WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

E. F. BEAN, Director

BULLETIN 71 ECONOMIC SERIES NO. 24

# THE GEOLOGY OF THE GOGEBIC IRON RANGE OF WISCONSIN

By
H. R. ALDRICH

MADISON, WISCONSIN
PUBLISHED BY THE STATE
1929

# WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY

---

## BOARD OF COMMISSIONERS

WALTER J. KOHLER,
*Governor of the State.*

GLENN FRANK, *President.*
*President of the University of Wisconsin.*

JOHN CALLAHAN, *Vice-President.*
*State Superintendent of Public Instruction.*

SAMUEL A. BARRETT, *Secretary.*
*President of the Wisconsin Academy of Sciences, Arts, and Letters.*

## STAFF OF THE SURVEY

ADMINISTRATION:

ERNEST F. BEAN, State Geologist, Director and Superintendent.
In immediate charge of the Geology Division.
HENRY R. ALDRICH, Assistant State Geologist.
LILLIAN M. VEERHUSEN, Chief Clerk.
GERTRUDE A. HEHL, Junior Clerk–Stenographer.

GEOLOGY DIVISION:

ERNEST F. BEAN, In charge.
HENRY R. ALDRICH, Assistant State Geologist.
JAMES M. HANSELL, Geologist.
EDWARD O. ULRICH, Consulting Geologist, Stratigraphy, by cooperation of the United States Geological Survey.
RAY HUGHES WHITBECK, Geographer.
FREDRIK T. THWAITES, Geologist, Well Records and Pleistocene Geology.

NATURAL HISTORY DIVISION:

EDWARD A. BIRGE, In charge.
CHANCEY JUDAY, Lake Survey.
FRANK J. MEYERS, Rotifera.
VILLIERS M. MELOCHE, Chemistry.

DIVISION OF SOILS:

ANDREW R. WHITSON, In charge.
WARREN J. GEIB, Editor and Chief of Field Parties.
CHARLES E. KELLOGG, Soil Surveyor.
KENNETH ABLEITER, Field Assistant.

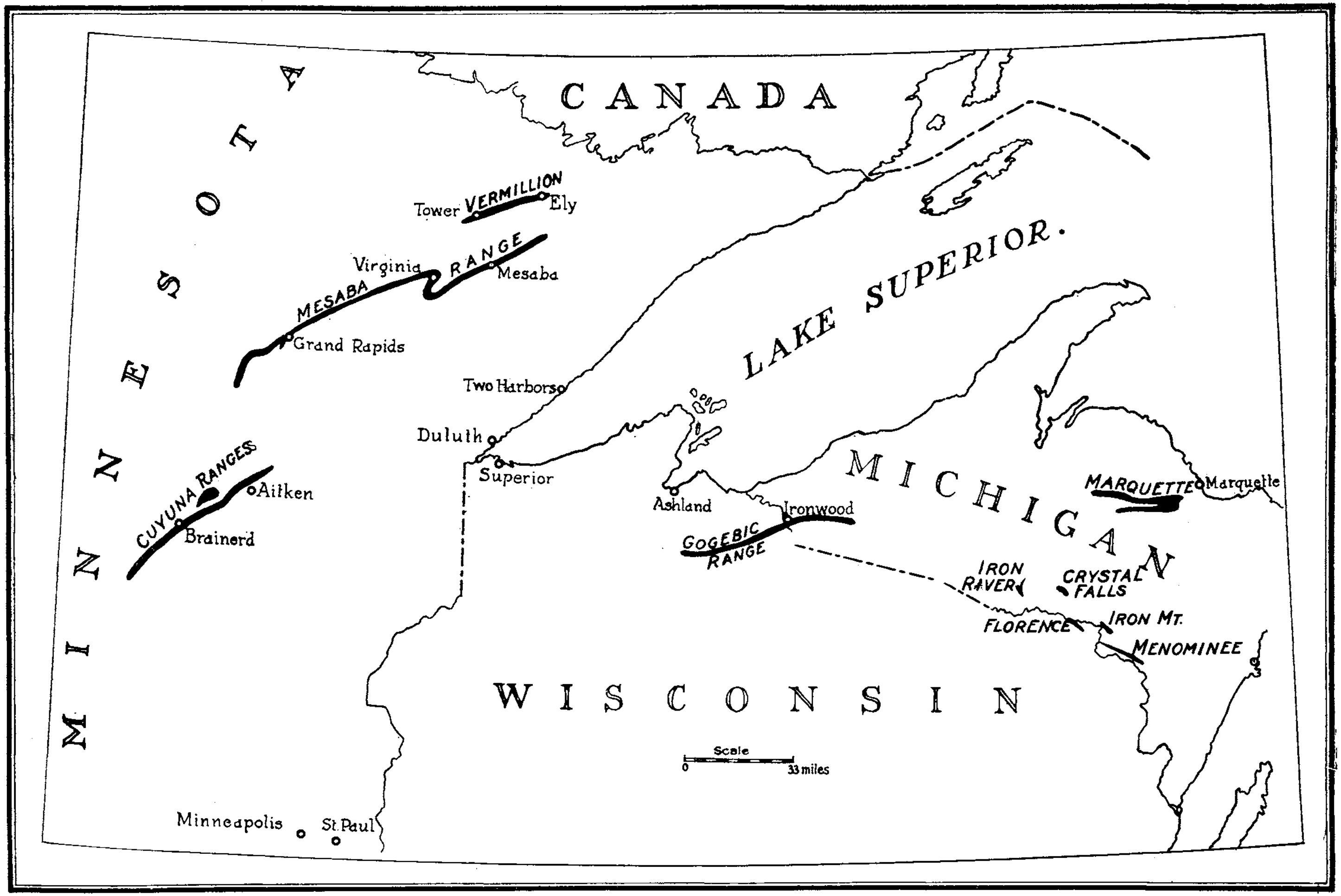



FIG. 1 THE IRON RANGES OF THE UNITED STATES IN THE LAKE SUPERIOR DISTRICT

# CONTENTS

## PART II

## MAPS AND DETAILED DESCRIPTIONS OF TOWNSHIPS

# ILLUSTRATIONS

# INTRODUCTION

In the summer of 1915 the State Geological Survey under the direction of Dr. W. O. Hotchkiss carried out a detailed examination of the townships containing the Penokee-Gogebic Iron Range. The particular reason for the work was not that earlier surveys had been in error but that they were lacking in the detail necessary to meet the inquiries coming from the interested public and the State Departments, particularly the Tax Commission. The parties placed in the field were organized to obtain the maximum of detail.

Three parties were engaged under the immediate supervision of Mr. E. F. Bean. The range was first attacked in the extreme west end and entire townships were examined. Traverses were thrown across the townships on all section and quarter lines. All exposures of bed rock were searched for and mapped, as well as the topography and drainage. In addition, at intervals of 50 paces observations were made with the magnetic dip needle.

With the coming of the World War and the need to divert attention to other affairs, the work of organizing a report on the field findings was interrupted. Advance maps showing the magnetic results were prepared, but this was the sum total of publication.

Following the War, in 1919, Dr. Hotchkiss became convinced from his observations made underground in the course of private professional practice, that the Ironwood was amenable to differentiation into five distinct members. Incidentally, from a practical standpoint this has proved to be the most valuable discovery in recent years. The question arose, however, whether this subdivision would hold throughout the western extent of the range. Accordingly, the survey laid plans to retrace the formation westward from the mining district with the hope of settling this question. The writer was given the charge of the party engaged on this problem and to it devoted the field season of 1919. The magnetic method was employed on a small scale seldom applied to an area of like size. It was found that the formation was not only magnetic as a whole, but that certain members were traceable if observations were taken at intervals of 10 paces. With these horizons traced through the range, it was a much simpler matter to correlate the various exposures and test pits with one or another of the five members. In the course of the season's work, it could be definitely stated that the five-fold subdivision held for the entire western district.

Furthermore, with the delineation of the several magnetic horizons on such a detailed scale, minor structural dislocations were revealed. It is in this way that the cross faults, some of which cut into the Keweenawan, were detected. At the same time it was found that locally oxidation had been extreme or that recrystallization had gone to a maximum. In fact a very considerable body of detailed facts was accumulated. Incidentally, at the same time that this last examination was made, there was in the field a party of the United States Geological Survey engaged in making a topographic map. This made it possible to correlate more directly the structure and distribution of formations with the topographic expression.

In the later months of 1919 Dr. Hotchkiss prepared a series of articles embodying the main results obtained by the survey and observations made in the course of private consulting practice. These articles were published by the Engineering and Mining Journal[1] and they met the needs of the mining men so completely that delay in the publication of the Survey was not felt.

Pressure of other work of greater service to the state necessitated postponement of the writing of the report on the iron formation. In 1921, however, six years after the completion of the original survey of the region, the responsibility for this report was delegated to the writer. A start was made with the examination of thin sections cut from the great number of specimens taken in the field. The magnetic results over the complete suite of townships were platted graphically on a single diagram. This is not included in the report but has been published in the meantime[2].

During the field seasons from 1922-1929, the Survey has been engaged with the mapping of the Keweenawan formations which overlie the Huronian of the Gogebic Range. From this study much light has been thrown upon the Huronian problems, particularly the structural and metamorphic problems. While the publication of this Gogebic report has not been intentionally postponed, the delay has afforded an opportunity to incorporate the views regarding the Keweenawan geology insofar as they are relevant to Huronian problems. This is perhaps of advantage since earlier

[1] E. & M. J. Vol. 108, September 13, 20, 27 and October 4, 1919.

[2] Geophysical Prospecting. Amer. Inst. of Min. and Met. Eng. pp. 385–400, 1929.

geologists have not had the details of Keweenawan structure for consideration.

This report, therefore, has had a varied career in finally coming to the light. The writer has been forced to rely upon the work of the parties operating in 1915 in dealing with the Archean, and with Huronian formations other than the Ironwood. With the upper Tyler he has had first hand experience in connection with the mapping of the base of the Keweenawan. Therefore, the writer shares responsibility with the others as to the geology of these formations. Whatever merit there may be in these connections belongs to former members of the survey staff. For views concerning the Ironwood sedimentation, for views in which the Keweenawan relationships are of prominence, and for the formulation and hypothesis of the cause of the structural deformation, the writer is wholly responsible.

The writer feels keenly the lack of experience in the eastern or Michigan end of the district. He has no intent to ignore conditions or the work of others in that region. In a sense, the treatment of a problem shared by two states can never be satisfactorily handled without simultaneous and cooperative study between the two surveys. The writer feels also the lack of familiarity with the problems of the series of formations as revealed in other districts around Lake Superior. It is hoped that critics will be kindly disposed in focusing their expert knowledge of other Huronian districts upon this work.

The report is expected to be of interest to land owners, dealers in mineral lands, operators of mining properties on the range, and students of geology in general.

For the first group greatest value will probably be found in the individual township reports of Part II. In these the various townships are described in no little detail with reference to topography, drainage, general geology, and especially the iron formation. The latter is described as to location, degree of oxidation or recrystallization, presence of dikes, cross faults, magnetic attraction, and the extent of exploration. For each township the promise of finding ore is described.

Students of geology will probably find particular interest in Chapters IV, VI, and VII. In the first of these is given some new views on the background of magnetic surveying, the sensitivity of instruments, and the interpretation of magnetic observations. In Chapter VI, on structure, the details of deformation are formulated into a simple statement relating them to one another. In Chapter VII the view is expressed that the prime factor operating in the development of the two distinct types of formation was the variation of concentration of the original solutions. This is of interest perhaps to students of sedimentation.

*Acknowledgments.* The writer would acknowledge personal indebtedness to Dr. W. O. Hotchkiss, E. F. Bean, J. M. Hansell, H. N. Eidemiller, J. Rudolph, H. B. Doke and other members of the survey organization. These men have respectively provided the opportunity to work with these problems, aided in analyzing and organizing the data, assisted in many ways such as in reading manuscript and recommending changes with view to making the volume of interest and service to the public, and are responsible for the excellent drafting of the various maps and diagrams.

The Survey acknowledges the friendly cooperation of various lumber companies and their representatives. We would mention particularly Mr. George B. Williams of the Willow River Lumber Company with headquarters formerly at Grand View, and Mr. George Foster of the Mellen Lumber Company and of the Foster and Latimer Lumber Company at Mellen. Thanks are also due to the various representatives of the Montreal and Odanah Mining Companies, and of the Republic Iron and Steel Company for many services. The latter company donated the drill core upon which the detailed description of the Ironwood was based.

Many others have contributed to the work. We wish to thank all who have in the many ways had a part. The several former part-time members of the Survey who by tireless efforts and loyalty to the organization brought the field work to a successful conclusion merit our sincere appreciations. It is hoped that all who have played a part will accept this expression of appreciation without specific mention.

Publication of this volume does not put an end to interest in and study of the geology of this region. With a great volume of detailed data at hand, it is extremely difficult to generalize without fear of overlooking points of interest. The Survey would be pleased to confer at any or all times with individuals concerning details not adequately covered.

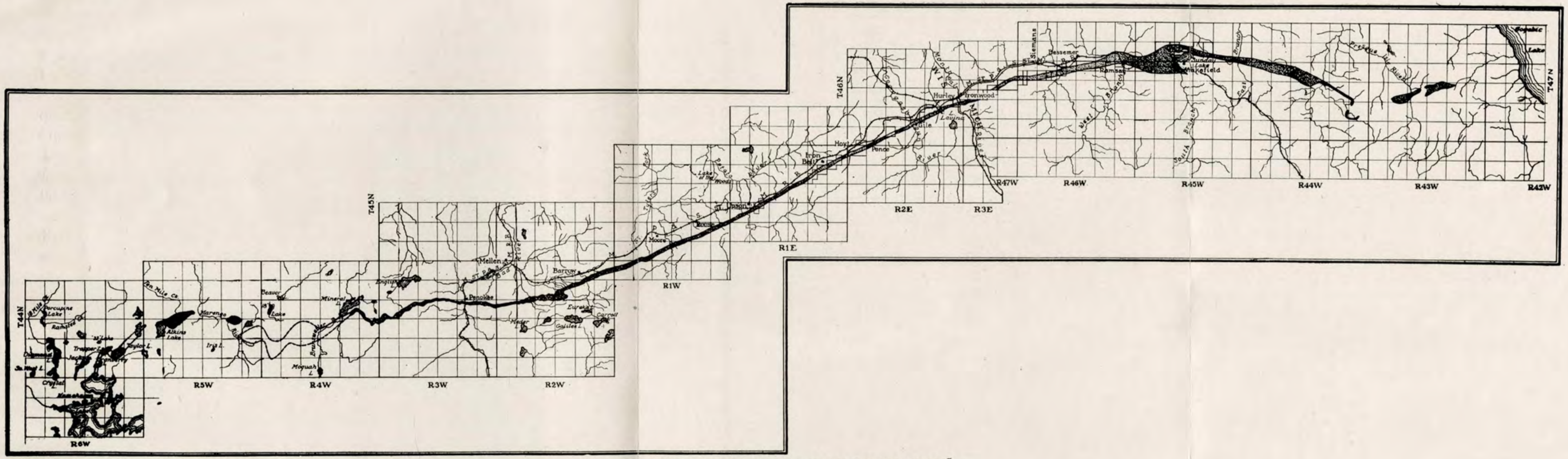



FIG. 2 LOCATION AND EXTENT OF THE GOGEBIC RANGE

# CHAPTER I

## THE GOGEBIC IRON RANGE

### Geographic Location

The Gogebic is one of the numerous iron-producing ranges embraced within the Lake Superior Region. See Fig. 1. It lies 25 to 30 miles south of Lake Superior, partly in Wisconsin and partly in Michigan. End to end it measures close to 80 miles, of which 53 miles lie within Iron, Ashland, and Bayfield counties of Wisconsin. See Fig. 2. Considered as a whole, the range is narrow, seldom more than a half mile wide, and it forms a gentle bow or crescent concave to the southeast with irregular bends at either extremity marked by prominent lakes, Namakagon in Wisconsin and Gogebic in Michigan. Although having this crescentic shape, the trend through short intervals is regular and essentially straight. From measurements taken within the regular portion extending at least 25 miles west of the state boundary at Hurley the trend is about N. 60° E.

Location is further defined with reference to cities in the vicinity. Mellen, Hurley, and Ironwood are the three most important cities on the range. Ironwood is in Michigan, but is separated from Hurley, Wisconsin, only by the Montreal River, the state boundary at this point. Mellen lies about 25 miles west of Hurley in Ashland County, and although it is a mile or more north of the range proper, it establishes the location of the range, and like Hurley, its development has been in no small way connected with the exploitation of the Gogebic iron ores. Both Mellen and Hurley are railroad junction points. The former lies on the Soo Line just north of Penokee Gap where the road pierces the range. Hurley lies on the main line of the Northwestern, and between this city and Mellen the Iron Range Branch of the Soo Line maintains connection. Ore shipments are hauled in either direction, to Mellen via the Soo Line or to Hurley via the Northwestern and thence to the docks on Lake Superior at Ashland, some 40 or 45 miles northwest.

## Geological Location

Geological location conveys an idea of spacial relationships although the factor in mind is time or age. The history of the earth is read from the records preserved in rocks. A bedded rock found to cover a second type where there are no irregularities such as inversion, was formed later than the underlying and each succeeding individual layer is younger. Thus, taking world wide areas, there is deposition taking place continually and the idea of a complete column of these deposits is known as the geological column. The column has been divided and subdivided into groups of rocks representing periods of time. In the table below, the geological column is presented and here some attempt has been made to estimate the duration of time for each era. Figures in parentheses are most recent and are taken from a most interesting paper by J. Barrell.[1]

Bearing this explanation in mind the reader will grasp the idea of geological location better than any attempt to state the exact age in years. The Penokee series of rocks forming the range are of the pre-Cambrian era. As a group, rocks of these eras occupy the lowest position in the column. Referring to the number of years during which these were probably formed, however, it is clear that a period is involved which exceeds the combined years elapsed from the close of the pre-Cambrian to the present. Accordingly the pre-Cambrian has been subdivided and in the following table this classification is shown.

The rocks found in the Penokee series are of Upper Huronian age. The Middle Huronian, according to this classification, is missing and the Lower Huronian members occur only in patches. The basement which is continuous over the great sweep of peneplain to the south is Archean, represented by Kewatin schists and intrusive Laurentian granites.

Above the Penokee series of the range proper, there is a mantle of unconsolidated materials which represents the glacial drift deposits of the Pleistocene. Thus, in the history of the range the chapters covering the time between the Huronian and the Pleistocene are lacking. In the ridge to the north of the iron range, however, the Keweenawan lava flows are found overlying the upper member of the Penokee series.

---

[1] Rhythms and the Measurements of Geologic Time. J. Barrell. Bulletin G. S. A. Vol. 28, pp. 745–904, 1917.

## TABLE SHOWING THE GEOLOGICAL COLUMN[1]

| Era | Period or Epoch[a] | Characteristic Life | Duration in millions of years according to various estimates |
|---|---|---|---|
| Cenozoic (recent life) | Quaternary[b]<br>Recent<br>Pleistocene or Glacial Period or Great Ice Age | Age of man. Animals and plants of modern types. | 1 to 5<br>(55–65)[c] |
| | Tertiary<br>Pliocene<br>Miocene<br>Oligocene<br>Eocene | Age of mammals. Possible first appearance of man. Rise and development of highest orders of plants. | |
| Mesozoic (intermediate life) | Cretaceous<br>Jurassic<br>Triassic | Age of reptiles. Rise and culmination of huge land reptiles (dinosaurs), of shellfish with complexly partitioned coiled shells (ammonites), and of great flying reptiles. First appearance (in Jurassic) of birds and mammals; of cycads, an order of palmlike plants (in Triassic); and of angiospermous plants, among which are palms and hardwood trees (in Cretaceous) | 4 to 10<br>(135–180)[c] |
| Paleozoic (old life) | Carboniferous<br>Permian<br>Pennsylvanian<br>Mississippian | Age of amphibians. Dominance of club mosses (lycopods) and plants of horsetail and fern types. Primitive flowering plants and earliest cone-bearing trees. Beginnings of backboned land animals (land vertebrates). Insects; Animals with nautilus-like coiled shells (ammonites) and sharks abundant. | 17 to 25<br>(360-540)[c] |
| | **Devonian** | Age of fishes. Shellfish (mollusks) also abundant. Rise of amphibians and land plants. | |
| | **Silurian** | Shell-forming sea animals dominant, especially those related to the nautilus (cephalopods). Rise and culmination of the marine animals sometimes known as sea lilies (crinoids) and of giant scorpion-like crustaceans (eurypterids). Rise of fishes and of reef-building corals. | |
| | **Ordovician** | Shell-forming sea animals, especially cephalopods and mollusk-like brachiopods. Culmination of the bug-like marine crustaceans known as trilobites. First trace of insect life. | |
| | **Cambrian** | Trilobites and brachiopods most characteristic animals. Seaweeds (algae) abundant. No trace of land animals found. | |
| Pre-Cambrian | **Algonkian**<br>Keweenawan<br>Huronian<br>Upper Huronian or Animikie (Penokee Series)<br>Middle Huronian<br>Lower Huronian | First life that has left distinct record. Low forms of sea weed (algae); possibly annelids (worms). | 20 to 40<br>(400–600) |
| | **Archean**<br>Laurentian<br>Kewatin | No fossils found. | (300+)[d]<br>50+ |

1. Reproduced with minor modifications from Bulletin 612 of the United States Geological Survey.

[a] The geological record consists mainly of sedimentary beds—beds deposited in water. Over large areas, long periods of uplift and erosion intervened between periods of deposition. Every such interruption in deposition in an area produces there what geologists term an unconformity. Many of the time divisions shown above are separated by such unconformities—that is, the dividing lines in the table represent local or widespread uplifts or depressions of the earth's surface.

[b] The geological periods represented by the rocks in Wisconsin are in black faced type.

[c] J. Barrell, op. cit. p. 884.

[d] J. Barrell, op. cit. p. 752.

This geological location in the pre-Cambrian may be said to place the series within a period from 1 to 1.5 billion years ago. These figures serve only to emphasize the fact that the iron formation is extremely old and that various geological forces have been active through countless years. The accomplishments of forces operating in the earth's crust through the ages can hardly be grasped, and in the following chapters these results are to be employed in deducing the theories concerning the origin and development of the range series.

## Physiographic Location

A description of the physiographic location of a natural feature such as the range should convey those ideas that are necessary to build a true mental picture of the land forms not alone of the immediate vicinity but of the more remote regions. It is for convenience in describing the physiographic location of a given spot that areas have been divided and subdivided into smaller areas on the basis of some natural factor. These subdivisions are natural areas or physiographic provinces. A physiographic province is a finite area characterized by unity of topographic relief and land forms which reflect a common history of development. Observation of rock texture and structure as the fundamental dominant factor involved in shaping the features of the earth's surface has been the basis for subdividing the state of Wisconsin into five provinces which are shown in figure 3. Two of these provinces should be examined to define the physiographic location of the Gogebic Range.

