24 percent and 0.48 percent by weight of molybdenum as powellite admixture. However, as was stated above, the tungsten and molybdenum are not present in sufficient quantity to constitute economic products by themselves or profitable by-products of the iron formation.

It should be kept in mind that the workings at the Magnetic Mine do not necessarily explore the optimum places for the occurrence of scheelite in the magnetic iron formation.

Allanite

The feldspar quarry of Sec. 22, T47N, R29W, also furnished a few rare minerals. One, allanite, was proven by optical and X-ray properties. Spectrographically it showed traces of Mn, Ti, Li, and Sr, in addition to the Ce which characterizes this member of the epidote group. Less than 0.05 percent Li is present. The cerium content is estimated spectrographically at 3 to 4 percent. The density of this allanite is between 3.2 and 3.4. It is altered to an isotropic substance with a refractive index of 1.703, with minute inclusions showing birefringence—probably remnants of allanite itself.

* Lindgren, W., Mineral Deposits: 4th edition, p. 728, 1933.

Apatite

Very little apatite of megascopic size was observed. One crystal occurred with the beryl of Sec. 8, T46N, R29W, and was the same size, color, and shape as the beryl, but inferior in hardness.

Bog Iron Ore

In the southwest corner of the northwest "forty" of Sec. 17, T46N, R29W is a deposit of spongy limonite. Its horizontal extent is unknown. At the place examined it was 9 inches thick. Since its recovery requires mere stripping of the sod and perhaps some shrubbery, the property may be worth investigating as a small proposition.

The Huronian iron ores are treated elsewhere in this report.

Feldspar

According to the Report of the Commissioner of Mineral Statistics of Michigan for 1902 and 1903, a carload of red potash feldspar was shipped to East Liverpool, Ohio, from the quarry in Sec. 22, T47N, R29W near Republic, and proved satisfactory for making porcelain. A partial analysis showed 13.4 percent K_2O (enough for 79 percent of microcline), 0.40 percent Fe_2O_3 (0.08 percent is the present allowable limit), and Na_2O not determined (although there must be nearly 20 percent albite). Another carload or two is in sight and perhaps it extends considerably farther under glacial cover. The individual feldspar crystals are measured in feet. This pegmatite is located just north of the belt of porphyritic granite north of Republic.

A pegmatite whose feldspar is white in color is situated along the new highway M-95 in the SE 1/4 of the NW 1/4 of Sec. 21, T47N, R29W. It contains immense biotites, easily separated, and graphic granite. Since it also is along the north edge of the belt of porphyritic granite, this suggests that further prospecting should be done between the two areas (a little over a mile apart) as well as the extension of the line in either direction. The combination offers the best chance for commercial feldspar.

Another pegmatite which has been explored is located in the SE 1/4 of the SE 1/4 of Sec. 23, T46N, R30W. A pink color again shows that the iron content is greater than permissible for commercial product. The same objection holds for nearly all pegmatites of the district.

Fluorite

Fluorite was found in several of the pegmatites, the most abundant being in the northwest corner of Sec. 35, T47N, R29W. No quantities of economic importance were discovered.

Garnet

Garnet, var. almandite, is apt to form wherever the ophiolite and the iron formation are in contact, but in a contact zone only 3 or 4 inches wide. Garnet also forms where the ophiolite has been thermally metamorphosed by the porphyritic granite in a wide contact zone.

Mica

Practically all the pegmatites contain mica of some sort. Biotite in books six or more inches across is found in the second dike mentioned under feldspar. Reticulations of fairly coarse biotite form part of the pegmatites in the knob just north of the village of Republic.

Muscovite in notable thicknesses is found in the pegmatites of the northeast corner of Sec. 7, and in the beryl locality of Sec. 17, but a piece one inch square would be unusual.

ISHPEMING GOLD RANGE

By A. K. Snelgrove

History

Although gold was first discovered in Northern Michigan in the eighteen 'forties, it was only in the last two decades of the past century that output of this precious metal figured at all significantly in mineral statistics. This meager development has been variously explained as due to: Lack of gold resources, preoccupation of the local mining industry with the abundant iron ores, ineptitude of early operators, inadequate financing, erratic or submarginal character of the deposits, and inaccessability of the supposedly most favorable prospecting territory in and south of the Huron Mountains.

Numerous discoveries of gold quartz veins were made in the area north of Ishpeming, following the finding by Mr. Julius Ropes, of Ishpeming, in 1881, of the deposit which later became the site of the Ropes Mine. In 1845 Dr. Douglass Houghton, Michigan's first State Geologist, had detected gold in a stream bed, presumably near Ishpeming, but details were not disclosed for fear his exploration party might desert its survey work, and knowledge of the exact location passed when Houghton was drowned in Lake Superior later in the same field season. Another early indication of the presence of gold in Marquette County that was not immediately pursued was the determination in 1864 of this metal in assaying quartz for silver from the Holyoke silver property, eight miles north of Ishpeming. Gold finds reported subsequently to 1880 included not only those in quartz veins but also numerous placer or stream deposits, some of which were in the glacial drift of the Southern Peninsula. A list of localities is given by Allen (1).* However, only the Ropes Mine, with a production record between 1882 and 1896 of $605,056.95 in gold and silver, or over 95 per cent of the State's entire output of these associated precious metals,** can be considered as having gone beyond the development stage. In 1896, Newett (5) published the gross value of bullion from other Michigan gold mines as follows: Michigan Gold Company, $17,699.-36; Fire Center Gold Mining Company, $2,063.-00; other prospects, $820.00 (Gold at $20.67 per oz.—Ed.). To serve the gold range the Chicago and North Western Railway built a spur line west from Ishpeming and terminating at a station called "Golden" (10).

The Michigan gold district failed to share in the spectacular gold developments in other parts of the pre-Cambrian Canadian Shield, especially in Ontario and Quebec, perhaps because of early local disappointments.

Appreciation of the price of gold in the nineteen 'thirties led to renewed interest in the Ishpeming Gold Range and a small production resulted from exploratory work and retreatment of tailings (12). In 1933 this amounted to 9.68 fine ounces, valued at $247.00 (Gold at $25.56 per counce); in 1934, 58.63 fine ounces, valued at $2,049 (Gold at $34.95 per ounce); and in 1937, 51.44 fine ounces, valued at $1,800 (Gold at $35.00 per ounce).

Private Canadian and Michigan interests in the nineteen thirties geologically mapped the area included in townships 48 and 49 north and ranges 26 to 28 west as part of a prospecting program in a region in which surprisingly little official geological data are available, although silver-lead-zinc-deposits, iron, talc, chrysotile asbestos, and verde antique marble are also known to be present.

The Calumet and Hecla Consolidated Copper Company of Calumet, Michigan, some years ago acquired the property and all outstanding stock of Ishpeming Gold Mining Company, owners of the Ropes Mine, but was forced in 1942, by governmental regulations restricting gold mining, to defer plans for operations (12).

The field work carried out in the Ishpeming Gold Range in connection with the present investigation consisted of examining as many of the numerous old surface workings and dumps as could be located, with a view to finding tungsten, molybdenum, and other ores. Much of the

* Numbers refer to bibliography on Michigan gold at the end of this section.

** This does not include the silver from the copper mines of Keweenaw Peninsula.

work was done at night, using the ultraviolet lamp to detect fluorescent minerals. At one prospect, the Grummet, the old workings were dewatered, and old trenches cleaned out and others dug. This work was done in cooperation with the U. S. Bureau of Mines.

In the following discussion no attempt is made to list all known gold occurrences in Marquette County. Instead, Allen's treatment of this subject (9) will be brought up-to-date insofar as new developments at three properties are concerned, with comments on geological features having relevance to the future of the district. Such new data as are available on the lead-zinc-silver-gold deposits of the Dead River Basin are presented in the last section of this report.

General Features of the Gold Deposits

The geological setting of the deposits was described by Lane in 1904 (6) as follows: "Running west from Marquette and passing but a mile or two north of Ishpeming and Negaunee and bounded and overlain unconformably by the basement conglomerates of the regular iron-bearing series of Negaunee and Ishpeming on the south and cut into by the granites on the north, and by a great many other igneous rocks, including some important masses of peridotite, is a series of green, largely volcanic, rocks, which correspond in composition and geological position to the Keewaatin of Canada and the Lake of the Woods. They are known as the Kitchi and Mona Schists by the U. S. Geological Survey, the two terms indicating merely different degrees of alteration. In this series the gold product of Michigan . . . has been found."

The gold in general occurs in quartz veins or lenses, less often in the pyritized wall rocks. "All the veins in the Gold Range vary much in width; some are in places only a few inches, and then swell out to a width of four or five feet, and some are even eight feet wide" (4). In addition to free gold, of which many spectacular samples are reported, the mineral associations recorded in the literature, include quartz, tourmaline, chlorite, dolomite, pyrite, pyrrhotite, calcite, epidote, feldspar, tremolite, magnetite, chalcopyrite, sphalerite, tetrahedrite, and sparse molybdenite. In this investigation, the tungsten ore mineral, scheelite (calcium tungstate), and associated powellite (calcium tungstate and molybdate) were discovered at several properties; bismuthinite (bismuth sulphide) was found at Michigan Gold Mine, a little fluorite was observed in a north-south striking vein in Sec. 26, T48N, R28W, and a little bornite in Sec. 25, T48N, R28W.

Felsite and diorite dikes, some of which are said to be post-ore (4 and 9) were encountered at several prospects.