The Northern Highland has been called a peneplain which may be defined as an area which is essentially a plain in that, despite undulations and an occasional hill, extreme relief of an earlier land surface has been reduced essentially to a level. The rocks of this highland are in great part crystalline, for example granites, gneisses, and schists. The granites are the dominant rocks exposed on the surface and these are characteristically coarsely crystalline. As far as our knowledge of consolidation of magmas will reach, the conclusion is more or less sound that these rocks crystallized under the protection of a considerable thickness of overlying rock. Considered individually, each rock type is highly resistant to erosion but when compared with one another differences are disclosed which result in some enduring erosion more effectively than others; consequently there are occasional hills and ridges remaining as residuals upon the peneplain. These are common features on peneplains and they are known as monadnocks.

The Gogebic Range is a monadnock of the Northern Highland and is situated near the boundary between that province and the


Fig. 3

Lake Superior Lowland. Between these provinces there is marked contrast. The lowland is not a plain, for in certain areas active erosion by streams has cut the region into an extremely hilly topography. The total altitude range is approximately from 1,000 feet above to about 300 feet below sea level (depth of Lake Superior).

The highland, on the other hand, has an elevation of around 1500 feet along its northern border and above this the Gogebic rises to an elevation of more than 1800 feet above sea level.

## TOPOGRAPHY[1]

From a vantage point anywhere along the range the view toward the southern peneplain is a picture of monotonous desolation. Uniformity of elevation and vegetation regardless of direction is broken only by a glittering lake, or a great repulsive burned area in which the blackened spars of tamarack or hemlock, gaunt against the sky, suggest a derelict fleet rotting in the shoals. It is in many respects fascinating in its passivity, dreariness, and desolation.

A far different reaction is experienced, however, on turning toward the north. Below is a broad intervale extending to a second ridge of lower elevation about two miles to the north. This ridge which roughly parallels the Gogebic is the Keweenawan series of lava flows. The inter-ridge area at some points is regular in topography, but at other points minor knobs and hills may be seen. Beyond the crest of the Keweenawan the far slope of that ridge cannot be seen, but against the sky the water of Chequamegon Bay on Lake Superior may be seen surrounded by the lowland area whose hazy blue contrasts markedly with the firm green of the immediate foreground.

Topographically, the range is the salient feature of prominence on the monotonous upland. Standing upon the Gogebic, the observer appreciates that it shares this prominence with the Keweenawan trap ridge across the intervale. From a considerable distance north or south, however, the fact that there are two can hardly be appreciated. From the south the Gogebic alone can be seen; from the north it is also the dominant feature. As recorded in an early account of exploration: "Proceeding to La Pointe, the ancient missionary station and trading post on one of the Apostle Islands . . . we had our first view of the Penokee Iron Range, the blue outline of whose summits could be seen bounding the horizon towards the south and southeast."[2] The boundary between the highland and the lowland at this point is a "low sloping wall" and from the north the Keweenawan lies at the culmina-

[1] For further reference to topography see U. S. Geological Survey Topographic sheets.

[2] The Penokee Iron Range: Wisconsin and Lake Superior Mining and Smelting Company, p. 23, Milwaukee, Starr & Son, 1860.

tion of a regular and continuous slope which conceals its real prominence.

In the above observation recorded from La Pointe, the serrated character of the ridge is emphasized. This is a fact sometimes lost sight of or not made, but a true picture of the range must represent it as a series of long, elliptical hills with the longer axes placed end to end. Possibly a dozen of these units occur between Hurley and Mineral Lake. The rocks dip to the northwest and for the greater part of the distance the strike is regular. The connected ridges or elliptical hills are consequently not in any way due to a more resistant bed recurring at intervals through folding, nor are they simple fault blocks. Erosion by streams in many instances facilitated by shear zones has done the work of excavating the sags between the hills.

## DRAINAGE

The Gogebic Range lies close to the divide between the Chippewa River basin and the basin of the combined Bad River and Montreal. There are eight streams crossing the range: from east to west the Montreal, Gogogashugun, (or west branch of the Montreal) Potato, Tylers Fork, Carrier Creek, the Bad River, Brunsweiler, and Marengo. Drainage is ultimately northward. The Montreal and its west branch the Gogogashugun, flow directly into Superior The remaining ones flow through the range and then swerve nearly at right angles along the inter-ridge valley to the west or east and unite with the Bad River which empties into Superior. The Bad is, therefore, the major stream. In fact the level of Penokee Gap is the lowest of all gaps, a factor which gives this stream an advantage possibly equal to the task of capturing the headwaters of all these streams in time to come.

The idea of streams having power to cut directly across the most resistant and persistent part of a plain is difficult to understand unless the past history of this region is studied. The indications found during such a study lead to the possibility that these rivers did not develop upon the peneplain. Possibly this part of Wisconsin was in early times, geologically, covered by rocks of the same general character and age as those found in the southern counties, limestones, sandstones, and shale rocks. The streams may have developed on these rocks and cut their channels. The river channels, being the lowest points, reached the base of these sedimentary rocks while the latter still remained in considerable volume in the interstream areas, sufficiently so, in fact, that they kept the streams in the old channels even though flowing upon the old peneplain floor. These circumstances may be likened to a strip of wood in a miter box. The saw moves in the guides and the cut in the strip can be made in that position and in no other. Thus these streams were maintained in channels across the range until gaps had been cut.

There are some gaps with no streams, one gap cut much deeper than the others, and two gaps which are broad and show none of the features that characterize the majority. The explanation is but a variation from that already outlined. A gap without a stream indicates the diversion of waters. For example, an adjacent river with greater effective gradient is a more powerful one and in its upper reaches may accomplish the capture of the waters of the first mentioned stream. The Bad River at the present time has the lowest gap in the range and the most direct course to the lake. It is the most powerful stream and possibly will accomplish the capture of the headwaters of some of the neighboring rivers.

Penokee Gap through which Bad River pierces the range has been cut much deeper than the other gaps. The cause of this is transverse faulting in a zone several times the width of the river. Reference to the map plate (XII) demonstrates the fact that in the southern part the river channel lies along the east wall of the fault zone in the footwall and farther north against the west wall. As a fault zone is a zone of weakness with shattered and sheared rocks readily removed by erosion, the Bad River has cut more deeply than the others.

It will be brought out in other chapters that several of these gaps are loci of cross faulting which materially promotes rapidity of erosion.

The crossings of the range by the Brunsweiler and the Marengo are broad sags. In each case, however, the underlying rocks are not the resistant Penokee series. Plate I. In place of iron formation there is gabbro which is a far different type of rock. Erosion in the iron formation forms ridges with steep scarps whereas in the gabbro it forms low rounded hills and broad shallow valleys. These rivers, therefore, have developed broad valleys. The gabbro is not greatly different from the crystalline types back on the peneplain.

The streams farther east, for example the Gogogashugun and the Montreal, cross the range where the iron formation is less durable and granites form the crest of the ridge. As in the gabbro, erosion in the granite produces low rounded hills and broad valleys. The gaps accordingly are broad.

Many smaller creeks flow down the north side and longitudinally along the soft slates at the foot of the gabbro and trap range. These, with the transverse streams, complete a trellised pattern of stream drainage.

## ROADS AND SETTLEMENTS

On the whole, the region immediately adjacent to the range is sparsely settled. If one travels from Hurley westward to Mellen, a distance of approximately 25 miles, the villages passed are Hurley, Gile, Montreal, Pence, Iron Belt, Upson, Moore, Ballou, and Mellen. The first five named are clearly built around the mining industry. In fact, mining activity present or past is reflected on every hand.

Red iron ore forms the road bed, huge dumps of ore or rock-waste dot the outer margin of the range, and not a few head frames may be seen along the south side of the ridge. Upson today shows the faintest trace of mining activity, but a stronger suggestion of lumbering. In driving from here westward, mining is less dominent and the saw mills and other evidences reflect the essential industry. Mellen is a railroad junction point and has several mills and factories. Veneer, box wood and lumber mills, a gabbro quarry and a creamery provide employment for many hands. In short, from Montreal to Mellen the settlements are derelicts surviving more active mining days or left stranded by the higher tide of logging operations.

None of these villages has agricultural possibilities under present conditions for populations much larger than those now living there. A few farms have been cleared in the intervale between the iron and trap ranges, but land here is not of the sort greatly to stimulate farming. There is very little industry excepting the saw mill at Ballou. There is practically no developed water power and the bulk of the timber has been removed. The future holds out three possibilities for these towns, a revival of the mining industry or the reclamation of the plain south of the range and the reproduction of the forest crop. Although the mineral possibilities are not necessarily negative as far west as Moore, the promise of immediate rejuvenation of these towns from this influence is slight.

When stimulus comes, however, if ever, these towns probably will furnish the nuclei for the newer communities, for they occupy the most desirable spots along the range.

The development of the region south of the range area shows almost no activity at present. As described above, this region is the old peneplain surface, undulating, covered by morainal deposits, and grown up to second growth timber. Swamp or poorly drained land abounds. The soil where turned into hay land in isolated patches here and there supports a luxuriant growth. It is excellent for producing these hardier grasses and clovers. For some time there has been considerable discussion as to the adaptability of this area to agriculture.

The future will demonstrate the possibilities. Probably the most serious obstacles today are the lack of good roads and the range itself which is a barrier. However, when the area is finally opened to settlers, the most logical town sites will be those on the railroads and those towns of which we have been speaking lie not only on the Iron Range Branch, but at the gateways to the gaps through the range. No more advantageous location could be found that that of Upson. In fact, it is apparent that these villages reflect earlier routes of transportation from north to south along lines of natural accessibility.

West of Mellen the towns are few and only scattered farms have broken the wilderness. At Foster a few miles west of Mellen one of the large lumber companies has its headquarters and junction of its logging railroad with the Soo Line. The settlement consists of a small group of houses, shops, and store. West of Foster there are only a few farms along the main road as far as Mineral Lake, and from this point west the number is still less. The western extremity near Atkins Lake is in a region unsettled as yet, but reached by the railroad of the Willow River Lumber Company[1]. This is a lake country and camps have been established as the only evidence of settlement. The whole sweep of country in R. 4 W. has been seldom traversed and its settlement and development are retarded by lack of railroad and wagon roads. The range itself may be reached as far west as the west of R. 4 W. by means of the Mellen Lumber Company Railroad, but roads opening up the country for settlers are absent.

[1] These logging railroads are now abandoned, 1928.

## Locational Advantages and Disadvantages

Comparisons with other iron producing districts probably provide the best way for describing the locational advantages or disadvantages. A first comparison with perhaps the ideal location may be of value in bringing out the features. Probably an iron ore deposit located near the large industrial centers already established and also close to a field of coking coal would be ideal. Birmingham, Alabama, nearly covers the point. Most of the ores from Lake Superior, however, go to Cleveland, Ashtabula, Pittsburgh, Toledo, Chicago, and Gary. They go down the lakes to industrial centers. Coking coals and fluxes as well as the ore are brought to these centers. The Gogebic Range, therefore, should be compared with other districts around Lake Superior. To this end it may be stated that the Mesabi Range lies no less than 42 miles from the nearest docks at Two Harbors on the north side of the lake and 65 miles from Duluth and Superior. The route to the lake ports lies through rugged topography and the railroad haul is consequently difficult. The Marquette range lies about 10 miles from its nearest lake port. The Gogebic Range occupies a mid position as regards extremely long rail haul and extremely short. It is approximately 28 miles from Hurley to Ashland. The topography as described is decidedly to the advantage of loaded trains. Well equipped established railways tie the range to the lake.

## Area Covered by This Report

The area covered by this survey is a strip varying from 3 to 9 miles in width and extending from T. 46—R. 2 E. to T. 44—R. 6 W. Generally the strip is 6 miles wide, covering the entire township within which the Penokee series is found. On account of the diagonal strike of the range only fractions of some townships were covered. The list below shows the area worked.

| | | |
|---|---|---|
| T. 46—R. 2E. | South half | 18 sections |
| T. 45—R. 2E. | North sixth | 6 sections |
| T. 46—R. 1E. | South sixth | 6 sections |
| T. 45—R. 1E. | North sixth | 6 sections |
| T. 46—R. 1W. | Entire | 36 sections |
| T. 44—R. 1W. | North sixth | 6 sections |
| T. 45—R. 2W. | South half | 18 sections |
| T. 44—R. 2W. | Entire | 36 sections |
| T. 44—R. 3W. | Entire | 36 sections |
| T. 44—R. 4W. | Entire | 36 sections |
| T. 44—R. 5W. | Entire | 36 sections |
| T. 44—R. 6W. | Entire | 36 sections |

Total area approximately—288 sections = 8 townships

This area was covered by field parties in 1915. During that season primary emphasis was placed upon location of the series by means of magnetic attraction, accurate location of all exposures, the footwall contact, and exploratory workings. In the field season of 1919, however, a much more detailed examination was made by a single small party. During the course of this work the Ironwood was traced in detail. The subdivisions of the formation were followed magnetically from end to end. At the same time a party of topographers from the Federal Survey were engaged, in cooperation with the State Survey, in the making of a topographic map. The maps accompanying this volume, therefore, are correct as to land net, as well as in regard to detailed geology.

Much valuable information was obtained in field seasons from 1922 to 1928 during the detailed mapping of the Keweenawan formation. The Keweenawan geology is closely related to that of the Huronian, so much so, in fact, that a comprehensive view of the Keweenawan features would seem to be indispensable to an understanding of the geology of the Penokee series.

# CHAPTER II

# HISTORY OF DEVELOPMENT

## INTRODUCTION

The tourist visiting the cities in the producing part of the range for the first time is impressed with the prosperity and the highly developed communities served by the most modern facilities and boasting of the very best in public buildings. At one and the same time he is made to see that iron ore and nothing else has made these things possible, and he falls to speculation upon the future of the communities. If he has approached the cities by rail, he has noticed iron ore or its associated red rock ballasting the right of way. If he motors along the highway, he is similarly led to the fact that here again, although to a limited extent in more recent years, the iron ore has furnished the road materials at least in the surface. On closer approach, the great head-frames lined up with their trestles leading out to the mammoth mounds of dirt and ore gain his attention. In town there is red ore on every hand. There is no other industry than those supported by the iron industry. Innumerable opportunities are afforded, however, for the observation that the enormous volumes of earth removed have already endangered the temporary safety of the communities, and lead to the query as to the point in time when the exhaustion of the ore bodies will send the communities into decline.

The stage of development now attained has been gained in a mere 44 years. Ore was first shipped in 1884 and 1022 was the tonnage. In 1927 there were shipped 6,385,558 tons. In the aggregate through the years there have been removed from the formation more than 150,000,000 tons of ore and with the necessary rock waste more than 200,000,000 tons or more than 2,000,000,000 cubic feet by volume have been excavated. How long continued will be the life of the industry and of the communities?

In reaching this stage of prosperity the cost has been great as measured in capital expenditures, in wasted energy, and in disappointment and blasted hopes. If one takes the trip along the formation on foot from the Montreal River to the Trapper's Lake region, some 55 miles southwest, he literally picks his way through a maze of pits, some shallow to be sure but some of considerable depth, shafts with carefully timbered walls, and the mounds of dirt and broken rock thrown out by those prospectors who literally combed the surface of the formation in search of iron ore. There are hundreds of these pits, shafts, and trenches. There is not a "40" from end to end of the range across which the Ironwood formation occurs which has not been well pitted in this surficial and superficial manner. Cabins, some crude, some pretentious, but all in decay, stand near the scenes of the labors. Over the yawning openings there are all manner of scaffolds giving way to the weather. Hand winches and old buckets which were used to hoist the dirt to the surface lie about in the encroaching brush. Here and there the old boilers toted in over the rough roads by more ambitious and hopeful ones have been abandoned. The cost of the information that the western reaches of the range are yet unprofitable places for explorations has been great. With the ultimate realization of this fact the attack has been concentrated upon the portion from Iron Belt eastward and there have been the appropriate rewards.

## THE ERA OF THE FUR TRADE

The earliest trace of the presence of the white man in the region is that in 1658 two Frenchmen engaged in fur trading with the Indians at the present site of Ashland. These were by names, Groseilliers and Raddison[1]. It would be very unnatural indeed if either the Indians or these fur traders had had any appreciation of or interest in any mineral not amenable to immediate use. The Indians did know of the native copper on Keweenaw Point and they could and did make use of it in their tools, ornaments, arms, and utensils.[2]

## THE PERIOD OF GEOLOGICAL RECONNAISSANCE

*Barnes and Whitney.* The first geologists of record to come into the region were Barnes and Whitney[3] who in 1847 were mapping

[1] Kellogg, L. P., The French Regime in Wisconsin and the northwest: State Historical Society of Wisconsin, Wisconsin History Series vol. 1, p. 109, 1925; Verwyst, Chrysostom, Historic Sites on Chequamegon Bay, Wis. Hist. Colls., vol. 13, p. 433, 1895.

[2] Kellogg, L. P. op. cit., pp. 74, 117–118.

[3] Irving, R. D., and Van Hise. C. R., The Penokee iron-bearing series of Michigan and Wisconsin: U. S. Geol. Survey Mon. 19, p. 6, 1892.

government lands in Michigan. It is said that their maps show they came to very close proximity with exposures of the Ironwood but no note was made of any observation of them. Their maps show a contact of the granites to the south with the traps of the north. No doubt, forest cover was most effective and the view limited to very short distances. Travel was also very difficult. Moreover, the magnetic attraction in this vicinity is not strong, no stronger in fact than on the Keweenawan basic rocks to the north. It is not difficult, therefore, to understand the failure of these men to discover the range at this time.

*D. D. Owen.* In 1848 Dr. D. D. Owen explored in northwestern Wisconsin and probably came very close to the iron formation in the vicinity of Lake Namekagon[1]. Exposures are very sparse in this region and the attraction, excepting over the iron formation, is not so strong as to arouse suspicion of the presence of unusually highly ferruginous rocks. Again it is not difficult to explain why Dr. Owen failed to discover the Ironwood.

*A. Randall.* The same year, 1848, when Dr. Owen was at work in the Namekagon region, Dr. A. Randall attached to a survey party engaged in running the fourth principal meridian north to Lake Superior noted the exposures of the Ironwood and their unusual nature in the vicinity of Upson.[2] As a matter of fact there are exposures directly upon the line and close to the footwall of the formation. There are other exposures just east on the east bank of the Potato River. These are probably the exposures discovered by Randall. Thus, not for 190 years after the first advent of the white man to the region was the Ironwood marked as a very special type of rock.

It is interesting to recall that the year of discovery of the Ironwood was still 7 years prior to the discovery of the steel process by Bessemer. Had discovery been made earlier, it is a question whether the world would have profited particularly. At all events, it is still another 35 years before there was a discovery of iron ore. While the Marquette had been producing for about 30 years, it is probable that the demands for iron ore to satisfy the steel industry were not so great as to stimulate intensive search for additional ore. There was no steel production prior to 1850, wrought iron met the requirements up to this time. In 1855 Bessemer

[1] Idem, p. 7.
[2] Irving, R. D., and Van Hise, C. R., op. cit., pp. 7, 28.

discovered a way to remove the impurities from pig iron and in 1860 some 10,000 tons of steel were produced in this country and 40,000 for the world. In 1865 the open hearth process was perfected and in 1870 steel production jumped to 300,000 for the world and to 70,000 for the United States. In 1880 the world production was 4,430,000 of which 1,250,000 came from United States plants. Growth in the succeeding decade is shown by the fact that in 1890 world output rose to 12,250,000 and that for the United States to 4,280,000 tons. Under the urge of this growth it is probable that the discovery of ore in 1883 on the Gogebic was opportune.

*Charles Whittlesey.* In 1849, the year following Randall's discovery, the United States government sent Colonel Charles Whittlesey to examine the belt of "iron-bearing" slates from the vicinity of Montreal River to English Lake.[1] He made the first map of the vicinity and it was naturally somewhat crude since it was made without the assistance of other surveyed lines than the meridian. It is interesting to note that from this earliest study of the formation, attention was directed toward the west end of the range, for Whittlesey wrote, "It should be borne in mind that the whole region is not only covered so thickly with trees that no distant view can be had without climbing trees, but the drift often conceals the rocks over a large proportion even of the elevated ridges. In addition the rocks themselves previous to the era of the drift have been the sport of giant forces which tossed and tilted them about at various angles and elevations realizing the fable of Atlas." No such tossing and tilting as Whittlesey refers to can be seen east of the high point of the range south of Mellen which bears his name. Furthermore, he repeatedly refers to the strongly magnetic and slaty outer horizons, probably the Anvil slates of the present day nomenclature.

In 1860 the Wisconsin Geological Survey sent Whittlesey back into the region. This was eleven years after his first visit. His previous work had been published in Owens' report (1852). In his report on the second survey of the region he says, "Soon after the publication of Dr. Owen's report the excitement of 1845-46 with reference to copper was repeated with reference to iron. The government was at last induced to make surveys of the region. Preemptors followed the surveyors erecting their rude cabins on each

[1] Irving, R. D., and Van Hise, C. R., op. cit., pp. 7, 22.

quarter section between the meridian and lac des Anglais, a distance of 18 to 20 miles[1]." Here once more it is clear that the principal interest was being directed to the western, more magnetic part of the range.

Whittlesey is responsible for naming this mineral range the Penokee, although he did not so name it. He had applied the name Pewabic which in the Chippewa tongue means iron. But a compositor set the name into type as Penokie. This name became fixed to the range although it apparently belongs to no language at all. In this connection it is interesting to note that on page 396, vol. XII of the Wisconsin Historical Collections, it is stated that the word Penokee which is applied to a range of hills and a town in Wisconsin is a corruption of the Chippewa opinikan (wild potato ground). And it is still further of interest to note that there is a stream crossing the range near Upson which is known as the Potato River. Whittlesey apparently had the best of intentions to connote the presence of iron on the range rather than wild potatoes.

*I. A. Lapham.* I. A. Lapham visited the range in 1859 and devoted his time to examinations between the meridian and Mineral Lake, with special attention to the gap at Penokee.[2] He was probably the first to detect the presence of the Bad River fault at the gap. Lapham apparently added little to the understanding of the nature of the formation beyond the recognition that the Tyler had been well indurated by influences ("probably heat and pressure"). It is fascinating, looking backward, to speculate upon the outcome had Lapham gone the one additional step and postulated that the Ironwood as well as the Tyler has been metamorphosed by the gabbros. It was not until Irving did essentially this very thing that the attention was diverted from the west to the east and the discovery of ores was made. Lapham's mind was not working in that direction, however, as indicated by the fact that he emphasized the importance of the magnetic formation at the gap. This is not at all surprising when it is realized that during this period the furnaces of the country were operating upon magnetic ores. He said in his report, "At Penokee where Bad River crosses the range, the ore exists in such abundance that it may be obtained from the face of the hill, much as stone is taken from an ordinary stone quarry.

[1] Irving, R. D., and Van Hise, C. R., op. cit., p. 28.
[2] Irving, R. D., and Van Hise, C. R., op. cit., p. 26.

Large masses that have fallen from the cliffs now lie loose upon the surface, and will supply a furnace for many years before it will be necessary to resort to the original bed.[1]"

*Summary.* Summarizing up to this point, the outstanding facts are that the formation was discovered purely by accident and not as the result of a specific search for iron ore, that the magnetic type of formation was uppermost in the minds of these earlier geologists, and that on that account they were concentrating their attention upon the western end of the range.

## THE DISCOVERY OF ORE

*Brooks.* The Civil War appears to have interrupted study of the range, but in 1873 Brooks published a report in which he stated for the first time that the Gogebic Range of Michigan was but the eastward extension of the Penokee of Wisconsin.[2] Up to this time it had been supposed that there were two ranges, but with the discovery of Brooks, the name applied was the hyphenated Penokee-Gogebic, which has of recent years been shortened to the Gogebic.