Parker, in an account written during the period of operations (3), noted the regularity of strike of the veins in a direction almost east-west, their steep dips, and an offsetting to the north or south by faults.

The greatest depth of ore indicated by drilling at the Ropes property is over 1,500 feet.

Disregarding unimportant traces of gold in the iron formation, the youngest formation penetrated by the gold quartz veins is the Siamo slate, as at the Billings-Murdoch prospect, E 1/4 Sec. 20, T46N, R27W.

Ropes Mine

The Ropes, Michigan's premier gold mine, is located in the S 1/2 of the NW 1/4, Sec. 29, T48N, R27W. (See Plate 4 for index map) Sixteen levels, to a vertical depth of about 850 feet, were worked between 1882 and 1897. Parker, in 1888, published a geological section (3).

According to Broderick (14), "The ore mined occurred in nearly vertical quartz lenses cutting diagonally across a vertical tabular body of Keewatin lavas and volcanic fragmentals separating two bodies of peridotite. The Keewatin and immediately adjacent peridotite are strongly sheared, the former being chloritized and the latter serpentinized and steatitized. In the vicinity of the quartz lenses the Keewatin is silicified, sericitized, and carbonatized. . . . The quartz veins carry tetrahedrite, pyrite, chalcopyrite, and minor amounts of other sulphides, and the ore milled ran about .2 oz. gold and .9 oz. silver per ton, of which nearly one-third was lost in the tailings. Recent explorations have shown another type of ore occurring as a pyritic dissemination in schist adjacent to the quartz veins. There is about eight times as much ore of this type averaging .13 oz. gold and .6 oz. silver as there was in the quartz vein nuclei."

Certain features of the Ropes deposit, mentioned by Newett (5), are included here because of their possible significance for other parts of the belt:

"At the 12th level the lode has a slight dip to the south, but from this point to the present lowest level it inclines slightly in the opposite direction, the walls being nearly vertical. The ore lenses have a pitch to the west. The bottom of the first main lens was found at the 5th level, that of the second at the 9th, and in 1896 they were working upon the east side of the shaft whereas in the upper levels the stoping was done to the west. In the lens encountered on the 16th level, the slate mixture is almost entirely missing, the vein being almost solid quartz, and giving an average of about $6 per ton (With gold at $20.67 per oz.—Ed.), this showing a better and stronger vein than has been found at any other point in the mine. . . The finding of ore of better quality, and in larger body than has heretofore been met with, is particularly encouraging on this lowest level."

Calumet and Hecla Consolidated Copper Company, in its annual report for 1936, stated:

"Diamond drill core samples, breast and back sampling of old workings, and large scale ore sampling indicate that there is a good possibility of there being about one million tons of ore in the Ropes ore body, averaging .13 ounces gold and .70 ounces silver. How much more there may be below the old workings is not known, although diamond drilling showed the ore body to exist for over seven hundred feet deeper."

The writers visited the dumps of the main Ropes shaft and of the West Ropes Mine (1.7 miles apart by poor road) and were able to find very little scheelite at either place. At the main Ropes dumps the scheelite is pale yellowish white in color with bluish-white fluorescence; it occurs in 1 mm. grains disseminated in chloritic sericite schist, on slip surfaces on this rock, and also in streaks over 1 cm. long in quartz veinlets. At the same dumps a few specimens were found to exhibit yellowish fluorescence which is attributed to disseminated powellite in quartz. The West Ropes dumps contain a little powellite in streaks 1 cm. long.

Michigan Gold Mine

The Michigan Gold Mine, opened in 1887, is located in the NW 1/4 of the NE 1/4 of Sec. 35, T48N, R28W. Exploration was pushed in 1890 and a little more was done in 1895. The official production was $17,699.36 (with gold at $20.67 per oz.) but flagrant "high-grading" of spectacular specimens doubtless accounted for much more. In the middle 'thirties, some further exploration was carried out and the old 10-ton mill was supplanted by a 100-ton flotation plant through which a total of some hundreds of tons of ore were run. The advisability of installing a flotation mill for this ore, which is said to be largely free milling and contains only a very small percentage of sulphides, may be questioned. The history of this property is one of prolonged litigation.

The workings are now flooded. The investigation of 1943 was primarily concerned with the occurrence of tungsten and molybdenum in the ore as determined by dump, ledge, and mill samples.

The main vein has been explored underground at intervals over 900 feet along its east-west strike. (See Plate 4) The property has not yet been carefully mapped geologically. Five distinct and more or less parallel veins were seen by the writers; the caretaker, Mr. Charles E. Secor, states that twelve veins can be recognized on the south half of the NW 1/4 of the NE 1/4 of Sec. 35.

The following geological account is abstracted from field notebook No. 88, 1890, of the late A. E. Seaman, in the files of the Michigan Geological Survey.

The vein seems to be divided by a horse of diorite most of the way to the surface. This horse is mineralized especially along the edges. Instead of running parallel with the walls of the vein, this diorite streak has an irregular course, causing the vein to narrow in one place and widen in another. The vein sometimes swells out and again narrows, but as a whole seems to hold a rather uniform width. Considerable schistose diorite is on the walls, particularly on the foot. This is filled in along the line of foliation with more or less quartz and is said to be "pay rock." At the west end of the first level a felsite dike which cuts off the vein was encountered and the work of drifting in that direction was tem-

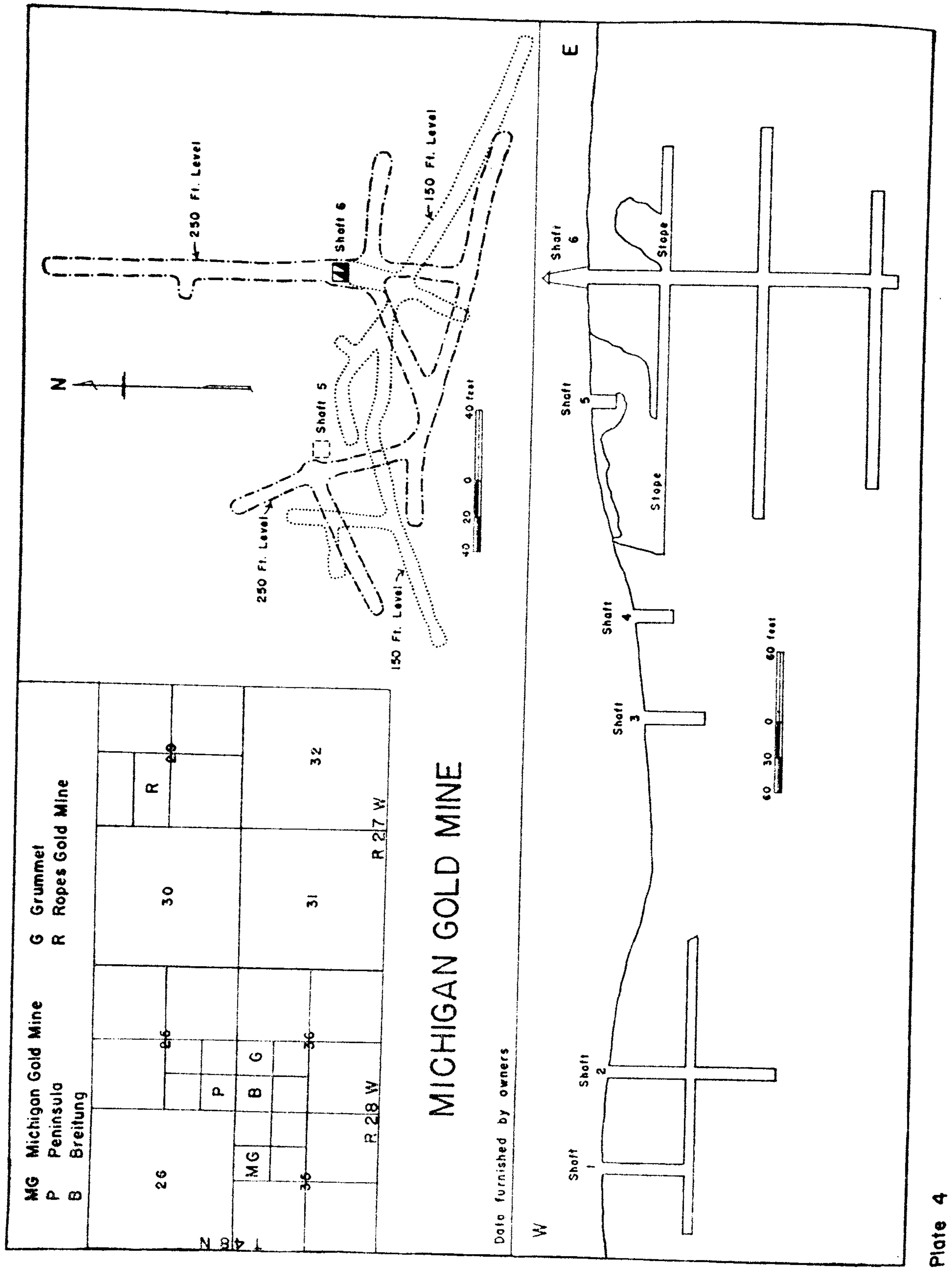


Plate 4

Plans and Section, Michigan Gold Mine

porarily abandoned, as about 12 feet of the hard felsite had to be cut before the vein could be recovered. The breast on the east end of this level showed up a good vein which was, however, somewhat narrower than at the shaft.

The dip of the vein is somewhat variable, having gentle rolls but the average to the first level is about 76° while from the first level to the bottom of the shaft 25 feet below it is about 80° or at a slight turn toward the vertical. (It is not clear whether the present No. 2 or No. 6 shaft is referred to.)

On the dumps considerable quantities of felsite or quartz porphyry can now (1943) be seen, which is said to come, in part, from the longer crosscut at the 250-foot level, in which the caretaker reports a 47-foot shear zone with quartz veinlets.

According to Lawton (1), the width of the vein varied from 2½ feet at No. 5 shaft to 8 feet at No. 2 shaft.

Thirty-five samples were collected at the Michigan Gold Mine. Analytical results on these samples must not be regarded quantitatively as their purpose was to try to establish the presence and the particular associations of the valuable metals. Grab samples of mill products ran as follows: Sands from bottom of classifier 0.995 oz. gold per ton; flotation concentrates 0.30 to 0.47 oz. gold and 1.40 to 1.56 oz. silver per ton, 0.09 to 0.11 percent molybdenum, 0.038 to 0.18 percent bismuth, and 0.37 percent copper; feed to amalgam barrel 2.38 oz. gold per ton; amalgam barrel tailings 0.39 oz. gold per ton; mill tailings near mill 0.015 oz. gold per ton; mill tailings from the end of the pile remote from the mill 0.04 oz. gold per ton.

Bismuth-containing ore samples were found in a vein 20 feet south of No. 3 shaft (0.09 to 0.11 percent Bi). The bismuth mineral is tentatively identified as bismuthinite, Bi_2S_3.

Despite Parker's (3) report of "black antimonial silver" which with galena were said to take the place of pyrite at depth in this mine, no antimony could be spectrographically detected in any samples.

Grab samples from the dumps of three shafts and from two subsidiary veins lying north and south of the main vein, showed traces of molybdenum; the greatest amount obtained was 0.015 percent Mo. A concentration of molybdenite at the east end of the 250-foot level is reported by the caretaker.

Although few spectrographic traces of tungsten were obtained from the samples collected, several dozen specimens of creamy white colored scheelite, fluorescing bluish white, were gathered on the dump of No. 6 shaft. The scheelite occurs as grains, as much as one-half inch long, in quartz and subordinately in green schist.

Sampling of the workings for molybdenum and tungsten is necessary before any conclusion can be reached as to the economic possibilities of these metals in the ore of the Michigan Gold Mine.

Grummet Prospect

The Grummet gold prospect, in the NE 1/4 of the NW 1/4, Sec. 36, T48N, R28W, was located in the 'eighties and explored by three shafts, the deepest 62 feet, and by several pits and trenches. (See Figure 5 and Plate 4)

Of the numerous deposits in the Ishpeming Gold Range examined by the writers, the Grummet was discovered to contain the greatest concentration of scheelite. Arrangements were therefore made with the Minneapolis regional office of the U. S. Bureau of Mines to dewater the old workings and to sample for this strategic tungsten ore.

In the No. 1 or main shaft the quartz vein is 2 to 4 feet wide and dips northward at approximately 80°. The vein is exposed at intervals over a strike length of 240 feet in a direction S75°W. (See Figure 5)

Several trenches were dug in 1943 in an attempt to extend the known limits of the vein system but without success. Having in mind the existence of a number of parallel veins at the Michigan Gold property, three "forties" to the west, and the possibility of a difference in the magnetism of felsite dikes, with which the quartz veins are associated at the Grummet, as compared with the greenstone country rock, a series of dip needle traverses was run, with readings every 5 feet, north and south, in the immediate vicinity of the Grummet workings. A Gurley dip needle, Lake Superior model, was employed; no significant results were obtained.

The vein at the Grummet location consists mostly of sugary quartz, a transparent, even-grained, tight mosaic with individual grains less than one-sixteenth of an inch across. Locally the grains may be as much as three-eighths of an inch in diameter, or they may be lacking entirely and the quartz appears quite massive. If the quartz is massive a banding can be noticed due to differences in transparency. Films, plates, or blocks of the altered wall rock are rarely absent. Sporadically the vein carries cubes of pyrite with traces of chalcopyrite and of scheelite.

White silky veinlets of tremolite cut the quartz vein near the east end. Irregular veins of carbonate, mostly calcite but some with brownish weathering ankerite, are younger than the quartz and tremolite.

deeper-seated mineralization. The fineness of the wall rock replacement, the abundance of chlorite, sericite, calcite, and pyrite indicate mesothermal conditions.

In ten preliminary dump grab samples of various mineral and rock association, some of which include bluish-white fluorescing scheelite, the presence of tungsten was confirmed spectrographically and chemically, some traces of silver, nickel, and lithium were determined, and gold assays running from 0.004 to 0.01 oz. per ton were obtained. Lithium was found in quantities less than 0.05 percent. The occurrence of scheelite, not only as a vein mineral, but also in some of the wall rocks, in quantities determined by the Jolliffe-Folinsbee method* to approach commercial grade, warranted a thorough sampling of the deposit.

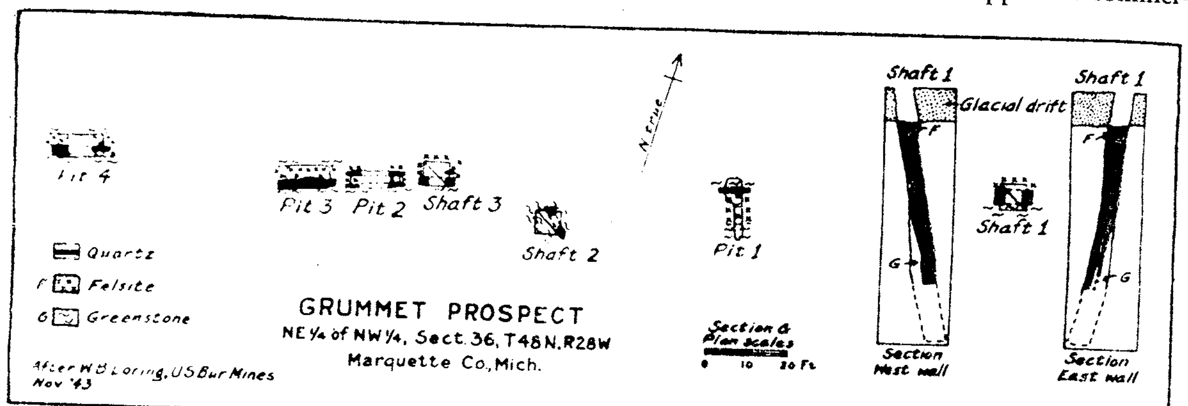


Fig 5

Geological Map and Sections, Grummet Prospect

The wall rocks are much altered. Part, at least, was originally a felsite porphyry, now more or less sericitized, and part may have been a coarser "diorite" mylonitized and changed largely to chlorite. These wall rocks are represented in Figure 5 as "Felsite" and "Greenstone" respectively. Both types are finely schistose, a light green bruise being the only megascopic evidence of the chlorite. The walls contain more abundant pyrite, some quartz lenses, and a little scheelite, and the secondary minerals chlorite, epidote, magnetite, leucoxene, and sphene.

The deposit appears to be of the mesothermal type. The absence of openings, the evenness of grain, and the lack of chalcedonic silica eliminate an epithermal origin; the lack of coarse texture and of minerals containing fluorine, boron, or phosphorus tends to exclude the possibility of

Fifty-one channel samples were cut from underground and surface. Spectrographic analyses revealed: Gold, none; tin, a small trace in 12 inches of greenstone schist from the footwall at Pit No. 3; tungsten, 7 large traces, 3 traces and 18 small traces; molybdenum, 1 very large trace (Shaft No. 2), 1 trace and 2 small traces; beryllium, 1 trace and 23 small traces; lithium, none; silver, 6 traces and 8 small traces; nickel, 9 traces; chromium, 3 traces.

Gold assays were made on all samples and were found to range from no gold in three samples,

* Jolliffe, A. W., and Folinsbee, R. E., Grading Scheelite Deposits with an Ultra-violet Lamp: Canadian Institute of Mining & Metallurgy, Transactions, volume 45, pp. 91—98, 1942.

to 0.01 oz. per ton in one sample; in all other samples not more than 0.008 oz. per ton was present.

At the Michigan College of Mining and Technology, quantitative analyses for tungsten were made on all samples showing spectrographic traces. Check analyses were made by the U. S. Bureau of Mines. The results are given in the

which the Michigan Gold Mine and Grummet prospect lie (Plate 4) were traces of tungsten found.

At the Peninsula Mine, SW 1/4 of the SW 1/4, Sec. 25, T48N, R28W, several shafts and a tunnel are in what has been described as quartz stringers in a granite which approaches a felsite in character (4). A grab sample of pyritic

TABLE 6

TUNGSTEN ANALYSIS OF GRUMMET SAMPLES

Sample No.	% WO_3 U.S.B.M.	% WO_3 M.C.M.T.	Sample No.	% WO_3 U.S.B.M.	% WO_3 M.C.M.T.
1	0.01		17	0.19	0.2018
2	0.01		18	Nil	
3	0.01	0.0126	19	0.01	0.0038
4	0.01		20	Nil	
5	0.01		21	Nil	
6	0.01		22	0.09	0.1009
7	0.02		23	0.08	0.0631
8	0.12	0.1009	23a	0.12	
9	0.01		24	0.01	
10	0.01		25	0.04	0.0757
11	0.08	0.0504	26	0.10	
12	0.02	0.0076	27	0.05	
13	Nil		27a	0.03	
14	0.01		28	0.03	0.0631
15	0.01		29	0.01	
16	0.01		30	0.58	0.6027
			40		0.0038

following table, which includes some additional determinations by the U. S. Bureau of Mines. (See Table 6)

All of the grades reported, with the possible exception of the grade on sample No. 30 (6 inches on the north wall of shaft No. 3 at 12 feet below collar) are below the present standard for tungsten ore.