*Irving.* The real important stroke was made in 1877 by the work of Irving. He reported to his superior that there was a "steady lessening of the disturbing influence exerted upon the magnetic needle by the iron belt of the Huronian as it is followed eastward. In its more western extension the variations observed on and near this belt are commonly as much as 90° and even 180°. The disturbing influence extended, moreover, for a long distance north and south of the line of greatest disturbance. By the time the Potato River is reached, the variations never approach 90° and that is observed along the very narrow belt only. Still farther east the attraction lessens more rapidly and on the Montreal River it is essentially lost. This lessening in magnetic attraction does not necessarily indicate a corresponding decrease in the amount of iron present in the rocks of the iron belt, but rather that the magnetic oxide is giving way more completely to the non-magnetic, or sesquioxide, which is always present, in greater or less quantity, even where the magnetic attractions are greatest. The outcrops observed bear out this conclusion, for a considerable quan-

[1] Irving, R. D., and Van Hise, C. R., op. cit. p. 24.
[2] Irving, R. D., and Van Hise, C. R., op cit. p. 30.

tity of very highly manganiferous red hematite is to be seen at all points from the passage of Tyler's Fork eastward."[1]

*The Colby Mine.* In 1883 ore was finally struck in the Colby Mine in Michigan and in 1884 there was shipped 1022 tons, marking the first output from the range.[2] With the establishment of towns and cities newspapers moved in and correspondents were assigned to the gathering of news from this new iron range.

The files of several of these organs have been examined and items of interest in connection with the development of the range have been extracted. These papers are:

Lake Superior Miner, Ontonagon, January 5, 1855–August 2, 1886.

Menominee Herald, April 14, 1886–November 2, 1867.

Milwaukee Sentinel, 1860–1865, 1872–1873, inclusive, and 1885.

Hurley Gogebic Iron Tribune, 1886–1893 }
Hurley Montreal River Miner, 1885–1912 } Consolidated

Ashland Press (weekly), 1872–1897.

From these papers it appears that the discovery of the Colby spurred the prospectors on to renewed efforts all along the range. News items tell of the wonderful strikes of ore made here and there, of the failure of this company and that, that this company went on the block, that Captain So-and-so has taken hold of the Blank property. The details are far from authentic, for example the assignment of the various properties to certain land description is in many cases obviously erroneous. They, however, do show the high run of enthusiasm in the district, the rise and fall of good times, and the depressions attending the country-wide panics. By those who may be further interested, the files in the Library at Madison can be examined, or the items of interest in connection with the development of the range can be examined in the files of the Survey.

*The West End of the Range.* This work of Irving following the projection of the range into Michigan by Brooks and Pumpelly was the most important development up to the time. Although a townsite had been platted at Penokee in 1856,[3] and although for-

[1] Irving, R. D., and Van Hise, C. R., op. cit., p. 43.

[2] Van Hise, C. R., and Leith, C. K., The Geology of the Lake Superior region: U. S. Geol. Survey Mon. 52, p. 40, 1911.

[3] Ashland Press, August, 1872.

mation had been shipped to the foundry for trial and been reported satisfactory, no extensive operations were carried on in the west.[1] In 1880, however, Mr. Breitung of the Marquette Range imported a diamond drill and operated it west of Penokee until the spring of 1881 when it was moved to the Michigan end of the range.[2] Little if any reference to the west end is noted after this, for the development of the eastern end went on rapidly.[3]

*East End of the Range.* In June 1882 the Montreal Mining Company was organized. In 1883 ore was discovered at the Colby mine in Michigan and in 1884 this mine shipped 1,022 tons.[4]

## FORMULATION OF GEOLOGICAL HYPOTHESES

*General.* With the opening of the mines and the opportunities offered for observation, the organization and formulation of ideas concerning the relationships between ores and the wall rocks and their distribution in various horizons of the formation could be begun. Many observers in many places were noting these things and making them public. Discussions and disputes arose. For example in 1885 Wright wrote of his observed association of ores with soap rock—the decomposed dikes— and with the quartzite footwall.[5] In 1887 Birkinbine wrote that although the idea had been advertised abroad that there were two veins of ore, his own observations were that there were no continuous veins.[6] This is, perhaps, the fore-runner of the differentiation between the hanging wall ore bodies as now known and the footwall bodies.

*Igneous vs. Sedimentary Origin.* As to the formulation of ideas and the discussions that arose, it is interesting to go back to the first of these hypotheses. No doubt, one of the first questions coming to the mind of a geologist at his first contact with this formation would be, "Is this a sedimentary formation, or is it igneous?" Today, perhaps, no one would even for a moment harbor the idea that this was an igneous formation. That some question was in the minds of the earlier geologists is made evident by the

[1] Ashland Press, August 15, 1880, October 2, 1880.
[2] Ashland Press, June 19, 1886.
[3] Ashland Press, June 10, 1882.
[4] Van Hise, C. R., and Leith, C. K., The Geology of the Lake Superior region: U. S. Geol. Survey Mon. 52, p. 40, 1911.
[5] Irving, R. D., and Van Hise, C. R., The Penokee iron-bearing series of Michigan and Wisconsin: U. S. Geol. Survey Mon. 19, p. 83, 1892.
[6] Birkinbine, John. Iron ore mining in 1887; U. S. Geol. Survey Mineral resources of the United States for 1887, pp. 30–57.

writing of Wadsworth in 1880. He says, "The ore and jasper seem to have been erupted in huge bosses and overflows, as well as intruded into the schist in the form of long arm and wedge-like masses or sheets.[1]" Wadsworth, thus called the iron formation igneous. But as early as 1860 Lapham had written, "It is supposed by geologists that slate rocks were originally deposited from water and that the layers were at first nearly horizontal. Whatever may have been the origin and the original position of this slate, the same must be assigned to the iron ore, the same causes continuing to operate throughout the whole period of the formation of the slates and the iron."[2] Here is registered a difference of opinion. It might be stated, however, that little space has been found devoted to the idea that the formation was igneous. Of course, it was of importance that the question of origin be kept in mind at that time. In igneous rocks distribution of mineral components is controlled by different factors and has different space relations than in sediments. Although the formation had been recognized as abnormally rich in iron, no great mass of the unenriched formation runs higher in iron than 35 per cent, which is not ore. The problem facing the geologists and prospectors was to locate large masses of richer rock. If igneous, the formation would promise richer bodies in certain positions. If sedimentary, variation in composition would be greater from bed to bed than along the bed within reasonable distance unless modified by secondary processes. The advice from Whittlesey and Lapham that the outer horizons would be found to be richer seems to have been in recognition of the idea that there was variation from bed to bed.[3] They do not appear to have realized, however, that no great original variation, certainly not enough to raise the iron tenor to the grade of shipping ore, could be found along the bed. They were concerned with magnetite.

*Conformable or unconformable contact.* In the meantime a controversy arose as to whether these formations were unconformable with the gneisses at Penokee Gap. This is aside from the economic questions but it shows that with accumulation of data attempts were being made to organize.

*Summary.* Had the geologists had the petrographic microscope, had they compared petrographically the condition of the formation at Upson with that at Penokee Gap, had they noted the changes in

[1] Irving, R. D., and Van Hise, C. R., op. cit., p. 57.
[2] Idem, p. 26.
[3] Irving R. D., and van Hise, C. R., op. cit., pp. 26, 29.

condition from foot to hanging and from east to west, the development might have been different. Had they noted the nature of differences and the probable nature of the processes that wrought these changes, the efforts of explorers might have been earlier steered eastward rather than westward. When Lapham concluded that the slates were metamorphosed by the Keweenawan gabbro,[1] he came very close to the secret of the unproductivity of the range west of Upson. Another step farther would have brought him to the conclusion that the iron formation was similarly metamorphosed. A tracing of the diminution of this effect would have taken him eastward where the antecedents of his magnetite—the carbonate—had, due to instability, been modified under quite different conditions but conditions of uniform activity.

## Discovery of Factors Controlling the Distribution of the Ores

*Footwall and Dikes.* With opening of the mines, however, ore bodies were developed and mined out. The footwall was seen to be the most promising locality. The ore bodies were found to have a second influential factor—the dikes. Then the most promising locality was seen to be the intersection of dikes with the footwall. It is interesting to examine the maps showing the distribution of test pits. They are clustered along the footwall, they crosscut the formation, or diagonally they follow the course of dikes. Apparently the explorer tested the foot at frequent intervals in search of dikes and having located a dike, he tested it across the formation. Or he crosscut the formation at intervals endeavoring to locate either dikes or rich members of the formation.

*Other Factors.* It has been noted that discovery had been made that dikes were the controlling structures and that the footwall was of first order importance. It has also been noted that by some the idea had been expressed that there were two veins. The last idea seems to be a first expression of the fact that the footwall is not the only promising horizon. With the opening of mines and with the introduction of drilling methods of exploration, it came to be realized that several horizons "made" ore when given proper conditions, that is a dike and an impervious understratum. Mine maps showed up these facts, for ore bodies had the habit of lying at rather regular horizons out from the footwall. A conglomeratic

[1] Irving, R. D., and Van Hise, C. R., op. cit., p. 26.

horizon fairly easily traced from mine to mine at a horizon about two-thirds of the way from foot to hanging had been noted. The formation north was commonly called the North Formation and that south the South Formation, the conglomerate itself the Middle Conglomerate. Ore bodies were found in both the north and south division, but continuous veins at any particular horizon were not found. In this connection, however, it might be noted that although there are not continuous ore veins at any horizon, there were continuous horizons which when cut by dikes and provided with their influence in concentrating waters made very good ore. These showed up as mine maps were compared.

With the development of this recurrence of ores at rather definite horizons and the recognition of the continuity of the Middle Conglomerate, it was also noted that other easily recognized beds recurred from mine to mine. For examples may be cited the foot slate, the foot conglomerate, and the black slate. These were convenient reference horizons for use in exploration underground. It was also noted that there were two rather distinctive types of formation, the thin, even-bedded or "slaty" type, and the coarse, irregular or cherty type with textures and structures peculiar to each. These alternated and also served as reference horizons. By reference to this series of horizons, a definitely known number of which were favorable ground for ore making, it became possible to carry on underground exploration with less waste of time, energy, and capital.

## Monographic Reports and Recent Publications

*Monograph 19.* In 1892 the United States Geological Survey published its Monograph 19 written by and based upon the work of Irving and Van Hise. This work set forth for the first time an account of the geology of the district with an hypothesis of the origin of the ores. It may be stated that broad contributions to the geology of the range since this time have been but few in number. Much work, however, has been done on the surface and underground. The formation is better known and by a greater number of geologists. Some have become familiar with certain groups of mines to the extent that they know where they are stratigraphically and from the appearance of the formation can judge with a considerable degree of accuracy their chances of finding ore.

*Monograph 52.* In 1911 the United States Geological Survey published Monograph 52 written by Van Hise and Leith. This is a general reference work on the Lake Superior region. In it the Gogebic Range is treated on a broad scale.

*W. O. Hotchkiss.* In 1919 Dr. W. O. Hotchkiss, then State Geologist of Wisconsin, published a series of papers* in which, for the first time, the formation was divided into five members. This series also presents the most comprehensive account of the details of structure encountered during the course of mining operations. The papers were written for the service of mine operators and are, perhaps, the most useful presentation of the practical phases of the geology of the range.

## The Economic Status of the West End of the Range

Naturally more is known about the formation within the producing district than elsewhere. The most western producer, the Iron Belt, was in the central part of T. 45—R. 1E., or about 12 miles west of the Montreal River. From that point the formation continues without a break to T. 44—R. 4W., a distance of 22 miles. There is no producer in this end of the range, although at least three mines have made small shipments, the Shores in section 10, T. 45—R. 1E., the Annie in section 20 of the same township, and the Tylers Fork Mine in section 33, T. 45—R. 1W. As stated elsewhere, however, the district west of section 11, T. 45—R. 1E. has not exhibited strong indications of having been particularly favorable to alterations which produce ore of present-day grade. On the other hand, it exhibits indications of having been altered by another process in such a way as to render it improbable that large ore bodies will be found. The characteristics of original deposition and sedimentation are apparently identical with the formation farther east. The iron content appears to have been quite as high as farther east, but it has been converted to hematite and magnetite as well as to amphibole and, therefore, is not subject to natural concentration. On the other hand, when shipping ores are depleted and concentrating ores are in demand, it appears that the formation west of the Iron Belt, and particularly in the far west, will be more attractive. The whole formation has a coarser texture than in the east, the silica is granular, the oxides are coarser grained, and crushing and separation could be more easily effected.

---

* Engineering & Mining Journal, September 13, 20, 27, October 4, 1919.

# CHAPTER III

## HISTORY OF PRODUCTION

### Introduction

Statistics of production for the Lake Superior district as a whole, as well as for each individual iron range, are available.[1] From these some interesting trends can be noted; for example, the rate of growth present and past for each range, the rank and importance of each over a long period of years. It may be seen that certain events have a definite effect in stimulating or depressing production. With statistics of probable reserves, and computed average rate of growth, it is possible to estimate the life. By comparison of statistics of price fluctuations with production, the relationships between the two may be seen.

### Production of the Lake Superior District as a Whole

On figure 4 the production for the Lake Superior district as a whole has been plotted for each year from 1883 through 1927.

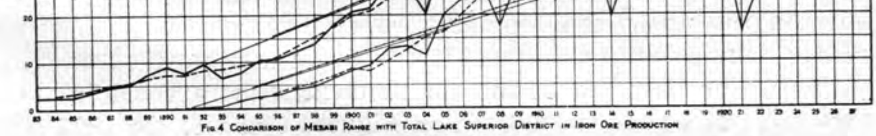



Fig. 4 Comparison of Mesabi Range with Total Lake Superior District in Iron Ore Production

This curve demonstrates the rate of increase in production up to the maximum in war years and the fluctuations from year to year. The curve up to 1893 is fairly regular, and the rate of growth is comparatively slow. From 1893 through 1914 a greater rate is

---

[1] U. S. G. S., Mineral Resources of the United States.

shown. During this period two subdivisions may be noted. The earlier subperiod up to about 1903—10 years—was characterized by marked regularity of growth. The second subperiod shows net average growth at a comparable rate but accomplished by sharp variations. The former of these suggests a rigid relationship between demand and capacity to produce; the latter shows potential production in excess of average demand, hence occasional excessive production followed by retrenchment.

From a marked low in 1914, a rapid increase in two years to the record output of all times up to the present shows response to the war stimulus. But the high was sustained only two years to fall gradually to 1920 and then precipitously in 1921. From this unparalleled depression production has not yet recovered and the total effect has been to establish a new trend of very slight growth since 1914, which, in view of the general prosperity of industry, suggests introduction of competition by other ores.

So far as total production goes, for the period 1883 to 1927, there are three significant portions of the curve, 1883–1893, 1893–1914, and 1914–1927.

On the same figure 4 is the corresponding curve showing Mesabi behavior and it is interesting to note that there is no exception to the rule that significant fluctuations of Mesabi production are strongly reflected in the curve of total production. The reason for this is apparent because from its start in 1892 Mesabi production has been the preponderant output for the region. Figure 7 shows the relative importance of the six ranges in terms of per cent of total annual production. Here is the main reason for the three segments of the total production curve. Prior to 1893 the Mesabi was not producing. The other ranges are operated largely by underground mining methods and by their nature operations cannot increase at a rapid rate. The Mesabi with its huge open pits, on the other hand, permits rapid exploitation. It meets sudden stimuli with facility and it retrenches with equal elasticity.

The major influence of Mesabi production is reflected in the curves for other ranges, as seen on Figures 5 and 6. In 1893 all ranges showed shrinking as if under the threat of the Mesabi potential. Practically all show the two phases in the second period 1893–1914; that is, fairly uniform growth up to 1903 with wider fluctuations from then until 1914. For all, the 1914–1927 period is sharply demarcated, but the reactions within this period vary. In general all but the Vermilion show immediate response to war stimulus and all but the Vermilion show a deep depression in 1921, but the relative importance of these two reactions differ from range to range. Most interesting of all is the recovery from the 1921 depression. The Vermilion is apparently beyond correlation. The Marquette, Menominee, and Mesabi show similarity of recovery

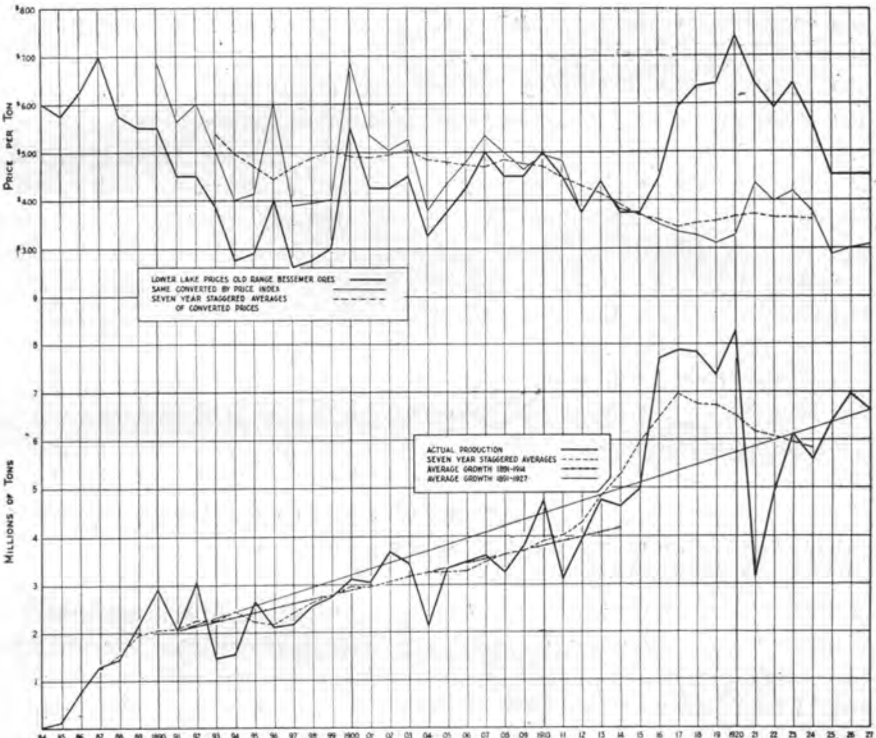



Fig. 5 Gogebic Range Production and Lower Lake Prices, Old Range Bessemer Grade

with the significant fact that none of these is back to normalcy. On the other hand, the Gogebic is apparently at about the same stage of growth where it would have been had there been no war stimulus.

## Production of Individual Ranges

On account of the apparent uniform subdivision of all curves into the three periods, as noted, and in order to secure some more quantitative estimate of the rate of growth and effect of the war on the production from each range, two straight lines appearing to indicate normal rate of growth for the periods 1891–1914 and 1891–1927 have been shown on each graph. These lines were drawn in this way.

The total production for each range from 1891–1914 was computed. This total then is the product of annual production times the number of years. Had there been no increase in production, the average would be simply total production divided by number of years. It is, however, obvious that production has grown and that growth has tended to follow a uniform rate. Graphically, the total production is an area when annual production is plotted against years, and if there were no growth, this could be resolved as a rectangular area, with height constant at average production. On account of the obvious growth and straight line rate, the area is really a trapezoid whose area is represented by the length multiplied by the average height. In any individual case, then, the length is the number of years; the one known height is production in 1891 and the equation can be solved for the unknown height which represents the production which would have been gained at the last year of the period if growth had been at a uniform rate. The same principle has been followed in computing the average rate of growth lines for the longer period 1891–1927 inclusive. The average rate of growth is computed in each case by dividing the difference between the 1891 production and the hypothetical production at the end of each period by the number of years represented in that growth. The slope of the straight line is an indication of rate of growth and it is seen that in every case, excepting the Gogebic, there is a considerable angular divergence between the two lines representing growth for the two periods. The ratio of the two average annual rates indicates the relationship of the two.

*Example. Marquette.*—Total production 1892 to 1914 inclusive was 76,793,552 tons. In 1891 production was 2,778,000 tons.

$$\frac{2{,}778{,}000 + x}{2} \times 23 = 76{,}793{,}552$$

$$(2{,}778{,}000 + x)\ 23 = 153{,}587{,}104$$
$$23x = 153{,}587{,}104 - 65{,}894{,}000$$
$$x = \frac{87{,}693{,}104}{23}$$

$x = 3{,}812{,}744$ = production 1914 assuming constant rate of growth
$2{,}778{,}000$ = production 1891

$1{,}034{,}744$ = growth in average annual production in 23 years, or 44,989 tons per year.

Total production 1892–1927 = 124,486,000

$$\frac{2{,}778{,}000 + x}{2} \times 36 = 126{,}665{,}000$$

$$(2{,}778{,}000 + x)\ 36 = 253{,}330{,}000$$

$$36x = 253{,}330{,}000 - 100{,}008{,}000$$

$$x = \frac{153{,}322{,}000}{36}$$

$x = 4{,}259{,}000$
$2{,}778{,}000$

$1{,}481{,}000$ in 36 years, or 41,139 per year

Ratio of total average growth to growth 1892–1914

$$\frac{41{,}139}{44{,}989} = 0.92$$

The series of computations for each of the individual ranges and for the combined group give the figures in the following table:

| I<br>Range | II<br>Average annual increase 1892–1914 Tons | III<br>Average annual increase 1892–1927 Tons | IV<br>Ratio of $\frac{III}{II}$ |
|---|---|---|---|
| Mesabi | 1,281,121 | 1,205,889 | 0.94 |
| Menominee | 137,089 | 117,927 | 0.86 |
| Marquette | 44,989 | 41,139 | 0.92 |
| Vermilion | 39,505 | 23,190 | 0.59 |
| Gogebic | 90,377 | 128,491 | 1.42 |
| Computed for all ranges | 1,620,375 | 1,516,350 | 0.93 |

The principal disclosures are that the Vermilion production is falling off rapidly, the Mesabi has been slowed up slightly as a result of the post war depression, but the Gogebic alone has not suffered; instead has even profited by that event. The Gogebic has taken precedence over the Menominee in growth over the long period as compared to the shorter.