Other Gold Prospects

In addition to the Ropes, Michigan, and Grummet deposits, numerous others of somewhat similar character were examined for scheelite, mostly with the ultra-violet lamp at night. Only in the east-west trending belt along

quartz in a pegmatitic vein from the dump yielded 0.005 oz. gold per ton.

In Secs. 14, 21, and 23, T48N, R28W, are a number of quartz veins and pegmatites in greenstone and granite, to which the writers were guided by members of the Pepin family, owners of some of the land. No tungsten or gold was detected.

Immediately southwest of Michigan Gold Mine, traces of molybdenum (less than 0.01%) were found with tourmaline and epidote on a shaft dump on Cleveland-Cliffs Iron Company land. Still more molybdenum (molybdenite and powellite) was noted on the "forty" lying east of Michigan Gold Mine; assays of grab samples collected several hundred feet east in the NE 1/4 of the NE 1/4 of Sec. 35 ran from 0.12 to 0.63 percent Mo. Associated are small quantities of silver (0.69 oz. per ton) and bismuth (0.16 percent). Somewhat further east on the Breitung property, in the W 1/2 of the NW 1/4 of Sec. 36, a 30-inch vein of quartz is exposed, striking S70°W and dipping 80°N; as at the Grummet, a felsite dike parallels the vein which consists of sugary quartz with a little pyrite. No gold or tungsten was found spectrographically in samples from this 30-inch vein.

Two shallow shafts sunk for gold near the south boundary of Sec. 25, T48N, R28W, are chiefly notable for small quantities of bornite associated with pyrite, chalcopyrite, and chlorite in quartz.

Asbestos*

At the Ropes Gold Mine property, in Sec. 29, T48N, R27W, the country rock for the most part is serpentine. A ridge of this rock, forming the footwall of the gold deposit, extends southwestward and has been quarried for "marble" (verde antique) in the eastern part of section 30. At the nose of the ridge to the northeast of the mine several pits have recently been opened, exploring for asbestos. The asbestos is in seams in the dark green serpentine rock, which is an alteration product of original peridotite. The seams are largely picrolite, a columnar variety of serpentine, not easily separable. The columns extend about 45° to the vein and are evidently due to shearing. Where the shearing is more intense the picrolite passes into chrysotile, the white silky asbestos variety of serpentine, with the fibers parallel to the vein walls. The asbestos at this locality thus differs from the usual chrysotile, which is "cross-fiber." It has an advantage over the usual type in the length of the fibers thus produced—six or seven inches is a common length. A near-surface weathering product of the asbestos resembles brown cedar bark. Sufficient long-fibered white material is in the deposit to warrant further investigation.

* By V. L. Ayres.

Verde Antique

About 3/8 of a mile southwest of the Ropes Gold Mine, in the NE 1/4 of the SE 1/4 of Sec. 30, T48N, R27W, is the quarry of the Michigan Verde Antique Company, opened in 1914. Though the serpentine, veined by dolomite, is of pleasing pattern, and good material is abundant, the company apparently could not produce verde antique at a profit. The Chicago & North Western Railroad spur, finished in 1918, has since been dismantled.

Farther southwest along the serpentine belt, in Sec. 36, T48N, R28W, is the Williams quarry. This quarry was not examined. During the summer of 1943 the old cables were cut up for scrap.

Conclusions

It seems reasonable to expect renewed interest and activity in the Ishpeming Gold Range after the war, provided gold is in demand. A thorough geological and geophysical survey of this area, where no doubt additional veins remain undiscovered beneath the drift, would facilitate the determination of possibilities for gold and perhaps also molybdenum, tungsten, and nonmetallic mineral production.

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BENEFICIATION TESTS ON SOME LOW-GRADE IRON ORES OF THE MARQUETTE IRON RANGE

By Frank J. Tolonen

The war-accelerated rate of depletion of direct shipping ores has stimulated added interest in the possibilities of concentrating the leaner portions of the iron formations on the several ranges of the Lake Superior district. The demands of the war for iron ore have emphasized the fact that the high-grade ores are not inexhaustible and that it is the concern of everybody whose well-being depends on these ores to examine future possibilities. Concentration of leaner grades has passed from the research field into the testing laboratories that have been established by the various operating companies.

It is rather difficult to evaluate any given deposit of iron ore because its economic value depends on many factors besides its metal content. Location, ownership, business connections, and possible users of ore all have to be considered. The present blast-furnace practice has been established on the basis of the high-grade ores and because of the rather exacting requirements as to raw materials and procedure, as well as the large units involved, experimenting with new materials will be costly and only resorted to when the present grades become hard to get. Any lowering in grade of raw materials will increase the cost of the product, which, in a highly competitive business, is to be avoided as long as possible.

Technically it is possible to extract iron from almost any iron-bearing rock, but rather strict limitations as to what is ore are set by economic conditions. Only those portions of the iron formations will be ore, at any given time, from which iron and steel can be manufactured at a cost comparable to the average cost of production for the district considered. It may be possible to limit the competitive area by tariff regulations and obstruction to cheaper methods of transportation. Still, as far as the Lake Superior district is concerned, the exhaustion of high-grade ores will not make all portions of the iron formation into valuable ore. Only those portions which can be cheaply mined and concentrated because of inherent physical or chemical properties will be of immediate value. The more difficult portions will have to wait for future developments.

Because of the economic situation at present, efforts will be made to produce concentrates that can be substituted for high-grade ores; that is, the concentrates must approach the present shipping grades in composition. This narrows the problem, as far as the operators are concerned, to search for ore bodies that will yield a concentrate equivalent to the present shipping ores at a reasonable cost.

With these limitations in mind, the samples submitted for examination under this program were tested and evaluated. Previous to the war, when the need for large-scale beneficiation was a future concern to be taken seriously twenty years hence, the consensus of opinion was that crushing to 1/4 inch or 3 mesh was the practical economic limit, and that size was used as standard for comparing concentration possibilities of the various samples submitted for testing. As this size coincided rather well with liberation due to structural features of most of the samples, there were no reasons for using any other size. More extensive study of the various types of iron formations has shown, however, that crushing and grinding to finer sizes must be resorted to in order to obtain the desired grade of concentrates.

The laboratory procedures followed in beneficiation tests on iron ores are described on pp. 9—10.

The following table gives the analyses of the samples from the Marquette Range submitted for concentration tests.

As in these samples are included carbonates, magnetite, and hematite it would be meaningless to try to give the results in the form of tables. For complete analysis the curves would have to be shown. In the following, the results on each sample are summarized on the basis of 10 percent silica in the concentrate, the standard Fe analysis of 51.5 percent, and also on the basis of 35 percent weight recovery as concentrate. This is on the assumption that for economic reasons it will not be possible to mine more than 3 tons of ore for 1 ton of concentrate. All analyses, unless otherwise stated, are on dried samples.

Table 7

Percentage Analyses of Low-grade Iron Ores, Marquette Range

Sample No.*	Fe	SiO_2	Mn	S	P
Brn-1	40.4	33.8	Tr	.014	.095
Fox-1	41.8	39.0	Tr	.131	.031
Go-1	28.7	45.3	Tr	4.640	.060
IFN-1	25.5	44.6	1.66	.057	.037
IFN-2	43.7	37.2	Tr	Tr	.029
IFP-1	35.0	31.4	.30	Tr	.071
Rp-36	38.6	43.4	Tr	.027	.020
Rp-37	40.9	39.0	Tr	.051	.010
Rp-63	39.1	43.1	Tr	.051	.020
SpW-3	28.2	58.2	Tr	.065	.028
WE-1	32.7	48.8	Tr	.110	.072
MM-14	25.4	56.9	Tr	.700	.083
MM-15	29.2	42.3	.08	.110	.032

Brn-1

Barron Mine, south shaft dump near old stack, E 1/2 of SW 1/4 of NW 1/4 of Sec. 11, T47N, R29W, iron formation with magnetite, specularite and sugary quartz; selected average sample.

This sample has granular texture such that crushing and grinding would effect liberation. A 44 percent weight recovery would be obtained when making a concentrate with 10 percent silica and 57 percent Fe. The metal recovery would be 63 percent and the silica rejection 86 percent. Finer grinding would improve the concentration.

Fox-1

Foxdale Mine, dump immediately north of U. S. Highway 41 near junction with County Road 601, NE 1/4 of SE 1/4 of NE 1/4 of Sec. 10, T47N, R29W; iron formation (magnetite with sugary quartz bands); selected average sample.

This sample has finer texture and there is considerably more fine silica in the iron-rich portions. Hence less than 10 percent weight recovery could be obtained in a concentrate with only 10 percent silica. On the other hand, assuming 8 percent moisture, then a 58 percent weight recovery of standard ore is possible as far as the Fe is concerned, but the silica would be 19 percent. Metal recovery would be 78 percent.

Go-1

Goodrich Mine, dump, NE 1/4 of SW 1/4 of NW 1/4 of Sec. 19, T47N, R27W; Goodrich conglomerate ore very close above contorted and shattered jaspilitic phase of Negaunee Iron Formation; selected average sample.

From the standpoint of SiO_2, a concentrate containing 52.5 percent Fe and 10 percent SiO_2 with a weight recovery of 28 percent is possible. One half of the Fe would be in the concentrate. Because of the high S, sintering would be necessary, permitting finer grinding and a little better recovery. There is considerable carbonate present; therefore without a sintering test exact analysis of the product is not possible.

IFN-1

Near Athens Mine, outcrop on north side of railroad cut, north of Athens shaft, near center of SW 1/4 of SE 1/4 of NE 1/4 of Sec. 6, T47N, R26W; cherty siderite phase of iron formation, oxidized only along cracks. Typical of original iron formation before change. Selected average sample.

The sample is mostly siderite with some hematite. There is no possibility of concentrates under 20 percent SiO_2, but after roasting an iron content of about 50 percent is possible. Considering that 35 percent weight recovery is essential for economic reasons, then the concentrate would assay after roasting about 48 percent Fe and 33 percent SiO_2.

IFN-2

Pit south of Ogden Lake, Cliff Drive, southeast of Ishpeming; NE 1/4 of SE 1/4 of SE 1/4 of Sec. 14, T47N, R27W; locally abundant phase of oxidized cherty siderite with little or no concentration; selected average sample.

There is no possibility of getting a concentrate with SiO_2 under 10 percent at 3 mesh. However, considering the Fe analysis, a 37 percent weight recovery is possible with a metal recovery of 48 percent. The SiO_2 would be 19 percent.

* Localities are given in the descriptions that follow.

Because of the rather high head analysis this siliceous ore would be included with the grades used at the present time.

IFP-1

VOLUNTEER-MAITLAND MINE pit, Palmer, W 1/2 of NW 1/4 of Sec. 30, T47N, R26W; somewhat oxidized cherty siderite including representative proportion of greenalite; selected average sample.

No low-silica concentrate is possible at 3 mesh. On the basis of 35 percent weight recovery a concentrate containing about 55 percent Fe and 27 percent SiO_2, after sintering, would be obtained. The metal recovery would be only 42.5 percent because the cherty portions are high in Fe.

Rp-36

KLOMAN MINE, Republic, SE 1/4 of SW 1/4 of SW 1/4 of Sec. 6 T46N, R29W; jaspilitic Negaunee Iron Formation, 20 paces stratigraphically below the Goodrich formation; 5 foot channel sample.

The sample consists of bands of chert and bands containing specular hematite. As the richer bands are considerably more friable, the fines are the richest portion. In this sample the richer bands contain enough SiO_2 so that no worthwhile concentration could be made if limited to 10 percent SiO_2 even with crushing to 10 mesh. On the basis of Fe analysis 27 percent weight recovery at 3 mesh and 51 percent at 10 mesh would be possible but the SiO_2 would be about 20 percent.

Rp-37

KLOMAN MINE, Republic, SE 1/4 of SW 1/4 of SW 1/4 of Sec. 6, T46N, R29W; relatively high-grade jaspilitic Negaunee Iron Formation, 20 paces stratigraphically below the Goodrich formation; 7½ inch channel sample.

In this sample the iron-rich bands are of lower grade than in the preceding. Silica would be over 20 percent in any case and even meeting the Fe requirements would necessitate fine grinding. Considering 35 percent weight recovery as necessary, the corresponding concentrate would contain 49.5 percent Fe and 26.5 percent SiO_2 with a metal recovery of 42.5 percent. In other words, it would probably have to be considered as a possible siliceous ore.

Rp-63

REPUBLIC MINE, Republic, waste dump between highway and Smith Bay; SE 1/4 of NW 1/4 of Sec. 7, T46N, R29W; jaspilitic phase of iron formation with rather more granular quartz than chert. Approximate average of top 100 feet of iron formation. Specular hematite about 30 percent, magnetite about 5 percent, chert and granular quartz about 60—65 percent.

This sample is more granular in texture and the specular bands are easily crushed and the included silica liberated. About 20 percent weight recovery would be possible in a concentrate meeting the present standard. About 80 percent metal recovery is possible in a concentrate meeting the Fe requirements but the SiO_2 would be about 18 percent. On fine grinding a considerable amount of concentrate containing around 68 percent Fe is possible.

SpW-3

U. S. Highway 41, 1/2 mile west of SPURR MINE, S 1/2 of SW 1/4 of NE 1/4 of Sec. 23, T48N, R31W; jaspilitic phase of Negaunee Iron Formation. Sixty foot thickness with neither top nor bottom exposed; grab sample.

From this sample no concentrate with less than 20 percent SiO_2 is possible and only a small amount of concentrate with Fe up to standard could be obtained. On the basis of 35 percent weight recovery as concentrate the assay would be 41 percent Fe and 40 percent SiO_2. As there are extensive areas of iron formation of this analysis available without concentration, this type is not of immediate interest.

WE-1

"NEW" WASHINGTON MINE dump, $\frac{2|1}{11|12}$ T47N, R29W and 1,700 feet east of the corner; banded, predominantly magnetic iron formation, with sugary quartz; selected average sample.

There is no possibility of acceptable concentrate either on the basis of Fe or SiO_2 at 3 mesh, although over 1/3 of the feed could be rejected as waste at this size. On the basis of 35 percent weight recovery, a concentrate assaying 52.5 percent Fe and 24 percent SiO_2 could be obtained. The reject corresponding to this would contain 21 percent Fe and 63 percent SiO_2. A metal recovery of 55.5 percent is indicated. Fine grinding of this concentrate would give a higher grade concentrate as this sample is granular.

MM-14

MAGNETIC MINE, westernmost dump, NE 1/4 of NE 1/4 of SE 1/4 of Sec. 19, T47N, R30W; average sample from 50 feet below top of iron formation; contains sugary quartz, magnetite, vein quartz, iron amphibole, pyrite, and muscovite; grab sample.

At 3 mesh about 19 percent of the weight would be an acceptable concentrate, but for increased recovery higher SiO_2 than 10 percent would have to be accepted. On the basis of 35 percent weight recovery the concentrate assay would be 51.5 percent Fe and 18 percent SiO_2, with a metal recovery of 70.7 percent.

As this sample was granular and the Fe in the form of magnetite, fine-grinding tests were made using magnetic separation. These tests indicated that grinding to 200 mesh or finer was necessary to obtain a concentrate under 10 percent in SiO_2. The metal recovery was well over 90 percent, however.

MM-15

MAGNETIC MINE, dump 350 paces NE along road from 1/4 post between Sec. 19 and 20, T47N, R30W; average iron formation showing good banding; grab sample.

At 3 mesh no concentrate corresponding to the present standard is possible. On the basis of 35 percent weight recovery the concentrate would contain 46 percent Fe and 21.3 percent SiO_2, with a metal recovery of 60 percent.

On crushing through 10 mesh no concentrate of present standard was obtained. On basis of 35 percent weight recovery the best concentrate would contain 49.5 percent Fe and 18 percent SiO_2.

On finer grinding and magnetic separation the concentrate even at 270 mesh grind would contain about 12 percent SiO_2 and 62 percent Fe. The metal recovery would be well over 90 percent.

Conclusions

These tests bear out the conclusions reached from years of previous work on the iron formations. The possibility of economic concentration depends on the structure and texture of the ore under consideration. Coarse banding or granularity permits separation of the richer portions from the leaner cherts on coarse crushing.* Thus, worth-while percentages of the feed may be rejected at small cost. In many cases, however, the richer portions saved still contain something like 20 percent SiO_2. In order to reduce this high percentage of silica, fine grinding is needed. For some ores the grinding necessary is far beyond anything that can be done economically, but with granular texture further liberation is possible. Microscopic investigation of the various structural constituents of the ore samples should enable one to determine this point.

* Broderick, T. M., Application of geology to problems of iron-ore concentration: Am. Institute of Mining & Metallurgical Engineers, Contribution No. 20, 1933.

DISTRIBUTION AND QUANTITATIVE OCCURRENCE OF MINOR OR RARE ELEMENTS OF POSSIBLE ECONOMIC SIGNIFICANCE IN MARQUETTE AND BARAGA COUNTIES

By A. K. Snelgrove

Technological advances in response to war-time demands have led to special uses of, and consequently accelerated search for, many rare or minor elements and minerals which until recently were merely curiosities of the laboratory and museum. Some of these elements have been found to occur in association with familiar types of ore deposits, such as vanadium in some iron ores; the origin, properties, and utility of many rare minerals and elements are still being determined.*

The availability of modern spectroscopic and X-ray apparatus for use in these investigations permitted a start to be made in the summer of 1943 on a study of the distribution and quantitative occurrence of these elements and minerals in certain mineralized zones in Marquette and Baraga Counties. The results, admittedly tentative and incomplete, are presented herewith as a possible guide in future prospecting. Cross references are given for elements discussed in other parts of this report in the sections on Lake Michigamme, Republic, and the Ishpeming Gold Range. Details on samples and analytical findings are on file at the office of the Geological Survey Division, Department of Conservation, Lansing, and at the Department of Geological Engineering, Michigan College of Mining and Technology, Houghton.

The system of notation employed in reporting spectrographic determination is T = very small trace, x = small trace, xx = large trace, xxx = larger trace, xxxx = very large trace. The absolute quantities represented vary with the elements. In the following summaries, quantities and ranges of the elements present in the several categories are stated when quantitative data are available.

The genetic relationships of most of the elements which have been introduced into their present sites subsequent to the formation of the enclosing rocks, as interpreted by W. A. Seaman, are shown in Table 3. Many of the elements in question occur as substitutes for commoner elements in minerals. The theoretical explanation of the substitution of ions of minor elements for ions of major elements in minerals is outside the scope of this report. The reader is referred to a recent paper by Bray* for a comprehensive regional study of this problem.