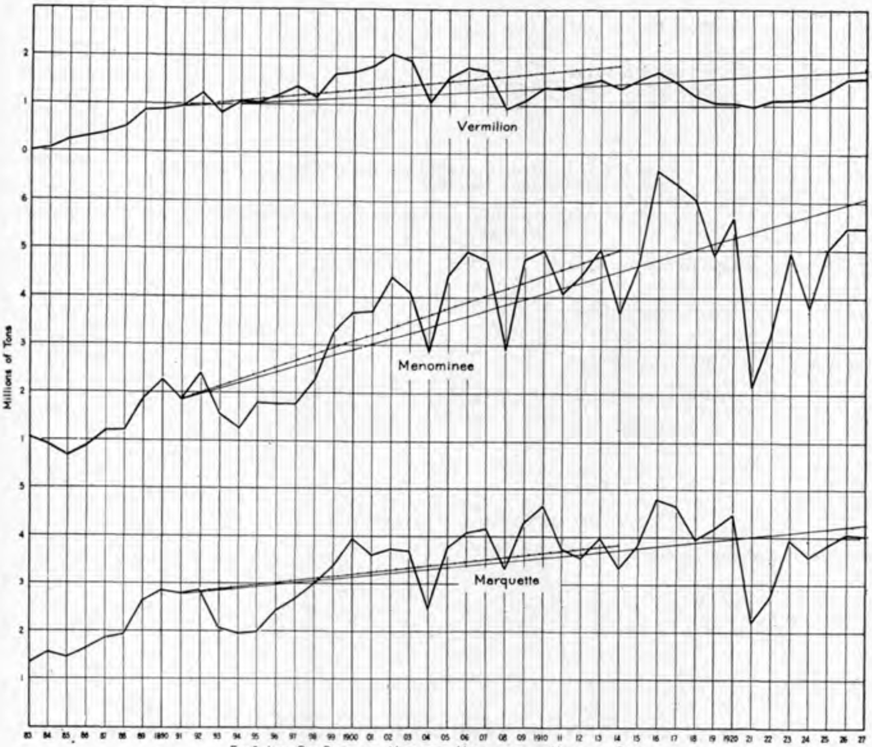



FIG. 6 IRON ORE PRODUCTION MARQUETTE MENOMINEE AND VERMILION RANGES

## PRODUCTION OF THE GOGEBIC RANGE

This exceptional behavior of the Gogebic merits some discussion. One factor has been alluded to but deserves further attention. In order to get a clearer picture it is perhaps well to study the Gogebic curve alone.

On figure 5 the data have been plotted. From the first appearance in 1884 production remained insignificant for two years, but grew very rapidly in the ensuing two years to attain a level close to the main trend followed for a long period. In 1890 and 1892, however, two levels were struck which were not sustained. In fact, a definite setback occurred in 1893, possibly on account of the nation-wide depression, possibly also on account of the threat of the Mesabi. Once adjusted, production clung closely to a line of uniform rate of growth for ten years.

*Entry of New Mines into List of Producers.* Some explanation of this is forthcoming from data upon the appearance of new mines. Five new mines were opened in 1885. This fact is reflected in the curve. So also is the appearance in 1886 of 8 more new mines among the list of shippers. In 1887 there were 2 more. The complete list is shown below.

| Year | New mines opened | Year | New mines opened |
|---|---|---|---|
| 1885 | 5 | 1906 | 2 |
| 1886 | 8 | 1907 | 1 |
| 1887 | 2 | 1912 | 1 |
| 1890 | 2 | 1913 | 3 |
| 1891 | 1 | 1915 | 1 |
| 1895 | 1 | 1916 | 1 |
| 1901 | 1 | 1918 | 1 |
| 1903 | 1 | 1919 | 2 |

At one time or another there have been 54 shippers. In 1927 there were 20. Many mines have been closed and several have lost their identity through consolidation. Following 1887 there have been comparatively few new mines, and hence growth has come from developments within existing properties.

*Classification of Mines According to Production.* The great bulk of the production has come from a small number of properties. Taking the total production for 44 years and classifying, we get the following table:

| | Number of mines | Range of individual production | Per cent of total |
|---|---|---|---|
| | 1 | More than 45,000,000 tons | 29.53 |
| | 3 | 8,000,000 to 20,000,000 tons | 23.57 |
| | 18 | 1,000,000 to 8,000,000 tons | 43.88 |
| Sub-total of | 22 | | 96.98 |
| | 2 | 500,000 to 1,000,000 tons | 1.07 |
| | 8 | 200,000 to 500,000 tons | 1.47 |
| | 2 | 100,000 to 200,000 tons | .14 |
| | 5 | 50,000 to 100,000 tons | .24 |
| | 8 | 10,000 to 50,000 tons | .09 |
| | 7 | Less than 5,000 tons | .01 |
| Total | 54 | | 100.00 |

It appears that 4 properties which are really groups of mines have produced more than half of the total. In the aggregate 18 shipped nearly 44 per cent, and the group of 22 account for 97 per cent.

*Order of Importance of Gogebic Mines.* It is of some interest to note that the leading producers have held high rank throughout the period,—that is, the in-and-outers have not to date held high rank. In the following table all mines of any importance at all are listed in order of their total production.

ORDER OF IMPORTANCE OF GOGEBIC MINES

TOTAL PRODUCTION 1884 THROUGH 1926

1. Norrie (Aurora, Pabst)
2. Newport
3. Montreal (W)
4. Wakefield
5. Tilden
6. Plymouth
7. Palms
8. Ashland
9. Cary (Kakagon (W), Nimikon, Superior, Windsor)
10. Colby
11. Eureka-Asteroid
12. Ironton
13. Sunday Lake
14. Ottawa (W)
15. Brotherton
16. Puritan
17. Yale
18. Keweenaw
19. Atlantic (W)
20. Iron Belt (W)
21. Mikado
22. Anvil
23. Townsite
24. Castile
25. Geneva
26. Germania (W)
27. Royal
28. Hennepin (W)
29. Section 33
30. Davis
31. West Davis
32. Meteor
33. Plumer (W)
34. Pike
35. Chicago
36. Jackpot
37. Pence (W)
38. Morgan
39. Shores (W)
40. Federal
41. Massie
42. Trimble (W)
43. Bessemer
44. Iron Chief
45. Upson (W)
46. Tylers Fork (W)
47. Winona

Mines located in Wisconsin are indicated with (W). Their aggregate production is 14 per cent of the total.

In 1927 the order of importance was as follows:

| Rank in 44 years | Rank in 1927 | Mine | Rank in 44 years | Rank in 1927 | Mine |
|---|---|---|---|---|---|
| 1 | 1 | Norrie | 16 | 11 | Puritan |
| 3 | 2 | Montreal (W) | 18 | 12 | Keweenaw |
| 2 | 3 | Newport | 9 | 13 | Cary (W) |
| 6 | 4 | Plymouth | 5 | 14 | Tilden |
| 4 | 5 | Wakefield | 31 | 15 | West Davis |
| 12 | 6 | Ironton | 23 | 16 | Townsite |
| 11 | 7 | Eureka-Asteroid | 41 | 17 | Massie |
| 13 | 8 | Sunday Lake | 30 | 18 | Davis |
| 14 | 9 | Ottawa (W) | 22 | 19 | Anvil |
| 7 | 10 | Palms | 25 | 20 | Geneva |

Only the Norrie holds the rank in 1927 which it has held in the long period. Three held a rank in 1927 removed but one place from that during the long period. The Newport and the Montreal exchange places in the two lists. The two open pits, the Wakefield and the Plymouth, hold high rank.

*Rank of the Gogebic among the Several Lake Superior Ranges.* The rank which the Gogebic holds among the other ranges of the Lake Superior district is of some interest. The Marquette had been producing for 30 odd years before the Gogebic entered the ranks of producers in 1884. The Menominee had been producing for 7 years. The other ranges are of the same or less age. The following table gives the order of importance of these ranges with the per cent of total shipments produced by each through 1927 and the number of producing years:

| Order of importance | Range | Per cent of total shipments through 1927 | Number of shipping years |
|---|---|---|---|
| 1 | Mesabi | 58.1 | 36 |
| 2 | Gogebic | 12.4 | 44 |
| 3 | Marquette | 11.9 | 74 |
| 4 | Menominee | 11.8 | 51 |
| 5 | Vermilion | 3.9 | 44 |
| 6 | Cuyuna | 1.9 | 17 |

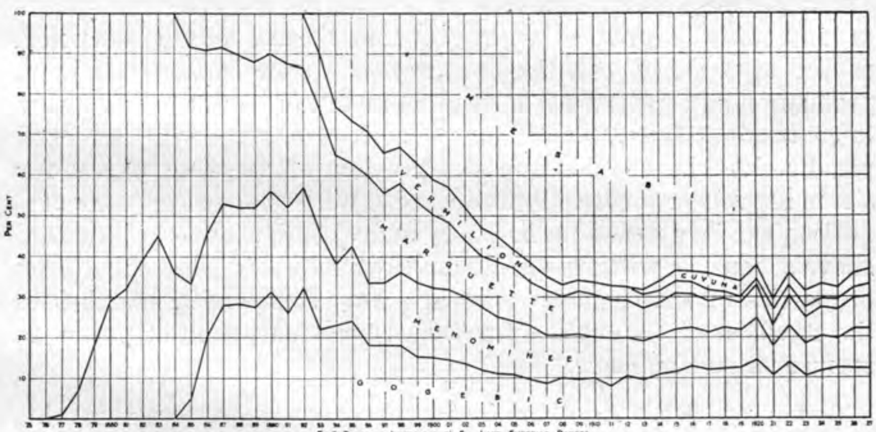



FIG. 7 RELATIVE IMPORTANCE OF SIX LAKE SUPERIOR RANGES

On figure 7 for each year from 1877 until 1927 the per cent of the year's total per range is shown. From 1854 to 1877 the Marquette was the only producer. In 1877 the Menominee produced 1 per cent of the combined Marquette-Menominee shipments. The output for the Menominee proceeded to embrace a steadily larger proportion until 1884 when the Gogebic and Vermilion ranges entered the list. Since that time the Menominee and Marquette have decreased in importance. In 1892 the Mesabi made its first shipment and with great rapidity gained rank of first importance. In 1911 the Cuyuna made its appearance and is now comparable to the Vermilion in annual output.

*Analysis of the Growth of Gogebic Production.* In order to smooth off the wider fluctuations of the Gogebic production curve, 7 year averages were computed and plotted for the mid-year of each series. This curve is shown in a broken line. Figure 5. It is seen that this line expresses the main trend of actual production. It follows more closely a lighter line drawn to show average annual growth 1891 to 1914. It shows a cusp of high average production during the war, from which it is now descending to meet the lighter line of average annual growth from 1891–1927.

These evidences support the idea that the growth of Gogebic production is more nearly stabilized in relation to the normal increase in demand. With 3 exceptions the mines of this range are underground operations. For these there is a "bottle neck" limiting production. This factor is the hoisting capacity and number of working places. In spite of an unusual stimulus, the underground mines cannot so greatly exceed normal production; nor, on the other hand, can they be dropped below certain minimum production because there is a certain amount of operation necessary to maintain efficient conditions. On the contrary, with an open pit district like the Mesabi, the number of working places for steam shovels is practically unlimited. With sudden demands production can be speeded up instantly and with the converse situation shovels can be withdrawn. The Plymouth and Wakefield iron properties of the Gogebic serve in a way somewhat analogous to the flywheel of an engine, for they represent potential power to carry over sudden loads.

*Grade of Ore.* Another factor probably represented in this stabilization is the grade of ore. On Figure 8 are two curves showing the trend of grade of ore for the district as a whole and for the Gogebic. It is seen clearly that Gogebic ores have not dropped in grade to the extent demonstrated by the district as a whole. Gogebic grade very peculiarly dropped to its lowest point in 1921 when its shipments were the lowest since 1897. In general, the Gogebic grade is higher by at least 1 per cent natural iron than that of the district as a whole. This would appear to mean that

Gogebic ores should have a distinctly greater demand than other ores, an advantage in times of depression.

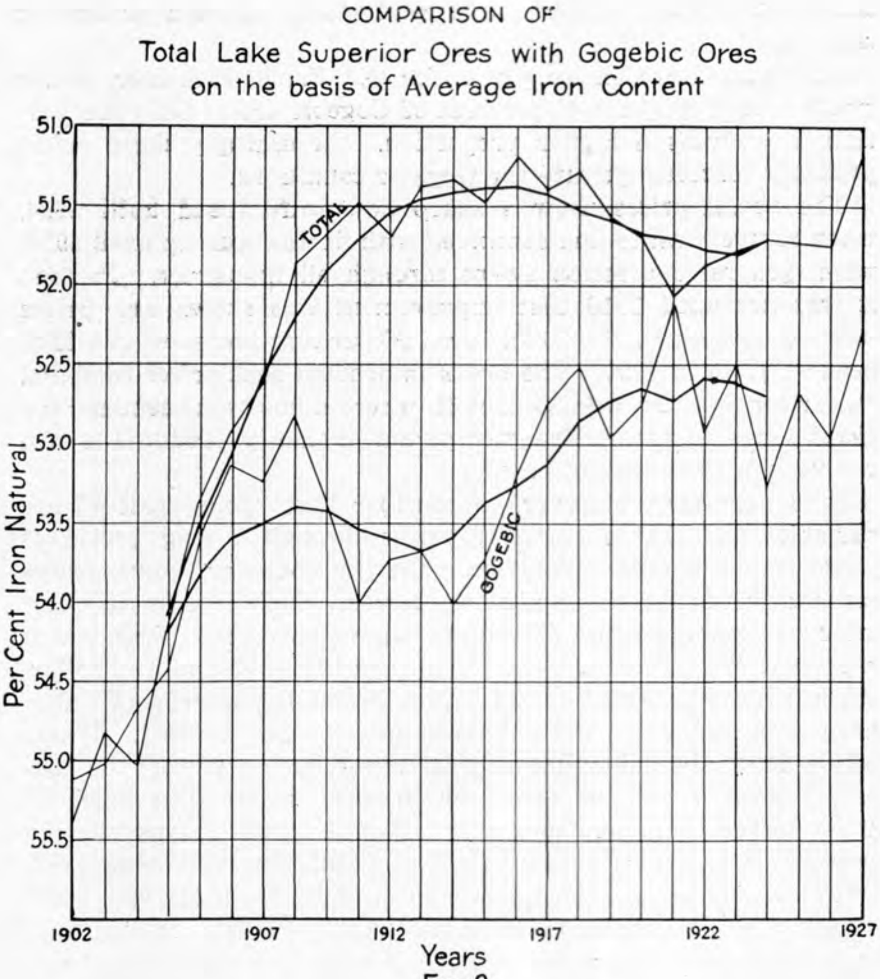



FIG. 8

PRICES

There is a certain relationship between price and production. Under the stimulus of greater demand and high prices production tends to speed up and vice versa. Production cannot cease during periods of low prices, for the organization and vital operations must be kept up. To keep a mine functioning in every respect requires ceaseless attention to drainage, timbering, ventilation, and also control of ground. There are limits to the time when ore may be taken, and if not taken at such times ore may need to be sacrificed. There is, however, a relationship between production and price level.

On figure 5 are shown prices for Old Range Bessemer, which grade is met by about 40 per cent of Gogebic ores. Only the Vermilion produces a higher proportion. Accordingly these prices probably correctly picture the Gogebic conditions.

The actual prices show a sharp downward trend until 1894, when recovery set in and continued with fluctuations up until 1914, when general depression swept through all industries. In fact, it was not until 1916 that improvement was shown and prices stepped up with 50, 60, 70 and even 90 per cent increases to a high peak of $7.45 in 1920. The break in demand sent prices tumbling rather consistently to $4.55 in 1925, where it has been sustained for the 3 years to date. The war period obviously produced a real recovery in prices as published.

It is necessary, however, to consider that "going prices" are variables and that a curve of prices through a long period of years is not a simple function. On the contrary, going prices contain the factor of purchasing power, which is a more exact measure of money value. Therefore, curves have been drawn which represent ore prices in terms of purchasing power of the dollar. Price indexes prepared by the United States Department of Labor have been applied to the published prices. See Table I. When, before 1913, the dollar had a greater purchasing power, the converted price is seen to have been in some instances as much as $2.00 higher than published price, that is, when the purchasing power was one-third greater than in 1913. But following 1913, when a dollar lost purchase power even to the point in 1920, when it took $2.262 to purchase the same quantity of "all commodities" as in 1913, published prices actually represented more than twice the real price. Hence, as seen on the curves, true prices for iron ore have been actually going down since 1915. There has been a slight recovery in 1921, 1922, 1923, and 1924, but the $4.55, at which level published price has clung for 3 years, actually represents the lowest level of history. The interesting question is how price will trend in the future. It has been definitely on the down grade at least since the beginning of the century. Will it continue on this trend?

## TABLE I

CONVERSION OF OLD RANGE BESSEMER PRICES AS QUOTED IN MINERAL RESOURCES TO STANDARD EQUIVALENTS THROUGH APPLICATION OF PRICE INDEXES.

(See Commerce Year Book, p. 60, 1925)

| Year | Index all commodities | Actual price | Seven year annual average of true price | True price | Year | Index all commodities | Actual price | Seven year annual average of true price | True price |
|---|---|---|---|---|---|---|---|---|---|
| 1880 | -------- | 10.00 | ------------ | -------- | 1904 | 85.6 | 3.25 | 4.85 | 3.80 |
| 1881 | -------- | 10.00 | ------------ | -------- | 1905 | 86.2 | 3.75 | 4.80 | 4.35 |
| 1882 | 92. | 10.00 | ------------ | -------- | 1906 | 88.6 | 4.25 | 4.74 | 4.80 |
| 1883 | -------- | 7.50 | ------------ | -------- | 1907 | 93.5 | 5.00 | 4.70 | 5.35 |
| 1884 | -------- | 6.00 | ------------ | -------- | 1908 | 90.1 | 4.50 | 4.85 | 5.00 |
| 1885 | -------- | 5.75 | ------------ | -------- | 1909 | 96.9 | 4.50 | 4.77 | 4.64 |
| 1886 | -------- | 6.25 | ------------ | -------- | 1910 | 100.9 | 5,00 | 4.71 | 4.96 |
| 1887 | 82. | 7.00 | ------------ | -------- | 1911 | 93.0 | 4.50 | 4.49 | 4.83 |
| 1888 | -------- | 5.75 | ------------ | -------- | 1912 | 99.1 | 3.75 | 4.31 | 3.78 |
| 1889 | -------- | 5.50 | ------------ | -------- | 1913 | 100.0 | 4.40 | 4.15 | 4.40 |
| 1890 | 80.5 | 5.50 | ------------ | 6.83 | 1914 | 98.1 | 3.75 | 3.92 | 3.82 |
| 1891 | 80.0 | 4.50 | ------------ | 5.62 | 1915 | 100.8 | 3.75 | 3.70 | 3.72 |
| 1892 | 74.8 | 4.50 | ------------ | 6.01 | 1916 | 126.8 | 4.45 | 3.60 | 3.51 |
| 1893 | 76.6 | 3.85 | 5.38 | 5.03 | 1917 | 177.2 | 5.95 | 3.45 | 3.36 |
| 1894 | 68.7 | 2.75 | 4.96 | 4.00 | 1918 | 194.3 | 6.40 | 3.53 | 3.29 |
| 1895 | 70.0 | 2.90 | 4.71 | 4.14 | 1919 | 206.4 | 6.45 | 3.57 | 3.12 |
| 1896 | 66.7 | 4.00 | 4.43 | 6.00 | 1920 | 226.2 | 7.45 | 3.66 | 3.29 |
| 1897 | 66.8 | 2.60 | 4.69 | 3.89 | 1921 | 146.9 | 6.45 | 3.72 | 4.39 |
| 1898 | 69.6 | 2.75 | 4.88 | 3.95 | 1922 | 148.8 | 5.95 | 3.66 | 4.00 |
| 1899 | 74.9 | 3.00 | 5.01 | 4.01 | 1923 | 153.7 | 6.45 | 3.65 | 4.20 |
| 1900 | 80.5 | 5.50 | 4.91 | 6.83 | 1924 | 149.7 | 5.65 | 3.62 | 3.78 |
| 1901 | 79.3 | 4.25 | 4.89 | 5.36 | 1925 | 158.7 | 4.55 | ---------- | 2.87 |
| 1902 | 84.4 | 4.25 | 4.95 | 5.04 | 1926 | 151.0 | 4.55 | ---------- | 3.01 |
| 1903 | 85.5 | 4.50 | 5.06 | 5.27 | 1927 | 147.0 | 4.55 | ---------- | 3.09 |

Probably the premium on Bessemer ore and the sustaining of grade have been of influence in maintaining steady growth of production from the Gogebic despite price reduction. No doubt economies have been effected in mining methods as well, but there is a limit to which economies can be wrought, and with increasing depth of mining, higher hoisting costs, pumping costs, and costs of timbering correlating with increasing depth, price reductions will have to be checked if Gogebic production is to continue to grow.

### PROBABLE LIFE OF THE GOGEBIC RANGE

The question concerning the point in time when the ores of the range will have become depleted is of great interest to all. Mineral resources are disappearing assets which are in no sense regenerative. On the other hand, iron ores are not in the same category with other ores, because they are in most instances not formed by the introduction of iron into country rock, such as in veins and replacement masses. They are instead phases of highly ferruginous formations enriched by secondary processes. The line of demarcation between an ore and the country rock is, therefore, determined by the results of sampling and analysis compared with the economic factors of metallurgical preference and price. As may be seen on figure 8 the grade of ore has decreased somewhat in the last quarter century, from which it may be inferred that enormous tonnages have been admitted to the classification of "ores" by these changes in the economic factors. These curves have been smoothed off by computing 7 year averages. On account of the flexibility of the definition of what constitutes an ore, it is difficult to estimate with any high degree of precision what the reserves may be at any point in time. Estimates have been made, however, and they may be of interest.

In 1926[1] the Gogebic Range of Michigan was estimated to have a reserve of 52,136,121 tons. With production on the range running about 6¼ million tons and with Wisconsin producing about 1¼ of this, the Michigan production rounds off at around 5,000,000 tons per year. Accordingly with a reserve of only 52,136,121 tons, the Michigan end of the range has an apparent life of only 10 and a fraction years. This period as an approximation of the limit of production is absurd. The factor which clarifies the situation is that the reserves are computed by representatives of taxing bodies and include developed ore and ore in prospect or stockpile. Such estimates made to meet the requirements for assessment are by nature conservative from the standpoint occupied in the present instance. Nor, at the same time, would estimates otherwise made by any presumed direct method be precise.

However, it is of some interest to note that the Gogebic has enjoyed a steadier and more rapid rate of growth during the past 44 years than any of the other ranges. And if this advantage is to continue by reason of continuity of the rate of growth, it appears that the reserves quoted above must be multiplied 6 to 7 times if the range is to have life even 40 years hence.

The need to multiply by 6 or 7 can be met by increasing the rate of projection of mining to greater depths, or by extending the ores along the range, or naturally by lowering grade or by beneficiation, that is, improving grade by various processes. These will all, no doubt, function in meeting demands but to each there will be severe resistance. To beneficiation there will be the resistance of

[1] Mineral Resources, 1925, p. 102.

costs. To lowering of grade will be resistance of competition of other ores, as well as resistance on the part of furnace practices. To the increase in the rate of deeper mining the resistance will be increasing costs. So far as costs are the supreme concern, there is reason to believe that by their resourcefulness the Lake Superior mining engineers will accept every challenge and continue their enviable record of successfully meeting requirements by engineering feats. So far as the extension of the ores along the range is concerned, the resistance is already in operation. The dominant ore bodies extend downward and to the eastward on the pitching dikes. The largest of the known ore bodies has already long since been mined up to the surface and exhausted, thus establishing an apparent western limit for ores. On the eastern end, in the structural abnormalties, principally the Sunday Lake Fault, and the reduction in the volume of iron formation east of the fault apparently by erosion, there has been established a limit at least to a certain degree, although ore bodies of good size are known in this region. In short, the progress of mining to depth has funnelled down the cross-section of favorable ground.

So far as information is available, there are no evidences of decrease in the intensity of ore making processes with depth. It might even be stated to the contrary that ore bodies are increasing in size with successively lower levels. Mining can, therefore, go to indefinite depths so far as presence of ore is concerned.

On account of the focusing of operations to increasing depths and the consequent greater pressure of economic factors, it is perhaps safe to assume that before a great many years have lapsed the Wisconsin portion of the range west of the Montreal Mine will come into the limelight at least for a more thorough exploration than ever yet has been accorded it. There is nothing inherently wrong with the formation as a whole, at least as far as Tylers Fork. Prejudice adverse to it has been built upon an assumption as to the position of the boundary of metamorphism induced by Keweenawan intrusion and deformation, but this factor can be quantitatively evaluated only by exploration. The experience at the Plumer Mine in T. 45—R. 2E., in which efforts to find ores were not generously rewarded, also has created the feeling of distrust in these western lands. However, there is no little evidence that Keweenawan intrusives not far to the north in the Tyler slate played a part in destroying the effectiveness of oxidizing solutions at this particular point. The Iron Belt, Atlantic, and

Shores properties to the west produced blocks of merchantable ores and the last situation, is one not wholly explained but possessed of magnetic evidence of promise. Still farther west, in section 16, evidences are again promising and this situation, no doubt, will be explored when the relief from pressure of deep mining demands extension along the range.

In the opinion of the writer, the Gogebic Range is not threatened with short life. In its curves of production and grade its vitality is well shown to be strong. With underground evidences pointing toward continuity, if not improvement, there is little or no cause for concern. And with mining to date concentrating operations into increasingly narrower range of ground, the possibilities of eastern expansion somewhat dampened by the bevelling of the formation by erosion, Wisconsin appears to be in best position for vigorous exploration in the next decade or two. There is no serious reason to doubt that new ores will be found between the Montreal and Tylers Fork.

Following proof that ores of present day definition are not available in Wisconsin in the district to the west of present operations, interest will be shown in the possibility of concentrating the iron minerals of the formation. While magnetic concentration is probably the method that will ultimately see greatest development, washing processes have been employed elsewhere and will probably see application on this range. Magnetite is no more important than hard hematite on this range and for this reason simple magnetic methods cannot cope with the problem. Whatever method is employed, the range from Tylers Fork west will be available and preference will be based on factors such as transportation, local relief, and water supply. The iron ratio in this region probably does not vary from point to point along the strike.

# CHAPTER IV

## MAGNETIC SURVEYING, FUNDAMENTAL PRINCIPLES AND FIELD PRACTICE

### THE IMPORTANCE OF THE METHOD IN THE MAPPING OF THE GOGEBIC FORMATIONS

Positive knowledge of the location, extent, relationship to adjacent formations, structure, and mineralogical constitution of a formation can only be had from a bald formation. Even a close approximation of the facts necessary for a comprehensive understanding of the essential features can only be obtained if the exposures are by chance distributed at critical points.

The Ironwood falls into neither of these categories. It is exposed probably for less than 1 per cent of its surface area. Glacial drift blankets the region with a thickness varying from a few feet to 100 feet or more. Vegetation supplements the drift in effecting a complete cover. Nor has the distribution of exposures been favorable to disclosure of essential information. In regard to the dispersion of outcrops with reference to important localities, it is notable that the eastern portion of the range is more poorly represented than the economically less important western extent. Thus, a line between promising ground and negligible formation may be drawn at the crossing of Tylers Fork in section 33 of T. 45—R. 1W. In the eastern division there are but a half score or so of outcrops, yet here is the region where ores are to be found if anywhere. West of the line, and increasing with distance, the number of exposures is very considerable. Moreover, the contact with the Palms at the south and with the Tyler in the north are horizons of importance for determining the relationship of the iron formation to its neighbors, and, of course, for marking the limits of iron concentration. Nowhere is there an actual exposure of the upper contact, and as is implied in the above statement, the lower contact may be studied only in the western division. Here, the contact is probably better and more continuously exposed than any other single horizon and for a perspective idea of relationships to the underlying Palms it is in most respects adequate. There still remains room for debate concerning the details of this relationship on account of the intermittent character of the exposures.

The presence of minor structures such as transverse faults, the bedding fault, the dikes, and the minor flexures is important both in connection with the formation of ores and in tracing the history of the formation. There are extremely few instances of the exposure of the formation in such critical locations.

The reasons for these circumstances are not difficult to explain. The Ironwood lies upon a most resistant quartzite but is overlain by a relatively soft slate. The dip is northward and hence there is no protection for the north contact. The southern contact is, however, so protected as to favor exposure and the movement of materials is down the slope to the north thus covering the upper members. In the eastern division, atmospheric agents have weakened the structure, oxidation has effected a breaking down of the texture, and solution has increased the porosity. Here the formation is particularly amenable to destruction and the development of depression. It is subject to cover by the drift of materials from the Archean formations which lie to the south. In the west, the formation was modified mineralogically before the erosion surface had cut to its depth. It was recrystallized, the chert being converted to crystalline quartz, the carbonate to oxides, or the iron of the carbonate and the silica of the chert were combined to form the amphibole needles which have knitted the whole into a very tough and resistant mass. Here the atmospheric agents had made relatively less inroad before the glacial episode. In glacial time, the valley of the Tyler slates was apparently occupied by a local tongue of ice moving along the trench to the southwest. In the east it was a powerful agent of erosion. In the west it accomplished less but scoured away the cover. In its recession, the deposits were evidently thickest in the depression of the east, less so on the heights of the west, and the trench itself received the great bulk of the ice debris. Subsequent wash bared the southern contact in the west and filled the trench to the north. At the same time the zones of strong cross faulting, being weakened by the fracturing, were easy work for the ice and streams which probably made use of them and cuts were made which latter were in part, at least, filled by debris.

In a situation such as this, geological work is unsatisfactory so far as ordinary methods go. Indirect methods must be resorted to. And consequently such a region is particularly attractive for the development of indirect methods. Physiographic methods or rather the close study of land forms and interpretation of them in terms of probable geological cause are many times serviceable in such cases. It was found on the Gogebic, for example, that the major gaps were suggestive of faulting transverse to the strike. In three of these at least, these suggestions were confirmed. These are Penokee Gap, the Potato River Gap, and the crossing of the West Branch of the Montreal River. It is probable that the crossing of the Montreal River is also influenced by a zone of faulting. However, there are other gaps which are equally suggestive of faulting but confirmation was not possible. On the other hand, innumerable cross faults were clearly detected where the physiographic evidence was practically wanting. This was accomplished by using the magnetic methods. The same method was found useful in suggesting flattening of dip, the presence of recumbent drag folds, and the change in the mineral constitution of the formation. For example, on the main highway along the range, at the railroad station of Moore, there are exposed slates forming a rather noticeable rise. Concomitant with this, on the Ironwood, there is a widening of the belt of attraction. This was later found to correlate with a recumbent drag fold of the iron formation and probably this is reflected in the Tyler slates. The rise of the Ironwood to the top of the local height of land west of the Tylers Fork is also a physiographic response to the higher resistance correlating with recrystallization. Thus, the indirect evidence of geological features as represented in the physiography was found of some service, but it left much indeed to be desired.

The indirect method which was pressed most closely, which has been responsible for the greater part of the information here assembled, and which has been found to be reliable to a considerable degree, is the Magnetic Method. To this the Ironwood is uniquely adapted. Iron minerals in general are more reactive to the magnetic methods than any others. Of these minerals, the oxide magnetite is most responsive. The formation as a whole contains a higher proportion of magnetite than any other in the district, which, therefore, sets the formation out in contrast with the adjacent formations, but what is more, the magnetite is not uniformly distributed through the column, nor along the formation. Accordingly, the method affords a means for differentiating the formation into divisions or members, and since the decrease of magnetite correlates with a greater promise of ore, the method offers some evidence upon which to base a conclusion as to the possibility of discovering ore bodies.

Since the magnetic method has borne the greatest weight in the gathering of data upon which the conclusions reached in this volume are based, and since the methods are familiar to but those geologists who have operated in the Lake Superior district, and to these only to the extent of tracing iron formations, the present chapter has been included in the volume. In considerable detail the fundamental considerations supporting the authenticity of the methods are discussed, the instruments which were used are described, and the field procedure is treated. In part the interpretations from the magnetic observations are given as to principle involved, but in detail this is reserved to the individual township reports in which the conditions along the range are discussed with view to indicating the promise as explorations.

## Fundamental Principles

*Magnetic Field of Force.* If a chip of iron be laid upon a table, and if a bar magnet be lowered gradually directly above it, a point will be reached with the magnet at which it will appear to have induced in the chip a tendency to move. The iron quivers, appears to have lost weight, or to have taken on life. If the magnet be lowered further the chip will leap to it and remain attached. This production of motion in a mass is a force. The distance through which a piece of iron will jump to a magnet depends upon the weight of the former and the strength of the latter. The experiment may be varied by sliding the magnet toward the chip along the horizontal surface. The same sort of behavior will be observed. Or, the magnet may be suspended on a thread. In this condition it will hang vertically as a plumb-bob. But if it be brought close to a large mass of iron, for example, an anvil, then the string will not remain vertical but will incline toward the anvil. As in the other experiments, if the intervening distance between the iron and the magnet be reduced beyond a critical value, there will be motion, the lighter of the two making a jump to the heavier.

These experiments show that there is a zone surrounding the ends of a bar magnet within which there is induced upon the magnet and the iron alike the tendency to produce attractive motion. There is a force tending to bring them together. This is magnetic force and the zone or field within which it is active is known as the field of magnetic force, or the magnetic field. Since the distance through which a chip of iron will jump depends upon the weight of the chip, as well as upon the strength of the magnet, it follows that the field extends away from the actual ends of the magnet to a distance depending upon the sensitivity of a detecting device.

The fundamental characteristics of a field of force related to a bar magnet can be demonstrated by placing a sheet of paper or glass over such a magnet and sprinkling the paper with fine iron filings. As these strike the paper they bristle and stand on end, and if the paper is moved gently, the erect filings sway, indicating that the force which animates them varies. If the paper is tapped causing the filings to be projected into the air slightly, then, on dropping back they organize themselves into a very striking pattern. There will be a concentration of filings at the ends of the magnets, which are called the poles. They form a thick stubby "beard". Further away there will be a less concentration and they will be segregated into the beginnings of a series of curved strings of filings which emanate from the one and close in at the other pole. These strings are symmetrical with respect to the polar axis of the magnet, they are close together at the poles and separate farther and farther to a maximum at the magnetic "equator". It is to be noted also that the plane of the paper is only one of an infinite number of such planes. In short the field of the magnet is three dimensional with the polar axis an axis of symmetry.

The noteworthy features of this experiment are that the strings of filings form symmetrical curves; that they change in direction from perpendicular to parallel with the axis; that the number of filings is greatest close to the poles; that this number decreases, the continuity of the strings decreases, and the strings are separated farther and farther with distance from the poles. These observations mean that the direction in which the force acts varies with position within the field, and that the intensity varies from a maximum at the poles to a minimum at the equator. The strings of filings play the part of "lines of force" demonstrating their direction directly. The closeness of packing of the strings is an indirect measure of the intensity at any point. The strings can be seen only a short distance away from the magnet itself so that it has to be assumed that the field extends only that far or else that it extends beyond and could be proven so if the filings were finer, or in other words, if a more sensitive detecting device were employed.

*Distortions of a Magnetic Field.* Let the experiments with the magnet and iron filings be repeated. But, within the area circumscribed by the strings of filings place a small piece of iron. When now the filings organize themselves in the role of lines of force, an appreciable difference will be observed. Instead of being distributed uniformly and symmetrically with respect to the axis of the magnet, there will be a concentration of filings in the neighborhood of the piece of iron. The strings will be diverted from their former paths and crowd together as they engage the foreign body, much as at the poles of the magnet itself. The field is not uniform, instead it is distorted and the presence of the piece of iron is responsible for the distortions. The lines of force are closer together indicating an increase in intensity close to the piece of iron.

To complete the picture, exchange the piece of iron for one of bismuth. Distortions result as before, but instead of changing direction to intercept, now they change to avoid or evade the piece of bismuth. The lines of force are farther apart indicating that the intensity has been diminished.

These experiments show that the field of a magnet is uniform only if the medium occupying that field is homogeneous, for example, in the first set of experiments with the iron filings when the field was occupied with the air and the table. But if the material of the field is not homogeneous, then the field is distorted. What is more, the distortions are of two types. The curvature of the lines may converge or diverge toward the change in material, and the intensity may increase with convergence or decrease with divergence. The nature of the distortions is dependent upon the nature of the material producing the distortion.

## Application of the Fundamental Principles to the Field of Geological Mapping

The earth is enmeshed in the magnetic field of its own generation which behaves as if there were a small bar magnet with the two poles deeply seated, lying close together upon a polar axis very roughly parallel to the axis of rotation. This has been arrived at by observation and computations at points all over the globe.

If a magnetic needle were mounted at its center of gravity upon a universal pivot so that it was free to move in all directions, at any given point, it would set itself parallel to the lines of force of the field at that point. If it were moved to a widely distributed series of points the positions would be different in every case. But if such observations were analyzed they would be found to vary in a regular manner. Thus, at any particular point, the needle would be inclined to the horizontal at a certain angle which would be characteristic for that point. This angle is the angle of inclination. If a vertical plane were passed through the needle it would be found that a compass needle contained in the plane would bear off from north by a definite angle also. This angle is the angle of declination. Furthermore, if the south end of the needle so oriented were given a counter torque just sufficient to neutralize the magnetic torque the force so applied would be a definite value and would be a measure of the intensity at that point. From the series of observations made over the globe, it would be found that inclination increases from a minimum in the magnetic equatorial region to a maximum in the polar regions, being thus a function of latitude. However, the magnetic poles and the geographic poles are not coincident so that the variation of inclination with latitude is not a direct function. Also, the analysis of the series of observations would demonstrate that the declination is a function of longitude. At the same time, it would be discovered that the intensity varies with latitude.

These facts are more or less familiar to engineers and all others who have had experience with a magnetic needle, whether it be in a transit, in a compass, or any other instrument. Every land survey job requires allowance for the local declination. In New England declination is westerly while in Wisconsin it is to the eastward. Furthermore, every such needle has an adjustable counterweight upon its south end which is necessary to maintain its horizontality and must frequently be adjusted if long moves are made in altitude. Even within the area of a square mile it is sometimes necessary to readjust frequently to prevent the one end from tipping and sticking to the cover glass. This is due to extreme local intensity.

The proof that the earth functions like a huge magnet makes it possible to apply the analogy of the small bar magnet and the distortions of its field. It was shown that uniform fields obtain only when the medium of the field is homogeneous, and that when the medium changes locally the field is distorted in a manner de-

### TABLE II

SPECIFIC SUSCEPTIBILITIES OF THE ELEMENTS

| Paramagnetic | (+) S x $10^6$ | Diamagnetic | (−) S x $10^6$ |
|---|---|---|---|
| Praesiodymium | 163.17 | Helium | .002 |
| Erbium | 130.36 | Chlorine | .007 |
| Cerium | 106.06 | Argon | .01 |
| Manganese | 80.00 | Caesium | .188 |
| Palladium | 66.00 | Silicon | .29 |
| Uranium | 60.96 | Indium | .57 |
| Platinum | 26.00 | Germanium | .62 |
| Chromium | 26.00 | Copper | .80 |
| Vanadium | 13.20 | Sulphur | .85 |
| Rhodium | 13.00 | Zinc | 1.00 |
| Ruthenium | 11.01 | Lead | 1.12 |
| Niobium | 10.80 | Bromine | 1.26 |
| Tantalum | 9.40 | Selenium | 1.30 |
| Barium | 6.90 | Gallium | 1.34 |
| Titanium | 6.65 | Arsenic | 1.40 |
| Molybdenum | 5.13 | Silver | 1.50 |
| Iridium | 4.90 | Phosphorus | 1.60 |
| Tungsten | 4.76 | Boron | 1.66 |
| Aluminum | 1.80 | Iodine | 1.73 |
| Calcium | 1.67 | Beryllium | 1.87 |
| Magnesium | 1.44 | Tellurium | 2.10 |
| Osmium | 1.35 | Mercury | 2.50 |
| Thorium | .89 | Thallium | 2.73 |
| Strontium | .86 | Gold | 3.10 |
| Potassium | .52 | Antimony | 4.70 |
| Sodium | .50 | Carbon | 8.00 |
| Zirconium | .39 | Bismuth | 14.00 |
| Tin | .35 | Cadmium | 15.23 |
| Lithium | .23 | | |
| Oxygen ($O_2$) | .146 | | |
| Rubidium | .126 | | |
| Hydrogen ($H_2$) | .008 | | |
| Nitrogen ($N_2$) | .001 | | |

pending upon the composition of the local medium. Iron produced one sort of distortion, bismuth produced another. All elements have specific effects in producing distortions. This specific property is known as permeability. It is convenient to visualize this as a measure of the ease with which the lines of force can penetrate an element, high permeability indicating ease of penetration, low permeability correlating with difficult penetration. In Table II[1] are shown Specific Susceptibilities of the Elements referred to their unit volumes. Permeabilities may be computed from the formula, Permeability $= 1 + 4\pi \times$ Susceptibility. Vacuum is taken as the reference medium, those more permeable elements are designated paramagnetic, those less permeable as diamagnetic. Iron, cobalt

[1] From an unpublished thesis by Dr. Noel H. Stearn. "Data from Smithsonian Physical Tables," 5th ed. 1910, "Smithsonian Miscellaneous Collection," vol. 58, No. 1, and Landolt-Bornstein-Roth-Sched "Physikalisch-Chemisch Tabellen 5, Auflage II".

and nickel are in a class by themselves; they are highly paramagnetic and are known as ferromagnetic.

The behavior of the elements suggests that their minerals should respond in a somewhat similar manner. This is the fact. Table[1] III shows the magnetic susceptibility of a number of minerals. The most significant feature of the list is that magnetite is most permeable by a wide margin. This mineral is one of the most

TABLE III

MAGNETIC SUSCEPTIBILITIES OF MINERALS

| Ferromagnetic | | (+) S x $10^6$ | Diamagnetic | | (−) S x $10^6$ |
|---|---|---|---|---|---|
| Magnetite | $Fe_3O_4$ | 300,000–800,000 | Epsomite | $MgSO_47H_2O$ | .63 |
| | | | Niter | $NaNO_3$ | .70 |
| **Paramagnetic** | | | Water | $H_2O$ | .72 |
| | | | Niter | $KNO_3$ | .72 |
| Hematite (Xtal) | $Fe_2O_3$ | 426.00 | Covellite | CuS | .74 |
| Manganosite | MnO | 349.44 | Marble | $CaCO_3$ | .75 |
| Hausmannite | $Mn_3O_4$ | 318.07 | Chalcocite | $Cu_2S$ | .78 |
| Alabandite | MnS | 177.28 | Copper | Cu | .80 |
| Pyrolusite | $MnO_2$ | 131.22 | Halite | NaCl | .82 |
| Pyrite | $FeS_2$ | 120.00 | Sulfur | S | .85 |
| Hematite (Amor) | $Fe_2O_3$ | 107.12 | Sassolite | $B(OH)_3$ | .89 |
| Melanterite | $FeSO_4$ $7H_2O$ | 80.00 | Sylvite | HCl | .91 |
| Bieberite | $CoSO_4$ $7H_2O$ | 68.00 | Kaolinite | $Al_2K_2(SO_4)_4$ $24H_2O$ | 1.00 |
| Limonite | $Fe_2O_3$ $nH_2O$ | 57.00 | Calcite | $CaCO_3$ | 1.00 |
| Platinum | Pt | 26.00 | Berzelianite | $Cu_2Se$ | 1.01 |
| Morenosite | $NiSO_4$ $7H_2O$ | 18.00 | Anhydrite | $CaSO_4$ | 1.12 |
| Chalcanthite | $CuSO_4$ $5H_2O$ | 14.30 | Villiaumite | NaF | 1.12 |
| Cuprite | $Cu_2O$ | 4.38 | Quartz | $SiO_2$ | 1.20 |
| Rutile | $TiO_2$ | .28 | Lead | Pb | 1.30 |
| Brookite | $TiO_2$ | .262 | Cottunite | $PbCl_2$ | 1.31 |
| Octahedrite | $TiO_2$ | .257 | Silver | Ag | 1.50 |
| Air | -------- | .024 | Bromyrite | AgBr | 1.53 |
| | | | Cerargyrite | AgCl | 1.55 |
| | | | Iodyrite | AgI | 1.66 |
| | | | Arsenic | As | 1.70 |
| | | | Diamond | C | 1.80 |
| | | | Zincite | ZnO | 1.85 |
| | | | Fluorite | $CaF_2$ | 2.00 |
| | | | Graphite | C | 8.00 |
| | | | Bismuth | Bi | 14.00 |

widely distributed occurring in practically all sorts of rocks. In igneous rock it is one of the very first to crystallize, hence it occurs in some degree of concentration along contacts. For the same reason it is frequently found in segregations more or less pure in the lower zones of laccolites, sills, and along walls of gently pitching dikes. In the destruction of these rocks, magnetite is highly refractory, it does not alter chemically very readily, it is also relatively

[1] From unpublished thesis by Dr. Noel H. Stearn, University of Wisconsin, 1926.

heavy and takes its place with the so-called heavy residuals. Accordingly, it is usually more or less uniformly distributed over the floor of basins undergoing sedimentation. In a sedimentary series, therefore, it is found concentrated in certain beds. Thus, magnetite is one of the most if not the most important mineral in the application of the magnetic methods to the general field problems of the geologist.

The facts that rocks are aggregates of minerals and different rocks are somewhat different chemically and mineralogically, suggest that rocks should have specific permeabilities. In a sense this is true, every specimen will have a specific permeability. However, permeability varies not only with composition, but with structure so that the well known fact that rocks are uniform in composition and structure only through very limited ranges will demonstrate that the rocks cannot have specific permeabilities which can be applied to large masses. Nevertheless, the fact that a formation has a limited range of composition and structure, and that as a result they may be easily differentiated from one another, indicates that each formation will have a characteristic range of permeability which will set it out in contrast with the adjacent formations. That is, while a sandstone has a wide range of permeabilities within itself, and while a shale also has a range, the comparison of these ranges will indicate a distinctive property for each. The important thing is that in all probability no two adjacent formations will have the same proportions of minerals or the same relative concentrations of these in the same relationship to the earth's field. So long as a formation represents a concentration of a given mineral unlike that in adjacent formations, the magnetic behaviour will be distinctive. The mineral concentrated may have a specific permeability close to the average and the distinctive property may contrast but slightly against the adjacent formations, but given sensitive instruments, theoretically the formation should be amenable to differentiation by magnetic methods.

It has been intimated that other factors than mere specific permeability come in for consideration. Volume is significant. Thus a large volume of a certain element or mineral will produce a proportionately large distortion. Furthermore, the distortion of the field due to a mass of a given mineral or element is not of indefinite extent. It can be seen in the simple experiments that the effect is negligible at a very slight distance from the disturbing body. If a detecting device were set close to the disturbing body a greater response would be felt than if the distance were increased. The effect is, therefore, variable directly with volume and inversely with distance. These three factors, specific permeability, volume, and distance, indicate that a small volume of magnetite, for example, far from the surface would produce an effect as great as that due to a much larger mass of say hematite much closer to the surface. A fourth factor is concerned with the orientation of the geometric axes of the body of concentrate with respect to the earth's field. Thus, if the body is roughly equidimentional it would make little difference which way the field traversed it. If there are two axes infinitely greater than the third, for example a sedimentary bed, much depends upon the attitude of the plane of the two greater axes to the inclination of the field. If the plane of these is parallel to the field, the effect is a maximum. If the two are perpendicular the result in apparently negligible. If the plane of the axes dips downstream on the earth's field the effect is an increase of intensity. If the plane dips upstream, the effect is opposite, the distortion amounts to a diamagnetic effect or the field is decreased.