Antimony. No traces of antimony were found spectrographically. This fact reflects the general absence in the area examined of low-temperature hydrothermal deposits, in which antimony occurs. Tetrahedrite (copper-antimony sulphide) has been observed in the Ropes Gold Mine, Sec. 29, T47N, R27W.

Arsenic. No arsenic was detected in any sample.

Barium. Barite, the sulphate, is a minor but deleterious constituent of some iron ores of the Marquette Range.

The occurrence of barium in trace quantities in the only other association noted, viz., pegmatites and granites, is attributable to the ease of substitution of barium for potash in minerals such as potash feldspar and hornblende.** In three dozen samples, on which data are available, barium and strontium show rather consistent coincidence of variation. One-third of these samples exhibit yellow or greenish yellow to reddish fluorescence on weathered feldspar surfaces.

Beryllium. Beryllium, a light-weight metal (S. G. 1.85), has many new uses; an important one is as an alloy with copper to impart high strength and fatigue resistance. It is derived from beryl (beryllium aluminum metasilicate) which occurs chiefly in pegmatites.

In addition to the beryllium-containing deposits described (p. 25 and p. 43), traces of the metal were found in pegmatite from an island in the northwest bay of Ives Lake, northeast 1/4, Sec. 4, T51N, R28W, and in a pegmatite veinlet cutting a "diorite" dike at the Erie Mine, Sec. 28, T47N, R30W. In the Erie Mine dike minute beryl crystals are visible. Neither of the two occurrences appears commercially interesting.

Bismuth. Bismuth occurs in minor quantities in and near the Michigan Gold Mine, Sec. 35, T48N, R28W, and at the Suneson prospect, Sec. 8, T46N, R29W.

At the Michigan Gold Mine the bismuth-bearing mineral is tentatively identified as bismuthinite, Bi_2S_3. It was seen in place as rare small blades in a quartz-sulphide vein 20 feet south of No. 3 shaft. The bismuth assayed 0.09 to 0.11 percent. Two hundred feet east along strike of the main vein on Michigan gold property, bismuth was detected in a quartz vein containing considerable amounts of sulphides, including chalcopyrite and molybdenite; an assay gave 0.16 percent Bi. Flotation concentrates in the Michigan Gold mill ran 0.038 to 0.18 percent Bi.

The Suneson prospect is described on p. 44.

Boron. Tourmaline, a borosilicate of aluminum, etc., which is not a commercial source of the element boron, is present in many quartz veins, especially those which cut the iron formation from Champion to Beacon Hill, T48N, R29W. On the dumps of the Magnetic Mine, Sec. 20, T47N, R30W, 2-inch black tourmaline "suns" were found in pegmatite. Tourmaline was also observed in some of the quartz veins of the Ishpeming Gold Range, e.g., Michigan Gold and West Ropes.

Cadmium. Cadmium is obtained as a by-product in the smelting of zinc ores. Its local occurrence is of interest only if some of the zinc-lead-silver deposits in which it is contained should prove commercial.

Cadmium is present in traces at two prospects in the Dead River district.

At the Holyoke Mine, Sec. 2, T48N, R27W, it was found on dumps on the shore of Dead River Basin and also in the valley immediately northward. The mineral associations are: On the shore dumps, pyritic ore in silicified slaty greenstone with rusty carbonate; and galena in quartz and slaty greenstone with rusty carbonate and minor amounts of sphalerite; on the inland dumps, milky quartz with much sphalerite, chalcopyrite, galena, and pyrite, with rusty weathering carbonate and some malachite (a grab sample ran 0.08 percent Cd); and quartz, pink feldspar, fluorite, sphalerite, galena, pyrite, with rusty weathering carbonate, and some malachite. The last-named are from an exposed vein 2 feet in width.

At Fire Center Mine, Sec. 35, T49N, R27W, a trace of cadmium is present with sphalerite, pyrite, galena, and chalcopyrite in quartz.

It may be noted that the richest cadmium-bearing zinc ores in the United States, in the Tri-State area of Oklahoma, Kansas, and Missouri, averaged 0.358 percent Cd.*

The cadmium:zinc ratio in the one sample on which quantitative data are available from Holyoke ore is approximately 1:82 as compared to 1:160 for Tri-State.

Cerium. Cerium, a minor metal, was recognized spectrographically only in the mineral allanite. (See p. 45)

Cesium. No cesium was detected spectrographically.

Chromium. Although serpentinized peridotite, the usual country rock for chromite, the ore of chromium, is represented by several fairly large masses in Marquette County, no concentrations of this ore mineral have been found in them. The top of the serpentine at Presque Isle, T48N, R25W, immediately beneath the Lake Superior sandstone, yielded only 0.26 percent Cr.

Numerous traces to strong traces of chromium were found spectrographically in pegmatites, in which it is presumably contained as a non-essential constituent of muscovite mica.

Other minor occurrences of chromium are described on p. 28.

Cobalt. Only a few localities and associations yielded traces of cobalt. They are: in Sec. 6, T47N, R30W, in an irregular pegmatite; at the Erie Mine, Sec. 28, T47N, R30W, with a diorite dike cut by a pegmatite containing chalcopyrite and beryl; at Presque Isle Point (T48N, R25W), in a nickel-lead-silver veinlet in which no distinct cobalt mineral was recognized; and in the White Pine Mine copper ore (T50N, R42W). The White Pine ore is notable for its relatively large proportion of copper sulphide in association with the native copper of the Keweenawan

* Mathewson, C. H., Metals of the Future: Mining and Metallurgy, pp. 5—11, January, 1944.

* Bray, Joseph M., Spectroscopic Distribution of Minor Elements in Igneous Rocks from Jamestown, Colorado: Geological Society of Am., Bulletin, volume 53, pp. 765—814, 1942.

** Ibid.

* Tarr, W. A., Introductory Economic Geology: 2nd ed., p. 324, 1938.

deposits. Detailed quantitative work on concentrates of native copper and chalcocite failed to reveal more than traces of cobalt.

Another spectrographic trace of cobalt in the Lake Michigamme area is reported on p. 28.

Columbium. Columbium, an element which finds uses in special steels, was sought for in all pegmatites and in some high-temperature quartz veins.

Two minor occurrences in pegmatites in the Republic area are described on p. 44.

Copper. Copper, in the copper-iron sulphide, chalcopyrite, is widespread in small quantities in quartz veins and veinlets. Of no economic interest are traces in pegmatites, in small quartz veins commonly cutting the iron formation such as at Magnetic and Michigamme Mines, in "diorite" intrusives, and with nickel in veinlets cutting serpentine (see Nickel, p. 64). As a component of lead-zinc-silver ores, chalcopyrite is notably present at Fire Center Mine, Sec. 35, T49N, R27W, and Holyoke Mine, Sec. 2, T48N, R27W, and at a prospect somewhat similar mineralogically, south of Deer Lake, Sec. 33, T48N, R27W, 0.9 miles west of the Carp River Bridge over the inlet to Deer Lake and 50 paces north of county road "GM." No quantitative determinations were made on these occurrences.

At the Michigan Gold Mine, Sec. 35, T48N, R28W, chalcopyrite is disseminated in the main and several other veins, and is associated with quartz or quartz porphyry, in places with tourmaline and molybdenite. A grab sample of flotation concentrate in the mill ran 0.37 percent Cu.

Tetrahedrite (copper-antimony sulphide) is a minor constituent of the Ropes Gold ore, Sec. 29, T48N, R27W.

A slate into which the Mesnard quartzite grades upward is found about a half mile west of the quarry, in Mesnard quartzite, near Harvey, south of Marquette. This slate carries considerable chalcocite which occurs in veinlets across and along the bedding.

For a description of copper traces in the Lake Michigamme area, see p. 28.

Gallium. The metal galluim has economic applications due to its low melting point and its property of expanding on solidification.

Uneconomic traces of gallium were found in all 36 granites and in two-thirds of 66 pegmatites which were studied spectrographically.

Because it is known that gallium occurs with some copper ores, such as the Mansfeld copper-bearing shale of Germany, the sulphide ores of the Dead River Basin and the native copper and copper sulphide ores of White Pine Mine (T50N, R42W), Ontonagon County, were exhaustively analyzed for this element; none was found in these associations.

Gold. Numerous spectrographic analyses were made for gold. Results of fire assay on some of the samples indicate that the spectroscopic method is not always reliable for gold.

Outside the Ishpeming Gold Range, pp. 47—55, gold was determined in some of the lead-zinc-silver deposits of the Dead River Basin. In grab samples from the Holyoke Mine, Sec. 2, T48N, R27W, gold runs from 0.004 to 0.01 oz. per ton. These results are not necessarily representative.

A trace of gold was found in only one iron ore—a grab sample of red earthy hematite with some limonitic and cherty bands from the Cambria-Jackson Mine, Secs. 35 and 36, T48N, R27W, and Sec. 2, T47N, R27W.

For gold in the Republic area, see p. 44.

Indium. No indium was detected spectrographically.

Lanthanum. No trace was found of the rare-earth element, lanthanum.

Lead. Spectrographic traces of lead were found in practically all granites and in both simple and complex pegmatites, in the serpentine of Presque Isle Point (T48N, R25W), in numerous quartz veins, in some diorites and schist, but rarely in iron formation. The occurrence of lead as the sulphide, galena, in the lead-zinc-copper-silver deposits of the Marquette district is of possible economic interest.* These deposits are located in

Section 30, T46N, R24W
Section 25, T48N, R26W
SW 1/4, Section 2, T48N, R26W (Sedgwick)
NE 1/4, Section 2, T48N, R27W (Holyoke)
Section 6, T49N, R26W
Section 35, T49N, R27W (Fire Center)

* Lamey, Carl A., Lead-Silver Veins of Michigan: Geology Dept., Mich. Coll. Min. & Tech., May, 1936 (Unpublished).

Section 30, T50N, R26W
"Near the headwaters of the Chocolate River"

For accounts of the history and features of these deposits, the reader is referred to:

Rominger, C., Marquette Iron Region: Geological Survey of Mich., volume 4, pt. 1, pp. 153—154, 1878—1880.

Swineford, A. P., Ann. Rept. of the Commissioner of Mineral Statistics of the State of Mich.: pp. 112—113, 1883.

Newett, George A., Mines and Mineral Statistics, Mich.: p. 171, 1896.

Newett, George A., Mines and Mineral Statistics, Mich.: p. 289, 1899.

Russell, James, Mines and Mineral Statistics, Mich.: p. 443, 1900.

Lane, A. C., Report of the State Board of Geological Survey of Mich. for the year 1902: p. 22, 1903.

A description of lead in the Lake Michigamme area appears on p. 28 of this report.

Lithium. Lithium, a light metal, is present as traces to small traces in practically all granite samples which were analyzed spectrographically. It is also fairly common in pegmatites; samples show as much as 0.05 percent Li. Several quartz veins, such as those at the Grummet gold prospect, Sec. 36, T48N, R28W, also contain as much as 0.05 percent Li. Allanite is the only lithium-bearing mineral analyzed (p. 45), but W. A. Seaman recognized spodumene in the Lake Michigamme area. No lithia mica (lepidolite) was identified.

Manganese. Manganese is a common trace element in the dark minerals of igneous rocks and even in muscovite.

In this investigation, manganese was sought especially in the ore and iron formation of idle iron mines and prospects. More than 5 percent natural manganese in a manganiferous iron ore commands a premium in the Lake Superior Region. Ores of this grade manganese are most uncommon in the Marquette Range where the production for 1933—1942 averaged 0.31 percent Mn.*

The highest grade manganiferous iron ore now produced in Marquette is from the Blueberry Mine of the North Range Mining Co., N 1/2 NW Sec. 3 and N 1/2 Sec. 4, T47N, R28W, which in 1942 averaged 1.43 percent Mn natural;* it is understood that parts of the Blueberry orebodies run considerably higher in this metal.

The occurrence of traces of manganese in practically all granites examined, in pegmatites, in the slate wall rocks of the iron formation, in various dikes, quartz veins, dolomite, manganiferous calcite, can be dismissed here as of scientific interest only. The manganiferous calcites which were analyzed exhibit red fluorescence.

The only phases of iron formation that revealed a manganese content in excess of the percentage in the average ore now being shipped are from the following inactive properties: 1) Imperial Mine, NW Sec. 25, T48N, R31W, Baraga County, with gruneritic magnetite running 0.43 percent Mn; 2) Spurr Mine, S 1/2—NW 1/4 and N 1/2—SW 1/4 Sec. 24, T48N, R31W, Baraga County, ore containing a vein of pinkish carbonate and quartz, yielding 0.53 percent Mn; 3) dump north of U. S. Highway 41 near Humboldt, Sec. 1, T47N, R27W, garnet, amphibole, and quartz containing 5.85 percent Mn, and 4) Magnetic Mine, Sec. 19, T47N, R30W, where garnet-rich amphibole rock containing some magnetite and scheelite ran 4.4 percent Mn. It must be emphasized that all of these were grab samples and are not necessarily representative. Residents of Republic state that a small tonnage of manganiferous iron ore was shipped from Magnetic Mine or vicinity during World War I.

Molybdenum. Molybdenite, the sulphide of molybdenum, is usually found in pegmatites, "contact metamorphic" and disseminated replacement deposits, and in veins of high temperature formation. Most of these types are represented in the area investigated. Minor amounts of powellite (calcium molybdate) are found in the Ishpeming gold-quartz belt.

The quantitative range of concentrations of molybdenum as reported from spectrographic analyses is: absent = less than 0.01 percent, trace = up to 0.12 percent, large trace = about 0.17 percent, and larger trace = about 0.63 per-

* Wade, Henry H., Mining Directory of Minnesota, 1943: University of Minn. Mines Experiment Station Bulletin, volume 46, No. 22, p. 206, 1943.

* Analyses Lake Superior Iron Ores, Season 1942: Lake Superior Iron Ore Assoc., p. 21, 1943.

cent. The last figure is in excess of the grade of the huge deposit at Climax, Colorado. However, no economic tonnages have so far been proved in Northern Michigan.

A summary follows of the geological and geographical features of the occurrence of molybdenum in areas other than those already described (p. 29 and p. 44).

Sporadic samples of molybdenite were found in the area around Champion (T47 and 48N, R29W). On the dumps of the Beacon Hill Mine or in ledge in these townships, this mineral occurs disseminated in granite pegmatite and granite gneiss; in quartz, usually with tourmaline; in association with garnet, tourmaline, chloritoid, and magnetite; in graywacke schist or gneiss; and in biotite-hornblende schist. No channel or grab samples taken in these areas showed more than a trace of Mo spectrographically.

South of the center of Sec. 25, T48N, R29W, 1½ miles east of Clowry, an irregular vein as much as 18 inches wide yielded on channel sampling less than 0.02 percent Mo.

Some of the lead-silver deposits of the Dead River Basin were found to contain traces of molybdenum. On the dump of the north shaft at Fire Center Mine, Sec. 35, T49N, R27W, molybdenum occurs in very small quantity in association with green schist containing a little quartz and carbonate; and with quartz associated with pyrite, galena, sphalerite, and chalcopyrite.

Wadsworth* observed that molybdenite occurs at the Michigan Gold Mine, NW 1/4 of the NE 1/4, Sec. 35, T48N, R28W, but had not been observed in the other veins of the Ishpeming gold belt. Dr. T. M. Broderick,** chief geologist of Calumet and Hecla Consolidated Copper Co., Calumet, Michigan, states that molybdenite has been found in small quantities in the lower levels of the Ropes Gold Mine, Sec. 29, T48N, R27W. Nineteen out of 35 samples collected from the Michigan Gold dumps, mill, and veins, NW 1/4 of NE 1/4 of Sec. 35, T48N, R28W, and from adjacent "forties" showed molybdenum spectrographically from "traces" to "large traces." The grade of molybdenum in the Michigan Gold ore is undetermined. Molybdenite appears to be concentrated chiefly at the edge of quartz veins but is disseminated in the quartz in places. None was found in unveined quartz porphyry. Samples taken from various products in the mill analyzed about 0.1 percent Mo. One sample of flotation concentrate contained more. On the surface, molybdenite and yellow-fluorescing powellite were found in greatest relative abundance east of the main shaft of the Michigan Gold property and in the adjacent "forty." In the flooded workings, Mr. Charles E. Secor, caretaker, reports* that an 18-inch vein at the east end of the 250-foot level contains a 2-inch streak of molybdenite in places. Systematic sampling of the workings for both molybdenum and tungsten, as possible valuable by-products in this gold deposit, should be part of any plans for future development of the Michigan Gold property.

Nickel. Although nickel substitutes for ferrous iron** in the dark minerals of igneous rocks, traces of nickel were found in only 3 of 50 granites of this area; only rarely was it found to occur in the pegmatites, diorites, and quartz veins. Seven of the basic dikes of Lighthouse Point, T48N, R25W, showed a small trace of nickel.

Three other local modes of occurrence deserve mention although none is of economic interest: in the iron formations, in weathered serpentine, and in a sulphide vein in serpentine.

In the iron formations, a trace of nickel occurs in the Bijiki at Bessie Mine, Sec. 35, T48N, R29W, and also in the Negaunee at Marine Mine, Sec. 30, T48N, R29W, and the National Mine, Sec. 16, T47N, R27W.

Since some nickel ores elsewhere were formed as residual hydrous silicates by the weathering of serpentine, search was made for nickel in the Presque Isle serpentine mass, north of Marquette City, where the serpentine is beneath the Lake Superior sandstone. In various types of serpentine, analyses ranging from 0.02 percent to 0.14 percent Ni were obtained. The top of the serpentine, immediately beneath the Lake Superior sandstone, ran 0.14 percent Ni. In what is presumably an admixture of residual serpentine mantle rock with the arkosic basal sediments of the Lake Superior sandstone 0.07 percent of nickel was found. That the buried topography of the top of the serpentine contains local accumulations of nickel is a matter of speculation.

* Wadsworth, M. E., Report of the State Board of Geological Survey for the Years 1891—92: p. 154, 1893.

** Personal communication.

* Personal communication.

** Bray, Joseph, M., Spectroscopic Distribution of Minor Elements in Igneous Rocks from Jamestown, Colorado: Geological Society of Am., Bulletin 53, volume 1, p. 797, 1942.

The occurrence in a sulphide vein is at the site of an ill-founded mining enterprise of early days at Presque Isle Point, Sec. 1, T48N, R25W, where the search for lead-silver is now commemorated by a signboard. Part of the vein explored in the serpentine can be seen in a cove along the east shore, near the north end of the point. It is ½ to 2 inches wide and consists mainly of galena, pyrite, pyrrhotite, and chalcopyrite. In polished section two nickel minerals can be seen in small quantity—violarite, $(Ni, Fe)_3S_4$, and millerite, NiS. The spectrograph indicates copper, silver, cobalt, manganese, much lead, and much nickel. A quantitative analysis shows 0.32 percent Ni.