In general, the observations on magnetic intensity at the surface depend upon the integrated effects of all formations at depth. In the case of an extremely thick series of flat-lying sediments, covering a great area, variations in intensity will be slight, excepting for those correlating with changes in the uniform field of the earth. But if the series departs from flat-lying, if there are disconformities, if the series is not extremely thick and the pre-sedimentary floor was one of considerable relief, or if the pre-sedimentary formations varied widely in composition and structure, or if there are intrusions, all of which represent local concentrations of minerals, there are inevitable distortions of the field which are certain to be detected providing the detecting device is sufficiently sensitive. Whatever modifies the "permeability profile" from place to place will give rise to distortions which will be reflected in the surface.

## Field Instruments Used by The Survey in This Work

The two essential properties of a magnetic field which vary with change of rock composition and structure are direction and intensity. The direction at any point could be determined by setting up a magnet balanced at its center of gravity on a universal pivot. The needle would set itself parallel to the lines of force. By applying mass to the south end exactly to neutralize or balance the magnetic force, the measure of the latter could be taken. If the needle were surrounded by moveable graduated circles the position of the needle at subsequent stations could be read and compared to the initial position. The series of readings would include angle of declination, angle of inclination, and relative intensity.

Such a device is not convenient to manufacture nor easy to operate with speed in the field conditions. Also, since the horizontal and vertical components of direction have to be measured and the horizontal component is necessary for maintaining locations of the station, it has been the custom to employ two separate instruments in the hands of two individuals. One is an elaborated, horizontal compass which is used in laying out the traverses, the other is a counterweighted needle swinging in the vertical plane of the magnetic meridian.

## *THE SUN DIAL COMPASS*

This instrument is fundamentally an ordinary compass equipped with level bubbles and a universal joint which fits upon a staff which in turn is thrust into the ground. The Sun Dial arrangement consists of an annular ring of celluloid attached to the upper surface of a cover glass in such a way that the center of the ring coincides with that of the compass and with the point of the compass pivot. Upon the ring are machined lines which, if projected, would intersect at the south of the dial. At this point of intersection is a small ring to which is attached a silk thread. At the north edge of the dial is a collapsible upright which is slotted to serve as a sight. When not in use this collapses flat across the face of the compass. When in use the silk thread attached to the ring at the south is passed through a hole in this upright and made fast so that it will be taut when the upright is in position.

If the instrument were mounted on the staff, leveled properly and turned so that the north-south line were approximately on the meridian and examined at intervals through the day, it would be found that the sun cast a shadow of the thread on the celluloid ring. The marks are so placed that the shadow will coincide with one or another at intervals of 5 minutes throughout the day. Quarter, half and full hour marks are intensified for convenience, and hour lines are numbered. In brief, it is a portable sun dial.

The instrument could be used to tell the time of day if it could be oriented correctly with regard to the meridian at any place, or it could be used to indicate correct position of the meridian if time were known correctly. Of course, the latter is the use to which the instrument is put.

To make use of the instrument in determining the meridian at any point, the user must have an accurate watch or chronometer. Moreover, the markings on the celluloid dial must be properly placed so that the shadow of the thread will fall at the proper place according to time of day. Also the thread must be so adjusted that the angle which it forms with the horizontal is the angle of latitude at the point of observation. Of course, these things could all be well taken care of in making the instrument, but in case of field repairs, such as replacing the thread, removing the dial to get at the needle or pivot for cleaning or reconditioning, there are abundant opportunities for the organization of the instrument to be upset. Also, the dial for one latitude would not be appropriate for others. Accordingly, care is taken to organize the various parts of the instrument as well as possible, but then instead of changing dials frequently, instead of changing the angle of the thread, and instead of assuming that the correlation of the dial and the meridian is correct, a calibration is performed at frequent intervals or whenever any obvious change in the adjustment has taken place.

*Determination of Compass Dial Corections.* For calibrating the instrument and determining the corrections which must be applied to watch time in order to set the compass in the meridian, a true meridian is the first prerequisite. One method for establishing a true meridian is based on Polaris observation at night.

A location is selected where an unobstructed view along the general trend of the meridian may be had for at least 50 feet. At the north end there should be a tall tree or other object such as a telegraph pole. From a high limb of the tree overhanging the fairway selected, is suspended a plumb line with a rock for a plumb bob. There is made ready a stake bearing a horizontal cross arm about 18 inches long. Other accessories needed are a couple of long stakes, a bucket of water, a pin or needle, a tape, a scale, and a watch. To review the method briefly, the stake bearing the cross arm is set in such a position that the approximate center of the cross arm, the plumb line, and the polestar can be brought into a common line of sight. The stake is set there securely. If a wind is blowing, the plumb bob is immersed in the bucket of water. The cross arm on the stake is placed in the east-west direction, the pin is set in the cross arm in line with the plumb line and the polestar, and the time is observed on the watch. The distance from the foot of the plumb line to the pin is then measured with the tape.

The line determined by the plumb line and the pin in the cross arm is a first approximation of the meridian. However, the polestar is not always in the meridian. It travels a circular orbit, whose center is at true north. That is, the center of the orbit is on the projection of the earth's axis. If then, the star were neither vertically above or below its center, the line established would not be a true meridian. There are, therefore, two choices open. Either the observation must be made at the time that the star is at upper culmination or lower culmination, or else a correction must be applied to the line as just established. The latter is the usual case because the time of culmination is not always a convenient one, and sometimes drifting clouds conceal the star at that instant.

*Computation of Correction to Base Line for a Station at Lat. 46 N., Long. 92 W., at 9:30 P. M. Central time, June 13, 1928.* For all data having to do with the movements of Polaris, or with observations on the sun, or the relation of sun time to mean or watch time, it is necessary to have access to either the Nautical Almanac or tables selected therefrom which the instrument makers publish each year. These are known as the Solar Ephemeris.

According to the Solar Ephemeris for 1928, for the meridian of Greenwich and for the latitude of 40N., on June 15th, Polaris reached Eastward Elongation at 2:06.5 A. M. The figure for June 13 is not given, but it may be computed as follows: The star makes a complete revolution about its orbit in 23 hours, 56.08 minutes, thereby gaining 3.92 minutes per day. On June 14th, Eastward Elongation would be reached at 2:10.42 A. M., and on June 13th at 2:14.3 A. M. But since it is intended to make the observation on the evening of June 13th, it is the observation for the early hours of June 14th which should be used.

The time of elongation computed above is for the longitude of Greenwich and this must be converted to the time of the station. Time west of Greenwich is earlier than for Greenwich by 4 minutes for each degree of longitude, and since the polestar rotates counter to the earth and since the star gains 3.92 minutes each 24 hours, the observation at Greenwich can be reduced to that for the station by subtracting that part of 3.92 minutes which is represented by the time difference which depends upon longitude. The 3.92 minutes corresponds to a rotation of 360 degrees. Or, for each degree subtract 0.0109 minutes. For the station where the observation is to be made the longitude is 92 degrees west. Eastward elongation, therefore, occurs earlier than the tables indicate by 0.0109 times 92 or approximately 1 minute. The time of elongation at the station is, therefore, 2:09.42 A. M. for June 14.

The time at which the observation was made was 9:30 P. M. on June 13. This is Central Standard time which is for the 90th meridian. For each degree of longitude the correction is 4 minutes to be subtracted or the Local Standard time will be 9:30 minus 8 minutes or 9:22 P. M.

The pin was set, therefore, 4 hours 47.42 minutes before eastward elongation. The diagram Figure (9) indicates the correction to be applied in inches per foot of base line (distance from pin to plumb line) for difference in time before or after the points of elongation or culmination. In the present case, the base line was 57 feet long. The correction is 0.09 inches per foot or a total of 5.13 inches. Since the observation was made before eastward elongation, the original pin is too far west. Therefore, the correction is applied to the east. It is to be noted that if the observation had been made at any time after lower culmination and before upper culmination, the correction would be to the east. A second pin is placed at this proper point and this point and the plumb line establish a meridian sufficiently accurate for the intended purposes. The line can be extended in either direction as far as desired.

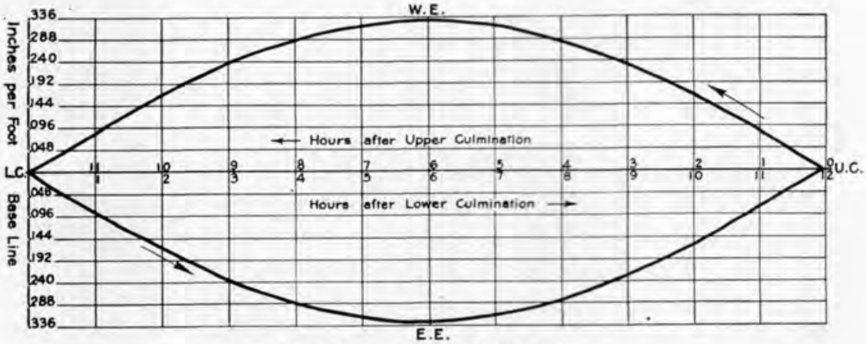



FIG. 9 CORRECTION TO BASE LINE

Early on the morning following the determination of the meridian, the Jacob staffs are all placed on the plane of the meridian. The compasses are all mounted on these, levelled, and the north and south points are turned into the plane of the meridian. The uprights are erected, and the readings of the shadows on the dials are taken at intervals of 15 minutes all day. As each dial time is recorded, the correct mean time is also recorded, the difference between the two giving the correction which must be applied at any time if the dial is to be set up with the sights in the meridian.

At any subsequent time and place, the staff is thrust into the ground, the compass is placed upon it and levelled, the watch is read, the corection is applied, the compass is turned on its mounting until the shadow registers the indicated corrected time. The needle is released, and the reading referred to the normal declination gives a measure of the local declination.

New corrections must be taken whenever any change is made in the organization of the instrument. Also, if the instrument is to be used at any great distance from the locality where the corrections were made, it is necessary to recalibrate the dial against watch time.

*Corrections for Equation of Time.* Watch or clock time is mean solar time. A year is divided into equal parts all of the same length. A true solar day is the time between successive passages of the sun across the zenith. These are of different lengths depending upon the location and the time of year. Only four times a year is true solar time in agreement with mean solar or standard time. In some months the sun time is faster than mean, in others it is slower. The differences between these two for each day of the year are given in the Ephemeris under the head of "The Equation of Time."

In view of the fact that the rate of passage of the sun is variable, the accumulation of differences between mean and apparent time must be kept in account so that they may be applied in the setting of the compass.

For example, in the above computations of the meridian for June 13, 1928 it was intended to make the corrections on June 14. If that day were sunny and the corrections were taken, any differences between mean standard time for the 90th meridian and for the 92d meridian would enter into the corrections and would remain constant. Also, on June 14 the solar time is slower than watch time by 2.1 seconds. This also is in the correction as a negative factor. If at 9 A. M. the corrections indicate that watch time must be reduced by 9 minutes to get true solar time, 2.1 seconds of this is equation of time and the remainder or 8 minutes 57.9 seconds is instrumental plus longitude correction. By June 21 the equation of time is 1 minute 33.1 seconds according to the tables in the Ephemeris, which should be subtracted from the watch time. If the original correction were used which was minus 9 minutes, an additional 1 minute 31 seconds should be subtracted making a total of 10 minutes and 31 seconds to subtract. Or if the instrumental corrections were maintained separately, the 8 minutes 57.9 seconds should be increased by the 1 minute 33.1 seconds making the same total of 10 minutes 31 seconds.

Not uncommonly difficulties arise in the application of this correction particularly when an inflection point in the equation of time is crossed so that several examples are here given.

| | | | |
|---|---|---|---|
| Correct on June 5, 1928. | Correction for 9 A. M. reads | minus | 9 minutes 0 seconds |
| | Equation of time | plus | 1 minutes 43 seconds |
| | Instrumental correction | minus | 10 minutes 43 seconds |
| To use 9 A. M. on June 14 | Correction determined June 5th reads | minus | 9 minutes 0 seconds |
| | Equation of time June 5th | plus | 1 minutes 43 seconds |
| | Equation of time June 14 | minus | 0 minutes 2.1 seconds |
| | Total equation of time June 5 to June 14 | minus | 1 minutes 45.1 seconds |
| | Total correction June 14 | minus | 10 minutes 45.1 seconds |
| Or, | Instrumental correction June 5 | minus | 10 minutes 43 seconds |
| | Equation of time June 14 | minus | 0 minutes 2.1 seconds |
| | Total correction June 14 | minus | 10 minutes 45.1 seconds |
| To use on June 21. | Correction determined June 5th reads | minus | 9 minutes 0.0 seconds |
| | Equation of time June 5 | plus | 1 minutes 43.0 seconds |
| | Equation of time June 21 | minus | 1 minutes 33.1 seconds |
| | Total equation June 21 | minus | 3 minutes 16.1 seconds |
| | Total correction June 21 | minus | 12 minutes 16.1 seconds |
| Or, | Instrument correction June 5 | minus | 10 minutes 43.0 seconds |
| | Equation of time June 21 | minus | 1 minutes 33.1 seconds |
| | Total correction June 21 | minus | 12 minutes 16.1 seconds |

A rule may be formulated as follows:

1. Take the correction observed on the line.
2. Deduct the equation of time for that date.
3. Apply the equation of time for any subsequent date changing the sign as indicated in the tables.

*Sources of Error in Using the Sun Dial.* The sun dial can be set up to within 2½ minutes of time. The marks are placed at intervals of five minutes. A difference of 5 minutes makes a difference of about 2 degrees in the reading of the needle. The compass corrections were made with the compass level and unless the instrument is level each time it is set up, an error will be introduced. So far as the declination is concerned, it is necessary to avoid external influences such as automobiles, railroads and their rolling stock. The condition of the instrument is, of course, important. The pivot is sometimes injured by shock and must be removed and resharpened. The needles are remagnetized once a year and the counterweights are adjusted.

## THE DIP NEEDLE

This instrument is not unlike a compass excepting for the fact that instead of a vertical pivot upon which the jewel of the needle rests, the needle is punched at its center of gravity, the pivot passes through, and both ends are fixed in jeweled bearings. It can be used as a compass by holding it in the horizontal plane, but its specific use is to determine the inclination of the field or the relative intensity as compared to a selected datum.

Although the pivot is fixed at the center of gravity, there are two soft brass lugs, one on either end which must be identical if the instrument is to be used as a dip circle to determine inclination. But when used to determine relative intensity, the instrument is taken to a location where there is known to be no local variation; the north lug is filed away until the needle will stand perpendicular to the field. Theoretically the needle should stand normal to the field if it is to measure the total strength of the field.

The needle swings within a graduated circle equipped at the base with a level bubble sufficiently sensitive so that when the level bubble disappears at either end the reading will not vary over a half degree. The needle is provided with a spring clamp actuated by a thumb screw to hold the pivots and protect them and the jewels from injury when the instrument is not in use.

In use, the instrument is held horizontally before the operator. He releases the needle and turns his body until parallel to the plane of the magnetic meridian as located by the needle. He faces magnetic west and, although the instrument has two faces, always reads the same side of the instrument. He finally clamps the needle at a definite point, usually about 10 degrees counterclockwise from the position of the normal reading. He then raises the instrument vertically to the level of his eyes, centers the level bubble, carefully turns the release screw until the needle drops freely for its first swing. The mid-points of the first two or three swings are computed mentally, and if these check very closely the reading is accepted and recorded. The reading requires about 15 seconds. It is essential to reproduce every gesture in the taking of an observation as closely as possible, thus clamping the needle at the same identical point when in the horizontal, releasing it with the same identical impetus when in the vertical, holding the instrument at the same level to avoid parallax, and maintaining as nearly steady conditions as possible while the needle is swinging.

The principal factors in the taking of authentic, reproduceable and at the same time appreciable observations, are the condition of the instrument and the establishment of the proper setting of the counterweight, which is commonly referred to as establishment of the normal.

The instrument is delicate and should be protected from abuse. The pivots and the jewels are the vital parts and are subject to injury by upsetting and chipping respectively. The presence of dust and dirt will also modify the readings if it gets into the bearings. There are duplicate glass covers on either side which are fragile and must be safe guarded.

*Instrument Reconditioning.* The evidence of maladjustment or faulty bearings is failure on the part of the instrument to reproduce its readings. At times, if given care, the instrument will go for weeks without requiring reconditioning but at other times it is necessary to give it attention even daily. The reconditioning process begins with removal of the spring guard ring which holds the glass face in place. The operation is made from the opposite side from which it is read. The wax seal is dug out with the point of a knife blade, and the glass is removed usually by sticking a ball of wax to its surface and carefully prying it loose. The jewel (rear) is unscrewed and examined for dirt. If found to be fouled with lint or any foreign matter it is laid aside with a mental note to that effect. The release is turned over and the needle lifted out of the second jewel taking care not to scrape the pivots. Both pivot points are examined under a magnifying glass. The tips are scrutinized for evidence of upsetting, for rust and for dirt. If the condition passes inspection as to mechanical features, but dirt is notable, the second jewel is examined. If dirt is the only obvious difficulty all parts are given a thorough cleaning and then are reassembled. In replacing the rear jewel great care must be observed to avoid getting it down upon the pivot point. Such a thing would result in upsetting the point or chipping the sapphire jewel. Approved practice consists in entering the jewel to within a close approximation of the final position. The clamps are then released so that the needle swings freely. With a stick of wood or other object the arm holding the jewel is tapped lightly to cause the needle to disclose any excess side play. At the same time the jewel is turned home with a screw driver until the tapping reveals a minimum of play.

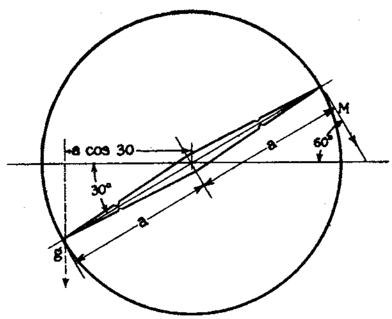
The cover glass is then replaced temporarily and the instrument is taken to a checking point and given a series of readings. If the instrument behaves properly as indicated by the precision of the successive readings, the conclusion can be drawn that it is ready for service. The glass is then cemented in place with a mixture of bees wax and Venetian turpentine, the retaining ring is reseated and the reconditioning process is completed.

When examination of the pivot points reveals upsetting, the procedure has entered a sometimes tedious process. The pivot is unscrewed from the needle. A small lathe for the purpose is carried as permanent equipment and the pivot is inserted in the chuck. As the lathe is turned a fine-grained oil stone is applied to the revolving pivot. Care must be taken to keep the stone in constant motion to avoid grinding plane conical shoulders. Furthermore, the pressure of the stone on the pivot must not be excessive else the pivot will be bent if not broken. The ideal shape for a pivot, as concluded from an experience of many years is that of a bullet. The profile of the pivot should be a smooth curve from the point of tangency with the cylindrical surface of the main shank to the very tip. The tip should be sharp but not of the proportions of a sewing needle. Following the grinding, a piece of high grade, fine grained, optical polishing paper is applied. This too should be kept constantly in motion. When properly ground and polished there will be no "high light" to be seen at the tip. The reverse end of the pivot is then given like treatment. The dressing with the polishing paper is quite as vital as the shaping with the oil stone.

When the reconditioning of the pivots has been completed, the parts are reassembled in the case for a reading test. This is a trial and error matter. Many times, for reasons absolutely unknown, the finest looking pivots will fail to produce constant readings. The process is repeated until check reading can be obtained.

*Setting of the Normal.* The establishment of a normal is attended to when work is begun in a region and must be repeated following the reconditioning of an instrument. Discussion of the principles involved in this process follow.

In the diagram, Figure (10), the forces acting upon the needle, disregarding friction, are represented. The requirements of equilibrium are given in the equation. The inclination is here chosen at 60 degrees. To detect changes in this force, regardless of sign, the needle should be balanced to stand at right angles to the lines of force. In the given case, the normal should be minus 30 degrees, which is a position 30 degrees above the horizontal. Assume the inclination to remain constant.




FOR EQUILIBRIUM
$g \times a \cos 30 = M \times a$
$M = g \times \cos 30$
$= g \times .8660$

FIG. 10 FORCES ACTING ON A DIP NEEDLE

When the center of gravity has been shifted by filing the lug on the north end to a degree which will produce a torque equal and opposite to that of the magnetic torque, the needle stands at right angles to the magnetic force and the condition of equilibrium is represented by the equation.

$$g \times a \cos 30 = M \times a$$

In the equation, g represents the force of gravity, a represents the torque arm, M is the force of the magnetic field and a is its arm. The two arms can be considered to be the lengths of the two ends of the needle measured from the pivot. This equation can be reduced to the form

$$M = g \times .8660$$

If now the needle be considered to have been deflected 15 degrees in the counterclockwise direction due to a decrease in the strength of the magnetic field, the percentage change in the field can be computed as follows:

$$g \times \cos 45 = M \times \cos 15$$
$$M = g \times \frac{\cos 45}{\cos 15}$$
$$= g \times \frac{.9659}{.7071}$$
$$M = g \times .7321$$

The difference between .8660 × g and the .7321 × g is .1339 × g or the field has to be decreased 15.4 per cent to produce the 15 degrees deflection. Let it then be computed what the field change would have to be in order to produce a 15 degree deflection in the opposite direction.

As before,

$$g \times \cos 15 = M \times \cos 15$$
$$M = g \times 1$$

The difference between 1 g and .866 g is .134 g or the field has to be increased in intensity by 15.4 per cent to produce this deflection. In other words the field changes of either sign produce numerically equal changes in the deflections.