For other minor traces of nickel, in the Lake Michigamme area, see p. 29.

Phosphorus. Phosphorus is not sensitive spectrographically. Only two quantitative determinations were made, both on samples of garnet-amphibole-magnetite ore from the Magnetic Mine, Sec. 19, T47N, R30W. The samples ran 0.02 percent P.

Platinum. Platinum was looked for spectrographically in what is elsewhere a common association, viz., the various phases of serpentinized peridotite, and in a sulphide veinlet in this country rock, exposed at Presque Isle, Sec. 1, T48N, R25W. The serpentine at the verde antique quarry, in Sec. 30, T48N, R27W, was also examined. No platinum was found at either locality.

Rhenium. The rare element, rhenium,* now in much demand, is reported to occur elsewhere in some molybdenum and tungsten minerals and in slime from copper refineries. It has a melting point close to the melting point of tungsten. The richest known source contains only 0.002 percent of rhenium.* All spectroscopic plates made in this investigation were carefully examined for rhenium, with negative results.

Rubidium. No trace of rubidium was found in the few samples in which it was sought.

Scandium. Scandium, for which few uses have been found, was looked for in pegmatites and quartz veins but without success.

Silver. In general silver is associated with the lead deposits described on pp. 62—63. In addition to the Fire Center, Holyoke, and Presque Isle Point localities, silver was found in spectrographic traces (i.e., up to 1.4 oz. per ton) in several other quartz veins, such as in the Chippewa (iron) Mine, Sec. 22, T47N, R30W, and the Grummet gold prospect, Sec. 36, T48N, R28W.

In connection with the sampling program at Michigan Gold Mine, Sec. 35, T48N, R28W, traces of silver were found spectrographically in 13 out of 33 samples analyzed. Grab samples of flotation concentrates in the mill ran 1.4 to 1.56 oz. per ton. A grab sample of a vein 200 feet east of the Michigan Gold property, and approximately along strike with the main vein of that mine, assayed 0.69 oz. per ton; this vein contained quartz rich in sulphides, including chalcopyrite and molybdenite. In addition, a grab sample of a vein exposed 20 feet south of the one mined at Michigan Gold shaft No. 3 ran 0.58 oz. per ton.

For silver in the Lake Michigamme area, see p. 29.

Strontium. Like barium, strontium is present in traces in many pegmatites. It was found spectrographically in allanite also, and in other rare minerals (p. 45).

Tantalum. Because of new applications of tantalum in surgery, careful search was made for it spectrographically in all pegmatite samples and also in some of the samples collected from the gold-quartz veins of the Ishpeming belt. No traces of tantalum have been found so far. For information on an element which commonly occurs in association with tantalum, see columbium, p. 44.

* Tyler, Paul M., Rhenium (and Masurium): U. S. Bureau of Mines, Information Circular 6475, 1931.

* Schoeller, W. R., and Powell, A. P., The Analysis of Minerals and Ores of the Rarer Elements: p. 238, 1940.

Terbium. Terbium, a rare earth metal, was not detected in the few pegmatites and quartz veins in which it was sought.

Thallium. Thallium, which at present has few uses, was found as spectrographic traces in most of the granites analyzed and also in a few pegmatites. These traces are not considered of economic interest; in general, the metal occurs in pyrite and is recovered from flue dust in the manufacture of sulphuric acid.

Thorium. Thorium, long employed in making gas mantles and in special alloys, now finds uses in electronics. It was not found in any of the granites or pegmatites which were examined.

*Tin.** A rock sample (BgB-9), which analyzed 0.03 percent tin, was collected southeast of the Huron Mountains in Sec. 18, T50N, R27W. It was part of a pegmatitic granite which intrudes dioritic gneiss in the first rock ridge north of the Yellow Dog River. No cassiterite (SnO_2) was visible in the specimen under a hand lens, but traces of what may be cassiterite were discovered in the heavy-mineral concentrates from the granite. In mountings which contained roughly 4,000 grains, six were found which had the optical properties of cassiterite, including an irregular zonal distribution of color and a pleochroism of reddish-brown to yellow, varying in intensity from very rich to quite faint. The granite consists of coarse microcline and quartz about 35 percent each, altered silicic plagioclase about 25 percent, and the remaining 5 percent mainly hornblende, biotite, and epidote. No hyacinth or normal zircon, and only a single grain of malacon could be located; malacon is indicative of a Huronian age for the granite (see p. 43). The spectrograph showed that zinc is present as well as tin but the mode of occurrence of the zinc remains an open question.

Another spectrographic indication of tin, which analyzed 0.01 percent, was found in specimen INq-6. It came from a one-half inch quartz vein containing chalcopyrite which had been injected into a uralitic diabase dike crossing Marquette County road No. 553, 1.8 miles north of the intersection with road No. 480, near the north boundary of Sec. 10, T47N, R25W. In this district, granitic gneiss is intruded by a younger granite which also converts Mesnard quartzite into sericitic and granite-like rock. This younger granite seems the probable source of the tin-containing vein. Manganese, vanadium, titanium, and copper are also present in the specimen as shown by the spectrograph.

Traces of tin (as well as of manganese, lead, lithium, and gallium, and a smaller trace of vanadium) were obtained from granite No. 36. This is an aplitic type granite, pink or white in color, which contains in addition to the felsic minerals, a dark muscovite (or perhaps zinnwaldite) in sparse, parallel flakes. The microscope also showed fluorite, magnetite, and unidentified brown spots. This granite is located in Sec. 14, T47N, R29W, along county road 601, about a mile and a half south of U. S. Highway 41 at Barron Mine.

At the Grummet Mine, Sec. 36, T48N, R28W, a trace of tin showed in specimen USBM Gr-1. It was found in a channel sample of 12 inches of greenstone which forms the south wall of a 26-inch quartz vein near the west end of the prospect. The north wall of the vein is a felsite dike. The sources of the tin and the associated tungsten are undoubtedly the same.

In Sec. 33, T50N, R27W, at the hairpin bend on highway M-35, the old-appearing granite gneiss carries a trace of tin, while at Palmer a younger (post-Huronian) granite dike showed tin spectrographically.

The granitic gneiss along Campeau Creek, Sec. 5, T48N, R25W, contains phases in which the pink feldspar becomes almost porphyritic. Tin occurs spectrographically in this phase, but not in the non-porphyritic granitic gneiss.

The largest trace of tin was found in magnetic concentrates from an old-looking gneiss southwest of Lake Pelesier in Sec. 10, T47N, R25W.

Two other tin-bearing rocks from Sec. 26, T48N, R30W and Sec. 31, T48N, R20W, each containing 0.02 percent tin, are described on p. 29.

Further work is now being done on the tin occurrences of Marquette County.

Titanium. Titanium is common in igneous rocks and was found in small to large traces in most granites and pegmatites and in some diorites, greenstones, and sericite schists. The largest quantitative result showed 0.6 percent Ti in amphibole-garnet-chlorite schist from the dumps of the Beacon Hill Mine at Champion, Sec. 31, T48N, R29W.

Small traces of titanium were also found in parts of the iron formation of the Marquette Range. Its presence in iron ore is undesirable.

Tungsten. Because in 1943 a shortage existed in American supplies of tungsten, intensive search was carried out with the aid of ultraviolet light ("Mineralight") which causes the tungsten ore, scheelite, to fluoresce. Discoveries of new sources elsewhere have radically changed the tungsten situation in the meantime.

Of 50 granites analyzed spectrographically, none showed traces of tungsten. From over 500 samples of other rock and mineral associations, chiefly high-temperature quartz veins and pegmatites, only 13 showed positive traces of tungsten.

All the traces found are in either the Republic area (p. 44) or the Ishpeming Gold Range (pp. 48, 51-53). None is of sufficiently high grade to be of economic value by present standards.

Vanadium. Vanadium is a critical war metal, used chiefly in alloy steels. Therefore it was the object of special search in this investigation. Only one possible location in the area studied was suggested. It was thought that some iron ores in the Marquette Range might contain sufficient vanadium to recover as a by-product. The results were negative.

Spectrographic traces of vanadium are widespread petrographically and geographically. Traces ranging from 0.002 to 0.05 percent V were found in some grab samples of magnetic iron formation, consisting of magnetite and chlorite, which were taken from the inactive Chippewa Mine, Sec. 22, T47N, R30W, and from a dump near the former site of the Chicago and North Western Railway depot at Champion, Sec. 32, T48N, R29W. The non-magnetic iron formation in the Ishpeming area of the Marquette Range showed smaller traces. On the whole, vanadium appears to occur in similar quantities in the wall rocks of the iron formations and in the iron ores.

The associations of traces of vanadium found in the Lake Michigamme area are described on p. 29.

Yttrium. Yttrium, a rare earth, was found in unimportant traces in four granites, mainly porphyritic, south and north of Republic.

Zinc. In addition to its occurrence in some quantity in the lead-silver-zinc deposits of the Dead River Basin (Fire Center and Holyoke), traces of zinc were detected in a number of pegmatites and quartz veins. These traces, like those in the Lake Michigamme area (p. 29), are of no commercial interest.

Zirconium. Only unimportant traces of zirconium were found; these occurred in granite.

* By V. L. Ayres.

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