When other deflections of 15 degree differences are computed in terms of the necessary percentage changes in the field, a curve may be drawn as shown in Figure (11). The values for this curve are given in the following table. Readings are preceded by the minus sign if counterclockwise from the horizontal position. Similarly, deflections from normal are negative if counterclockwise from that point.

| Reading | Deflection from Normal | Relative value of M | Percentage change in M as compared to Normal |
|---|---|---|---|
| —120 | —90 | —00 | —00 |
| —105 | —75 | —1.0 | —215.4 |
| — 90 | —60 | 0.00 | —100.0 |
| — 75 | —45 | 0.366 | — 57.73 |
| — 60 | —30 | 0.577 | — 33.37 |
| — 45 | —15 | 0.732 | — 15.47 |
| — 30 | 0 | 0.866 | 0.00 |
| — 15 | 15 | 1.000 | 15.47 |
| 0.00 | 30 | 1.154 | 33.37 |
| 15 | 45 | 1.366 | 57.73 |
| 30 | 60 | 1.732 | 100.0 |
| 45 | 75 | 2.732 | 215.4 |
| 60 | 90 | 00 | 00 |

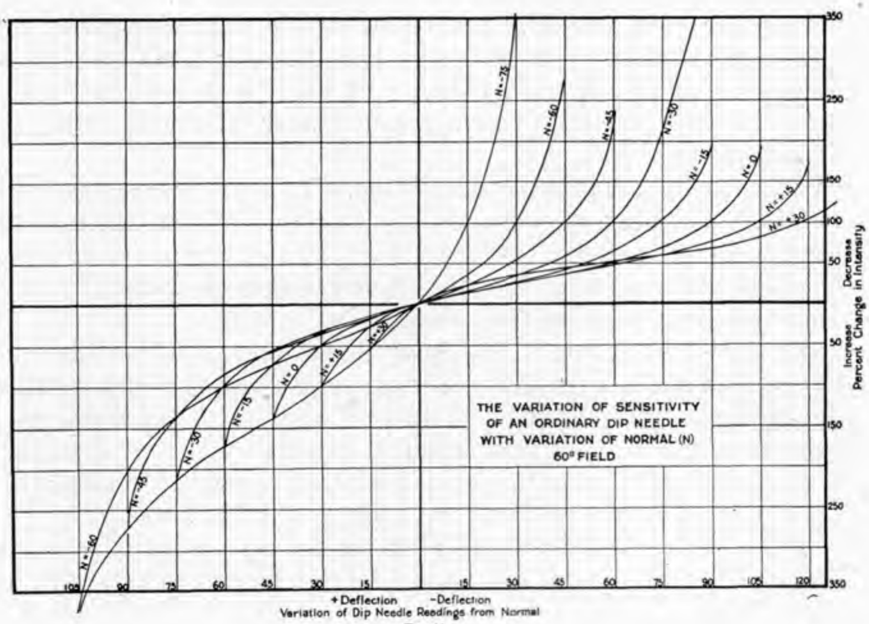



FIG. 11

*Sensitivity.* These computations show conclusively that if the inclination remains constant a normal setting of – 30 will give the instrument equal sensitivity to changes of the field of either sign. They indicate also very conclusively, that for increasingly greater deflections from normal the field changes must increase at a greater rate. In other words, the principles involved in the instrument are such that the sensitivity to small increments of field change decreases with the deflection. This is an inherent weakness in the principle of the instrument.

Additional computations have been made and plotted which show that if it is desired to increase the sensitivity toward slight changes in the field of positive character, that is to cause deflection from normal in the clockwise direction, a normal should be chosen at an angle counterclockwise from the position perpendicular to the field. The limit of this is indicated on the graph. It is to be noted also that if this increased sensitivity to positive changes in the field is selected, the sensitivity to decreases in the field is sacrificed. The converse conditions hold true, that for increased sensitivity to decreases in the field a normal at an angle clockwise from the position perpendicular to the field should be chosen. Here too the sensitivity to changes of positive character is sacrificed.

Variation with Normal. For sensitivity to small changes in the field from normal the curves show that there is little choice between that furnished with normals of plus 30, 15, 0, minus 15, 30 or 45, since the curves follow approximately the same paths for slight distances.

Variation with change in inclination. This discussion has been restricted to cases of constant inclination. If the inclination changes, as is indicated by the curves, sensitivity must change. Over limited areas it is probable that changes in inclination are much less likely to occur than changes in intensity.

The curves in Figure (12), show the manner in which the sensitivity changes if normal is set at minus 30 and the field inclination increases from 60 to 85 at intervals of 15, 5, and 5 degrees. Only the curve for an inclination of 60 degrees is symmetrical, that is, only this normal gives a deflection of equal amount with equal changes of the intensity regardless of sign.

The most significant fact pointed out by the curves is that the instrument is in general more sensitive to changes of intensity as

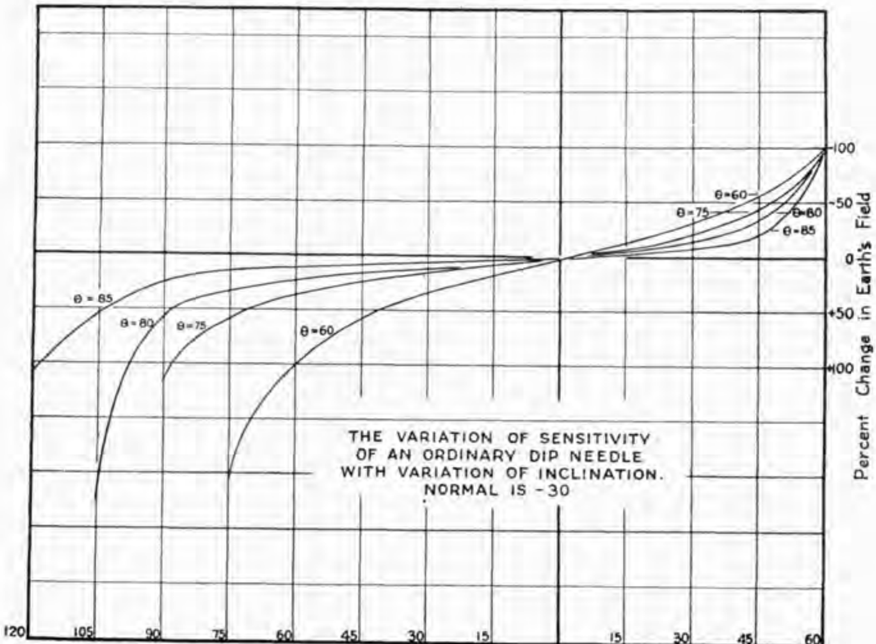



Fig. 12

the inclination of the field changes. Thus, in the north where the field is more steeply inclined, the instrument responds more to slight changes in the intensity. Were the field to stand perpendicular, the instrument would be of infinite sensitivity, which means that if the normal be set at zero, the slightest change in the field would produce total displacement (disregarding friction).

If an instrument is used with a constant normal on a traverse of considerable length, north and south, allowance must be made for the change in both inclination of the field and its intensity due to the normal field itself. There is a regular steepening toward the north and a corresponding increase in intensity.

*Sources of Error in the Use of the Dip Needle.* The best all-around safeguard against error in using the dip needle is to reproduce every gesture in the most minute detail. The level bubble must be centered each time since a shift in this shifts the normal position. The points must be kept in condition and if possible the instrument should be checked against previous observations. It is Survey practice to require each geologist to check and record his readings at a designated point in camp each morning and each evening. If these readings do not remain constant, the needle is condemned for reconditioning. With extreme changes of temperature the readings of the instrument change. In the times of year when the daily range of temperature is great, this factor must be watched. In cold weather particularly, there is a chance of developing a static charge upon the cover glass. This can be removed by rubbing the glass with the hand or by breathing upon it.

Protection against damage to the pivots or jewels due to accidental release of the clamp while the instrument is being carried can be secured by slipping a leather guard on the shank of the release screw and turning the screw down upon this to the limit.

Error is introduced if the plane of the instrument is not in that of the magnetic meridian, whether departure be from the vertical or from the meridian. It is a simple matter to hold the instrument so rigidly that the top or bottom is pushed out of the vertical. However, if the error in position is not over 15 degrees any way, the error in reading is negligible.

Instruments vary in sensitivity, and if two needles are read at the same point it is not uncommon to obtain two different readings. In general it is possible to expect a 1 degree deflection for a per cent change in intensity, although this does not hold for large deflections as has been shown. Relative sensitivities can be measured by reading the several instruments at the same points on a traverse across a belt of variation.

## FIELD PRACTICE

It is the practice of this Survey to make magnetic observations during the regular mapping traverses. These are on the north and south section and quarter lines. The work is done by parties of two men, one a compassman who runs the line and paces. At intervals of 100 paces an observation of the declination is taken. At the half interval, or every 50 paces, the dip needle is read. There are then 20 observations of declination and 40 observations of intensity taken in every mile of traverse.

Following the completion of the mapping, the dip needle observations are plotted to scale upon a map. If the area has disclosed variation from normal the distribution and characteristics of the variation can be seen graphically. These are then analyzed. The variation may be extremely local, perhaps encountered only on a single traverse. Or several adjacent traverses may disclose similar variation as more or less narrow belts. Or there may be a broad area revealed by a number or traverses.

Usually, variation showing upon the preliminary sheet is followed up in detail by additional traverses between the original ones. For example, locallized variation is generally surrounded by a series of traverses to determine the limits. Additional traverses are placed to obtain data upon the probable origin of the disturbance. Thus in one case locallized variation was detailed and found to take the form of a four-pointed cross with maximum intensity lying along lines representing the simple cross, and a maximum at the point of intersection. This variation was interpreted as the intersection of intrusives, or the presence of intrusive rising along intersecting joints.

In case adjacent traverses disclose variation apparently along a continuous belt, a line joining points of similarity within the belt is a measure of the strike of the disturbing body. The detail traverses are placed to obtain additional points upon the line, to determine its continuity, to detect presence of dislocations, or flexures, and its extent. Such belts indicate the strike of one feature or another. It may indicate the regional strike of the formations, it may indicate the strike of a dike, or in one instance it was found beyond a doubt that such a belt represented a ridge controlled by joints which cut at a high angle across the actual strike of the formation.

One determination which can be made by means of the detail traverses is the presence of cross faults. This is applicable to the work on the Ironwood, where individual horizons with distinctive magnetic properties were traced with traverses sometimes not over 50 paces apart and with readings at 10 pace intervals. When in the course of tracing such features an abrupt, locallized change in position is encountered, it is highly probable that a cross fault has been encountered. The strike of the fault can be determined if 2 such magnetic horizons some distance apart can be traced across the break. This is the case with the more important cross faults across the Ironwood. The base of the Keweenawan, some 2 miles north is a prominent magnetic feature and the stronger faults can be located magnetically along this horizon as well as in the Ironwood.

Details of the interpretations from the magnetic results along the Ironwood will not be given since these are discussed in detail in the chapter describing the local geology by townships. However, in this place it is perhaps relevant to point out the general features of the magnetic observations.

The traverses from south to north show a practically constant intensity across the Archean, the Bad River dolomite, and the Palms. Immediately on intercepting the Ironwood the intensity increases and the curve of the readings rises more or less abruptly. Increase continues to a maximum which varies in relation to the particular horizon with the location. From the maximum the curve is commonly smooth as the intensity returns to tangency with the smooth normal intensity over the Tyler slates. This is a typical curve. If the traverses be placed at frequent intervals, it will be found that for considerable stretches a line connecting the change of the curve from normal over the southern formations to increased intensity over the Ironwood is essentially straight. In many instances, however, this line is offset thereby pointing to dislocation by cross faulting. Toward the west the line will have gentle curvature representing flexing without dislocation.

It will also be noted that the variation in the east is of much lower degree than in the west. This is a first class manifestation of the degree of recrystallization, magnetite being one of the products of the process. A case in point is to be seen in section 16 of

T.45—R. 1E. Here the traverses show extremely weak intensity and yet in the adjoining sections it is strong. If the sort of variation found over the productive area in T.46—2E. is examined it will be found to compare favorably. In this instance section 16 would appear to be promising as explorable ground.

A service supplied by the method is exemplified in T.44—R. 4W. At Mineral Lake in section 13 there are exposures of the Ironwood. In section 23 in T.44—R. 5W., some 6 miles west there are other exposures. Between the two areas of outcrops there are no exposures of any sort. The fate of the Ironwood in this stretch of country and the nature of the formations occuring beneath the drift are in question. The magnetic method has a suggestion. In the ordinary run of field work, the method is used to extend or extrapolate from the known situation through the unknown and again to the known. This is the main province of the method as it is employed in association with other field methods. The question arises as to the limiting distance through which the method may legitimately carry a formation between points of known conditions. This question applies in the above problem because there may be detected across this gap of unknown country a belt of magnetic variation, whose characteristics referring to both regularity and intensity, are identifiable with the Ironwood and with no other formation in the district. Exposures to the south, southeast and southwest are granitic with no magnetic distinctiveness excepting normal intensity. To the north so far as scattered exposures are to be found the formations are intrusive gabbros and the anorthositic phases of the gabbro. These formations also are lacking in magnetic properties. It is conceivable that the belt of variation may arise from a segregation of magnetite in the base of the laccolite but if such were the case, it would be difficult to explain why this segregation took place only where the presence of the Ironwood is in question. The base of the anorthosite further east is not magnetic. It is not likely that a mass of magnetite originating in this way would give rise to the regularity of variation shown. On the other hand, it is evident that the variation is not so strong as is found over the shallow Ironwood. To this must be applied the fact that whatever the formation is in this wide stretch of covered country it is deeply buried in drift including outwash. It must also be borne in mind that evidence is strong that there are several strong bedding faults in the vicinity and that the intrusives occupy these. This would impose the possibility that the Ironwood is covered not only by the drift but by a thin layer of anorthosite or gabbro as well. Furthermore, it is a fact of experimental determination on the north limb of the Keweenawan formations that the attitude of the formations with respect to the inclination of the earth's field plays a part in determining just how intense the influence of a formation will be in distorting the field. In case the Ironwood were present in this area lying flat or dipping gently south, its effects would be much less prominent than in the case of the beds dipping north at an angle slightly less than that of the inclination. The main force of the magnetic evidence is that the variations arise on exposure of the Ironwood and they have been traced to other exposures of the same formation. So far as exploration is concerned probably there is little occasion to be concerned because the chances are great that if the Ironwood is present in this region of complex intrusions, these have recrystallized it to amphibole magnetic rock. At the same time, there is no direct evidence on this nor on the possibility that the Tyler may not be present in force. The exposures of anorthosite and gabbro within 2 miles of the belt of variation are mere ridges or knolls in the drift. If these are minor intrusives the main country rock may be Tyler.

Much reliance has been placed upon the magnetic results in connection with the abrupt changes in the width of the belt of variation along the range. These abrupt changes occur at the cross faults and suggest that the movement on the fault planes was rotational. The dip flattens to the westward and would appear to accomplish this gentle dip by sharp changes at the faults.

The magnetic results have been the mainstay in putting together the structural situation. Fortunately, the magnetic survey of the Keweenawan to the north has been completed. This has thrown considerable light upon the problems of the Ironwood, particularly those pertaining to structure.

# CHAPTER V

# GENERAL GEOLOGY

## INTRODUCTION

In this chapter are described all of the formations which occur in the strip of country containing the Gogebic Range. These formations other than the Ironwood are not described because of any intrinsic interest in them. Several of them are quite without outstanding characteristics of size, composition, structure or economic values. Others, in particular the Keweenawan, are sufficiently interesting to warrant a separate volume which is in preparation. Nor are these formations treated here because of any appreciable contribution of their substance to the Ironwood. As a matter of fact, the Ironwood has defied all attempts to detect any contribution to it of material by any earlier formation. Some of them have contributed heat and pressure for the reorganization of the mineralogical composition of the Ironwood and are included on that account. However, the main reason for concern with these other formations is that they contain the record of events and processes which have wrought the Ironwood that we know today.

These events and processes have been incorporated in chronological order in a history of the Ironwood, which is Chapter VII. It is not intended here to duplicate that chapter, but it is convenient in the interest of systematization to treat the formations in the order of their decreasing age. It so happens that this order is the same as that in which they occur from south to north across the monoclinal structure. Accordingly the descriptions begin with the oldest, or most southerly, and proceed with the successively younger or more northerly.

## THE ARCHEAN

The oldest formations to be found within the mapped area are extremely variable in character. On individual exposures this variability is striking, and the strip of country between the Montreal River and Trappers Lake in T. 44—R. 6 W. reveals variations even in the perspective view. However, on the broadest basis of classification these formations may be differentiated into two main groups. These are found to be in contrast with respect to relative age, general composition, and secondary structures. Thus, there is one group much older than the other. It is on the whole much more basic and it is characterized by a better developed rock cleavage. Exposures of this group are referred to as greenstones, more specifically as greenstone schists, and they are assigned to the oldest period of time represented in the district, the Kewatin. The net result of the connotations is the name Kewatin greenstone schists. The second group is obviously younger since representatives may be observed cutting into and across the greenstone schists. They are in general richer in silica and the alkalies. They are lighter colored, and they are commonly free from the intense secondary structures. These are assigned to the Laurentian period of geologic time and are referred to in a general way as the Laurentian granites.

As indicated on the map, Plate I, the two groups of rocks may be separated in a general way by a boundary drawn southwesterly across the east of section 26, T. 46—R. 2 E., thence across 35 of the same township, and through the south line of section 3 of T. 45—R. 2 E. about a quarter of a mile west of the south quarter of that section. On the east of this line lie the formations assigned to the second group, the Laurentian granites. On the west lie the Kewatin greenstone schists, and they continue, with minor exceptions, as the formations underlying the Penokee series as far as the vicinity of Penokee Gap in section 14 of T. 44—R. 3 W. The western extension of this boundary line is highly generalized on account of the paucity of outcrops, but along the Bad River flowing through Penokee Gap are exposures showing granites which finger or interleave with the schists. To the west the granites are dominant again. Hence, the boundary is drawn as shown. Thus, for more than 25 miles along the range from Hurley, the Kewatin is the formation immediately underlying the sedimentary series. The granite is in force to the east and on the far southwestern wing.

*The Kewatin Greenstone Schists.* The two most opportune points at which to study these most ancient formations are between Pence and Hurley, and south of Upson.

The following description of the greenstones between Pence and Hurley is taken from a field report[1].

"The rocks are generally dark green on the weathered surface, showing the presence of chlorite. The fresh surface is usually a lighter green, probably due to the presence of much hornblende. Crystal forms can seldom be distinguished, though micas, chlorite, and hornblende were determined. Some phases were found to contain amygdaloidal fillings of quartz and chlorite, and possibly of prehnite. Phases of this sort look like igneous flows. Other phases show parallel banding crumpled into drag folds with cleavage parallel to the axial planes of the folds. This type of schist suggests that the rock is a metamorphosed sediment. The general strike of the cleavage is N-S with a general dip to the east."

From this description, it is clear that the greenstones present several different phases, some evidently intrusives, some extrusives, and some possibly of a clastic origin. In the description of the "granites" to follow, reference is made to the fact that in some instances there are granite textured basic rocks of the gabbro type found in the granites with no sharp boundaries, and hence suggestive of the possibility that these were coarse-grained gabbro phases of the older greenstones which have been but slightly modified by the later granite.

The exposures south of Upson are found along the valley sides of the Potato River. The rocks are green schists with an abundance of chlorite and with crystals of carbonate, which, on weathering, dissolve out and produce a pitted surface.

*The Laurentian Granites.* The granites are best exposed in the southeast of T. 46—R. 2E. and in the north of the township to the south.

The rock is usually coarse-grained with size of crystals up to a quarter of an inch. The important minerals are quartz, orthoclase, hornblende, and biotite. Usually the rock is not gneissic in structure, but appears younger that the gneisses seen in T. 44—R.3W.

In the NW¼ of section 25, T.46—R. 2E., a basic rock occurs which may be a phase either of the greenstone or of the granite. The material outcropping looks like gabbro. There are many phases differentiated on the basis of color and percentage of quartz. These suggest that the mass is a differentiate from the granite.

[1] M. C. Lake, 1915.

"Careful mapping failed to disclose a single place where a sharp contact could be drawn between the basic green rock on one hand and the siliceous granite on the other. It was impossible, from field observations to draw the boundary between the two formations. The green rock may be intrusive into the granite, a differentiation phase of the granite or a "partly fused" greenstone."[1]

"The granite as a whole seems to be very changeable in composition. The proportions of quartz, hornblende, and feldspar vary in different localities. Intruded into the granite are large numbers of pegmatites of very coarse crystallization. These are sometimes nearly pure orthoclase, again nearly pure quartz, and they generally lack the ferromagnesian minerals. The feldspars will sometimes average several inches in diameter with large orthoclase cleavage faces producing broad smooth planes. The quartz crystals are often over half an inch in size. These pegmatites are found in the green schists as well. Near the contact of the granite and the schist the latter contains larger quantities of biotite than usual and appears more schistose."[2]

Throughout the Archean area there are exposures of gneissic material, either in the greenstone area or that of the granite. These are subject to interpretation and the writer is inclined to the idea that in many cases they represent the green schists with injection of the granite juices along the planes of schistosity. In other cases they are "squeezed granites".

At Penokee Gap, and along the Bad River south of that feature, there are numerous exposures of the Archean which are typically gneissic. The secondary structure strikes approximately with the bedding of the Ironwood and Palms, but the dip is to the south. The gneiss consists of alternating bands of light and dark aggregates of variable width, composition and texture. The darker bands are dominated by hornblende and the lighter by pinkish feldspar. The general situation is strongly suggestive of a derivation through the injection of the pink, granitic material into the shreds of the basic schist.

In the early days questions arose as to the relationship of these gneisses to the sediments to the north, and as to their origin. The banding was a suggestion of bedding and it was supposed that they were metamorphosed sediments. This seems to be hardly the

---

[1] Field Report of M. C. Lake, 1915.
[2] Idem.

case, although there has been no microscopic work which would place the stamp of finality upon the problem.

From Penokee Gap to Pence and Hurley, there are very few exposures excepting those referred to at Upson. The few exposures which have been examined add little to the general statement. From Penokee Gap west, there are no other significant exposures of the schists, and it is believed that the granites are present in force. The exposures are most numerous in the upper reaches of the Marengo in the southeast of T. 44—R. 5W. From the standpoint of a general interest, it is perhaps safe to state that these granites are identical with those first mentioned in the vicinity of Hurley, although they are more commonly gneissic. It is to be noted, however, that in this western region dynamic metamorphism is universally far more intense than anywhere to the east. They are in general medium to coarse-grained pinkish rocks carrying quartz and a minor amount of ferromagnesian mineral. In the same township there are exposures close to the Ironwood near Coffee Lake which are of Keweenawan age and must be distinguished from the Archean in the southeast of the township. The main distinction in the field is the more or less well-developed gneissosity of the Archean granites.

The entire suite of varieties in the Archean area are of interest in the study of the Ironwood perhaps solely for this reason. The materials of these older formations are identifiable with those which represent their destruction, transportation and redeposition, the Palms slates and the Tyler. The correlation is so evident that "the part of the belt (of Tyler) west of Penokee Gap has received nearly all of its material from the syenitic granite to the south and west".[1]

In a general way, it seems clear that the Archean formations were long exposed to the elements and agencies of weathering existent in that period of the earth's history. So far as there is any clue to the subject, there was insignificant life on the land, from which it follows that probably there was little aid from any carbon dioxide that could have originated in the decay of organic matter. If there was no cover of vegetation the disintegrating effects of wide range in temperature due to insolation must have been great. The result of this would have been a reduction of the surface to a gravel of feldspar and quartz grains or an accumula-

[1] U. S. Geol. Survey Mon. 19, p. 345.

tion of slabs and shards of schist. There is no other evidence than that the terrain had been reduced to a more or less smooth or at the outside gently rolling peneplain prior to the deposition of the first of the formations of the sedimentary series.

## THE LOWER HURONIAN

The formations north of the Archean are of sedimentary origin. They were originally deposited horizontally in a basin of water and the lowermost was the first to be laid down or it is the oldest of the series. It is a carbonate formation, a limestone, with an upper phase which is richer in chert than the base. However, on account of the notable quantity of this hard siliceous material, the formation is known as the cherty limestone formation, or more specifically, the Bad River cherty limestone. The name is given to connote the fact that one of the most extensive exposures occurs on the Bad River at Penokee Gap.

The sedimentary series of which the Bad River limestone is the lowermost includes the Palms, the Ironwood, and the Tyler. These four bedded formations contain the record for that period of the earth's history known as the Huronian. However, between the Bad River limestone and the Palms formation there is a very obvious break in the sedimentary record. For convenience in comprehending the situation it may be considered that a chapter, long or short, has been removed from the record following the deposition of the Bad River limestone. Thus, the record through the Huronian consists of an earlier or lower part, and a later or upper. The Bad River formation is, therefore, considered and referred to as the Lower Huronian while the three succeeding formations are classified as the Upper Huronian.

In the eastern part of the Gogebic district, in Michigan that is, there is a quartzitic formation underlying the Bad River and into which the Bad River formation grades. This is the Sunday Quartzite. It was deposited upon the crystalline rocks of the Archean after the latter had been reduced to an approximation of a plain. The Sunday formation was not apparently deposited in Wisconsin for unknown reasons. In Wisconsin, then, the lowermost of the series and the sole member of the Lower Huronian is the Bad River Limestone.

*The Bad River Dolomite.* This formation is to be found only intermittently at the base of the series in Wisconsin. It varies in thickness. In places the overlying Palms rests directly upon the Archean. In many places the base of the Palms contains relics of the Bad River. Consequently, it is generally accepted that the Bad River formation was succeeded by a period of time during which deposition was held in abeyance and in its stead the formation was subjected to erosion. It may be that the formation is a great deal more continuous than is shown on the maps, but it was only found in the few places where shown. It seems probable that it was entirely eroded in places and what is now to be seen constitutes merely patches or remnants of its former extent and thickness.

The several places where the formation was found by the members of this latest survey are from east to west, section 10 and 11 of T. 44—R. 2W. near Ballou; the NE of section 17, T. 44—R. 2W.; section 14, T. 44—R. 3W. at Penokee Gap; in the northeast of section 24, T. 44—R. 4W., southeast of Mineral Lake; and in section 22 of the township west, T. 44—R. 5W., near Marengo Falls. At three other localities the formation had been reported, but diligent search was not rewarded. These are in section 15, T. 45—R. 1E.; section 33, T. 45—R. 1W.; and section 16, T. 44—R. 3W. In the case of the first of these places reported, there are no formations outcropping whatsoever. There are several pits sunk in exploration for the footwall of the Ironwood, and it may well be that the original report was based upon material thrown from one of these pits. But the pit had either caved, or the exposure had been concealed in the thick brush which now is effectually concealing the range. The second in the northeast of section 33, T. 45—R. 1W. was reported by the work done in the 70's but a thorough scouring failed to disclose its presence. The third locality, the southeast of section 17, T. 44—R. 3W., showed dolomite in a small exposure some distance from where it could be reasonably accepted as an outcrop in place. It was considered to be of doubtful character and was not shown on the maps. It is possible that the formations here have been folded and the limestone thrown to the south, thereby accounting for the great distance through which this exposure is removed from its normal position.

There appears to be a twofold subdivision of the formation into a lower cherty dolomitic phase and an upper dolomitic cherty phase, although throughout, the two component materials, chert and dolomite, are apparently intermixed. The carbonate phase is a mixture of calcium and magnesium carbonates in such proportions as to indicate a dolomitic character rather than a straight limestone. Iron is seldom important in amount and the formation is not apparently possessed of significant magnetic properties.

The most extensive exposures are in T. 44—R. 5W., in the south of section 15 and the north of section 22 along the west side of the Marengo River. Here the strike is N. 45° E. and the dip is around 20° NW. A thickness measurement based on outcrops and conforming with the observed dip is 270 feet, although the structural situation is such as to indicate strong possibility that there has been duplication by folding or faulting. The exposures lie between showings of Ironwood and to the situation there has been applied an anticlinal structure pitching to the northwest. The formation is intensely recrystallized, as are the other formations in the vicinity, probably due to the nearby igneous intrusions and the intense dynamic metamorphism.

The exposures in the northeast of section 24, T. 44—R. 4W., are small, badly crumpled, and a measurement of thickness would be of little value.

In Penokee Gap the thickness is of the order of 100 feet. The base of the formation is dolomitic, more or less tremolitized, and shows a structure much like that of the Kona Dolomite of the Marquette Range in Michigan, at which point it is diagnosed as of algal origin. The beds are thin, ranging from 1 to 2 inches, and this member is of the order of 50 feet thick. Above it lies the cherty phase, a gray and hard, sometimes fragmental type.

In sections 10 and 11 of T. 44—R. 2W. the upper cherty phase is not seen. The rock is a gray buff fine-grained limestone or dolomite. Its upper surface is irregular and the bedding planes of the overlying Palms are cut off against the irregularities of the dolomite. The actual contact between the two contains a breccia of cherty fragments probably representing the remains of the upper cherty member. The exposure indicates a thickness of the order of 50 feet. The occurrence in the northeast of 17 of this township is possibly not Bad River formation at all. It is rich in magnetite, an anomaly, and it occurs in the region of known intensive movement, so that what has been so identified may well be a faulted segment of the Ironwood chert.

There is no reasonable doubt about the unconformable relationship of the Bad River to the overlying Palms. At Potato River, for example, the Palms lies directly upon the Archean. In the several instances noted, the base of the Palms is commonly characterized by a profusion of fragments of the chert which represents the top of the Bad River.

## THE UPPER HURONIAN

### *The Palms Quartz Slate*

The Palms formation is coextensive with the Ironwood from end to end of the range. It unconformably overlies the Bad River, as indicated above. It is a sediment of highly siliceous composition, with quartz and alkalic feldspar the dominant minerals. On the whole, it is poorly classified material, although the upper 50–60 feet are beds of extremely well classified quartz, now indurated and cemented into a quartzite. The thickness of the formation is remarkably constant over considerable lengths of outcrop but there is a gradual thickening toward the eastward. In Michigan it is reported to be considerably greater than the average of 450 feet for Wisconsin.

The formation is divisable into three members or units. The lowermost is a conglomerate some 3–10 feet thick. The central part is made up of thin-bedded quartz-feldspathic slate. This constitutes fully 90 per cent of the thickness of the formation. The upper unit is the quartzite referred to above, which is 50–60 feet thick in Wisconsin but increases to as much as 100 feet in Michigan. These units can be traced along the range and more detailed descriptions follow.

*The Conglomerate.* There is approximately one exposure of the base of the formation to each township. These show that the base of the Palms is derived from the immediately underlying material.

In the SW¼ of section 32, T. 46—R. 2E., the Palms rests on a 2-foot bed of greenstone into which granite is intrusive. The conglomerate is here about 6 feet thick and made up of well rounded fragments averaging about 2 inches in diameter, although occasional boulders up to 8 inches in diameter are found. These fragments are mainly whitish granite, although there are some of graywacke and quartz. Their characteristically flat shapes with well rounded edges appear to indicate considerable working over by water action before deposition in their final resting place. The material cementing the fragments in the conglomerate is dark green in color and contains abundant chlorite, feldspar, and quartz particles. On the whole, the grains of quartz are well rounded but the feldspars, which are pinkish in color and probably orthoclase, are quite angular, and, embedded in the greenish material, give a porphyritic appearance to the rock. The greenish color is probably due to the presence of ferromagnesian material, possibly largely chlorite in a more or less fine, flaky form. This conglomerate grades upward becoming more finely fragmental and very highly feldspathic and finally appears to grade into thinly banded slaty quartzite and graywacke.

In T. 45—R. 1E., at the section across the Palms exposed along the Potato River, the basal conglomerate is 2 feet thick and rests on a slightly schistose amygdaloidal greenstone. The conglomerate contains fragments of greenstone, with their schistosity parallel to the bedding of the quartz slate, chert, quartz, and a 2–4 inch band of magnetic jasper which appears to be continuous for several feet. The maximum size of fragments in this exposure of the conglomerate was about 10 inches. Some carbonate was found in the matrix of the conglomerate.

In T. 45—R. 1W. the conglomerate is exposed about one-fourth of a mile south of the center of section 33. Here it is found resting on a greenish mashed igneous rock, which appears to have had an irregular erosion surface on which the conglomerate was deposited. The relief on this erosion surface appears to have been as great as 10 feet, and hence there is considerable variation in the thickness of the conglomerate from place to place. On the high points of this greenstone floor it occurs as a thin paste separating the greenstone from the quartz slate, while in the depressions it has variable thicknesses. Fragments in this exposure of conglomerate vary from minute to 4 inches in diameter. The coarser of these are quartz, chert, greenstone, jasper, and what may be dolomite. These coarser fragments are well rounded but the smaller, although apparently of the same general composition, are quite angular. The matrix consists of well rounded quartz grains in a soft, dark, argillaceous appearing material, which is the first to be removed on weathering.

At Mount Whittlesey, in section 9, and in section 10, T. 44—R. 2W., exposures of the base of the Palms show it to be resting on a slightly uneven surface of the Bad River formation. In section 10 the Bad River formation ends and to the east the Palms appears to lie on greenstone. The upper portion of the Bad River formation is a recrystallized, sugary white chert containing in places bands and lenses of magnetite. Much of this portion of the Bad River is brecciated and it is fragments of this material, from one-half to 8 inches in diameter, which here make up the thin conglomerate. These fragments are in part well rounded and are cemented in the quartz slate phase of the Palms. The conglomerate here is usually a few inches in thickness. Bedding planes of the Palms can be seen ending abruptly against the sides of depressions in the chert showing very clearly the unconformability of the two formations.

The most westerly exposure of the conglomerate is in section 14, T. 44—R. 3W. Here it varies from a few inches to 3 feet in thickness and in appearance resembles a breccia more than it does a conglomerate. The fragments are generally quite angular. The angularity is made more striking by the fact that the fragments are mostly of a white, recrystallized, sugary chert set in a dark colored ground mass. Occasional well rounded fragments, however, show that this is a conglomerate rather than a breccia. The fact that the fragments are practically all recrystallized chert, very much like the chert member of the Bad River formation, indicates a probable derivation from that formation; and the angularity of these fragments suggests a surface rubble on the chert which was cemented without much transportation or working over by water action. Some fragments of practically pure magnetite occur mixed with the chert fragments, and in places well rounded pebbles of quartz up to one-quarter of an inch in diameter are found in considerable abundance. The cementing matrix is dark greenish to blackish in color and made up of rounded grains of quartz and small octahedra of magnetite held together by silica. The presence of the fragments of magnetite in the conglomerate suggests that the magnetite in the ground mass may well be of fragmental origin, although now quite well recrystallized.

*The Quartz Feldspathic Slate.* The greater portion of the Palms formation, which constitutes more than 90 per cent of the formation, is a thin-bedded, dark colored rock classed as a quartz slate. These beds vary from a fraction of an inch to over an inch in thickness and consist of purely fragmental coarse quartzite, novaculitic material, soft blackish shaly material, and gradations between all of these.

Good sections across the quartz slate are exposed along the West Branch of the Montreal River in section 27, T. 46—R. 2E., along the Potato River in sections 19 and 20, T. 45—R. 1E., along Tylers Fork in section 11, T. 45—R. 1W., along the road south of Ballou in section 11, T. 44—R. 2W., and at Penokee Gap in section 14, T. 44—R. 3W. At all of these exposures the quartz slate shows similarity both as to composition and as to thin type of bedding.

The beds of coarser fragmental material are made up of quartz grains, the larger of which are well rounded. These grains are cemented either by silica or a fine, dark, argillaceous appearing material, which, under the microscope, is seen to be mainly sericite with some chlorite, and in places carbonate. From T. 44—R. 2W. to the Montreal River in T. 46—R. 2E., considerable feldspar is found in the fragmental beds near the base of the formation. However, in the central and upper portions this material is apparently lacking. From the geographic distribution of the feldspar, coinciding as it does to the igneous basement on which the Palms rests, and from its stratigraphic occurrence toward the base of the formation, it appears to substantiate the idea that the basal conglomerate has been derived from immediate local sources. No feldspar was noted in the quartz slate farther to the west where the Palms rests on the Bad River formation and where the basal conglomerate was made up of chert fragments similar to the chert in the upper portion of that formation. The color of these quartzite beds varies from gray, brown to black.

The finer novaculitic appearing beds appear to be made up of fine fragments of angular quartz in a siliceous, often iron-stained, or sometimes dark colored probably micaceous cement.

The blackish, argillaceous, beds present a true shaly or slaty appearance macroscopically. Microscopically they are seen to be made up largely of sericite with some chert, chlorite, and magnetite. The brownish color presented by slides examined in plain light may be due to carbonaceous material. Flakes of white mica are quite characteristic on the bedding planes all through the quartz slate.

As specimens are studied progressing from east to west along the formation, very few changes are noted other than that the carbonate disappears west of Tylers Fork and magnetite in small well developed octahedra becomes more abundant. Sericite flakes become larger on the bedding planes, and a tendency for schistosity and fracture cleavage develops in the slaty beds.

Ripple marks are common in the more coarsely fragmental beds all along the formation. At the Potato River section 53 studies of ripple marks gave 25 in the lower portion of the formation as formed by currents coming from the northwest, and 25 higher in the formation gave currents as coming from the southeast. Cross-bedding is also noted in these fragmental beds.

*The Quartzite.* The most distinctive phase of the Palms is the vitreous quartzite which marks the top of the formation. This relatively massive, practically pure quartzite tops the entire length of the Palms in Wisconsin and ends abruptly, yet with apparent conformability, against the overlying Ironwood formation.

The quartzite consists of medium sized, well rounded, quartz grains, some of which show secondary enlargement when examined macroscopically and a goodly portion when examined under the microscope. A little mica is present on bedding planes. Colors range from white, green, brown to red. The reddish color is usually found at the top where iron solutions from the overlying Ironwood have seeped in, oxidized, and stained the quartzite. The thickness of this portion of the Palms is never less than 20 feet, where only partial measurements can be made, and where measurements completely across it have been made it has a thickness of 50–60 feet.

Progressing westward along the formation from the Montreal River, magnetite in small grains begins to appear in this massive phase. In T. 44—R. 2W. fibrous radial tufts of amphibole are seen in one specimen, and from T. 44—R. 3W. westward the quartzite commonly assumes a mottled appearance. These mottles are greenish colored areas up to a quarter of an inch in diameter or sometimes occur in the form of irregular, discontinuous bands or lenses. These greenish areas are usually surrounded by colorless quartzite. They are segregations of ferromagnesian impurities, chlorite and radial amphibole, lying in the interstices between quartz grains.

In T. 44—R. 5W. the Palms is intruded by basic and granitic igneous rocks. Here the massive quartzite is amphibolitic but not mottled, and where in contact with the granite is cut by veins of red feldspar, which evidently fill fractures. Specks of this red feldspar can be seen disseminated in the quartzite.

*Metamorphism in the Palms.* Induration or the compacting and cementing of the unconsolidated sediment into a hard coherent rock was the first change developed in the Palms formation. In the conglomerate this induration was accomplished by silica binding the fragments together, and in the development of mica and chlorite from the clayey material deposited around the fragments. In the coarse fragmental beds of the quartz slate the induration has followed much the same lines; in some beds silica acts as cement, while in others the original clayey material has been changed to a micaceous mass which incloses the fragmental grains. The blackish slaty or shaly beds were probably deposited as a mud or clay made up of very finely fragmental material, kaolin, and colloids. In their induration there has been a development of sericitic mica, some chlorite, and chert, with probably a loss of water, and hence a decrease in volume. The massive quartzite at the top of the formation shows cementation by silica and secondary growth of quartz grains. Impurities, probably ferromagnesian material such as chlorite, lend a drab color to some of the quartzite, and iron oxide infiltration from the overlying Ironwood formation stains the upper portion of the quartzite red, particularly so in the eastern district. Carbonate occurs in these well compacted beds from the base of the formation upward, but whether as an original or secondary mineral cannot be said. Some little magnetite is also present.

In addition to induration, dynamic forces have had some effect. These dynamic forces have caused the Palms formation, in conjunction with the other Huronian and Keweenawan formations, to assume a steep monoclinal dip to the northwest, have caused both longitudinal and transverse faults, and in T. 44—R. 4W. and the western portion of T. 44—R. 3W. have caused drag folds to be superimposed on the monoclinal structure. In conjunction with this minor folding schistosity has been developed in some of the slaty beds and fracture cleavage is often seen in these least resistant beds. The coarser fragmental beds appear to have been more competent and the differential movement caused by the stresses set up was effective only in the less competent argillaceous beds. Just what mineral changes can be assigned to dynamic metamorphism in the Palms other than the development of mica cannot be said.

A still further anamorphic change is that of heat, or in a broad sense, contact metamorphism. West of Mineral Lake, basic and acid igneous rocks of Keweenawan age intrude the Ironwood, Palms, and Bad River formations. It is in the vicinity of these intrusives that the greatest folding is seen in the Palms. This suggests that the dynamic forces which produced the folding of the formation in T. 44—Rs. 3, 4, and 5W. were accompanied or followed by intrusives. It is also in the vicinity of these intrusives that minerals are found in the Palms formation which are not common to sedimentary rocks unless they have been subjected to contact metamorphic action. An amphibole in radial fibres and tufts is the most common of these minerals, although some garnet is also found. This amphibole occurs mainly in the massive quartzite at the top of the formation. The greenish mottled quartzite found commonly at the top of the formation in T. 44—Rs. 3 and 4W. seems to owe its mottling to the segregation of ferromagnesian minerals as interstitial growths between the quartz grains. The minerals occurring in these mottles are amphibole and greenish chlorite. Around these spots, or irregular bands, as is sometimes the case, is usually a colorless quartzite. It appears that the greenish impurities have been drawn from these colorless areas by the higher temperature environment induced by the intrusives, and segregated or concentrated in these dark spots and bands. In T. 44—R. 5W. the quartzite is not mottled but seems to be uniformly filled with minute fibres of amphibole. The most easterly known occurrence of amphibole in the Palms formation is in T. 44—R. 2W.; hence the contact effects of the intrusives must have extended this far east in the Palms and probably farther. The gradual increase in magnetite from the Potato River westward, and as it increases, the corresponding gradual disappearance of carbonate, suggest that these compensating changes are in some way related to the contact action of the Keweenawan intrusives out to the north, either as injected material, or as is more probable, recrystallization of iron originally in the rock as oxide and carbonate into magnetite. This increasing abundance of magnetite progressing westward along the formation is the only striking effect of the intrusives shown in the quartz slate and the conglomerate.

*The Contact with the Ironwood.* The Palms is succeeded by the Ironwood. The most striking observation along the contact is the abrupt appearance of chemically deposited chert and iron carbonate following the deposition of the coarse quartz. This is sufficiently impressive immediately to engender the idea that the coarse clastic deposition and chemical precipitation must have been separated by long continued fundamental changes of environment. In other words, one is prompted to speculate upon the probability that the Palms was long exposed to the atmospheric conditions, eroded, silicified, and thereby indurated into a quartzite, before the environment conducive to chemical deposition could be organized. This phase of the problem bears upon the origin of the Ironwood. Suffice it to say here that the view to which the writer inclines is that the Ironwood was deposited from magmatic contributions which were introduced into the basin catastrophically and not through the medium of the normal surface agencies. There is no divergence of strike or dip. There are no conglomerates. The silicification of the top of the Palms could well have taken place when the Ironwood and the Tyler were thoroughly silicified at a later date. There is no phase of the observations which one can make along the contact of the Ironwood and the Palms quartzite which coerces one to the belief in an unconformity, either due to intervening erosion or lapse of deposition. The strongest direct evidence of continuous deposition is the fact that the lower 5–10 feet of the chemically precipitated Ironwood are characterized by an admixture of clastic quartz grains to all intents and purposes identical with those of the upper Palms. These are admixed with the chert of the Ironwood. In short, there is here a bed which partakes of the most diagnostic characteristics of both the contacting formations and it shows very clearly the gradation from the one to the other.

The most fascinating features observed in the Palms are (1) the lack of any degree of classification of the sediment of the lower part (90 per cent); (2) the clear evidence of almost perfect classification of the quartzite forming the upper 50–60 feet; (3) the invariable presence of this quartzite below the Ironwood; (4) the uniformity in thickness of the formation as a whole and of the quartzite over shorter intervals; (5) the gradual thickening to the eastward, which is comparable to the behavior of the Ironwood; and (6) the lack of chert and carbonate below the beds of gradational change and the presence of the quartz grains for at least a short distance up into the Ironwood.

The environmental conditions under which the Palms was deposited have been discussed at length in connection with an outline of the origin of the Ironwood in Chapter VII.

### *The Ironwood Formation*

The Ironwood is the iron-bearing formation of the series and the only one suspected of immediate economic importance in the district.

This formation is one of a number of iron-bearing formations which have made the Lake Superior region the largest iron producing region in the world. The group has certain characteristics not common in formations of more recent geological periods. They present problems, therefore, which cannot be attacked by observing present day processes. The rocks themselves are unlike any of the more common formations. They are chemical precipitates with but a nominal amount of only the very finest of clastic material. They were accumulated in a body of standing water, without the slightest doubt, but they are entirely outside the common classifications which include sandstones, limestones, and shales. Only in the sedimentary structures of certain special beds are they like or similar to any of the ordinary geological formations. In composition, texture, structure, mode of weathering, and response to changing environment, they are unique. On account of these various singular characteristics, the problems are extremely difficult to handle, and in any handling, while observational facts remain fixed, significance and interpretations vary according to the views of the geologist.

The formation is composed of quartz and iron minerals, with a ratio put roughly at 65 per cent quartz and 35 per cent iron minerals. It is a bedded formation and one bed is marked off from its neighbors by reason of a variation in the proportion of these minerals, by reason of differences in the size of grain, of the organization of the minerals, or differences in the structure of the bedding.

The quartz which constitutes so large a proportion of the total mass is not in the form of sand grains. It was initially clearly a precipitate from solution. It is of variable character texturally. In some specimens the texture is so fine as to lead to the opinion that it is isotropic and the X-ray is necessary to prove its crystalline structure. In other specimens it is so coarsely crystalline as to be distinguishable with the naked eye. In many specimens all grades of texture are intermixed. These varieties are all grouped under the general name of chert.

The iron minerals may be carbonate or oxide, either hematite, limonite, or magnetite, or they may be silicates. The particular iron mineral present is somewhat closely correlated with the texture of the quartz. Thus, the uniformly coarsest texture is always associated with the silicates, and usually has magnetite and hard blue hematite in association. The most dense-textured quartz (chert) is associated only with carbonate. When soft hematite and limonite are present, the quartz is of variable texture. These facts follow because the carbonate was the dominant original mineral representing the iron content and because the original quartz antecedent was an amorphous precipitate, or gel. The coarse texture associated with the silicates reflects the process of recrystallization. The mixed or variable textures associated with the soft hematite and limonite indicate solution and redeposition by percolating, oxidizing, surface waters.

The beds are marked by variation of the proportions of the quartz and iron minerals. On this basis there may be distinguished two main varieties of beds, those richest in carbonate with an admixture of fine quartz, and those dominated by chert with admixed carbonate or other iron minerals. These two types are respectively the cherty iron carbonates and the ferruginous cherts.

Another distinction between the beds is the organization of the minerals. These differences correlate with the proportions of the minerals just described. Thus, in the ferruginous cherts the silica (quartz or chert) is commonly organized into tiny, pin-head sized units usually referred to as "granules" or "oolites". In the cherty iron carbonates these are positively *never* found.

Correlating again with the proportions of minerals is the structure of the bedding planes. Thus, the cherty iron carbonates are characterized by smooth, straight, regular bedding planes. The ferruginous cherts are bounded by extremely irregular or wavy bedding planes.

Furthermore, the wavy-bedded, highly siliceous, ferruginous cherts with the oolitic texture are thicker bedded by far. The average thickness of these beds is of the order of 3 inches but varies from 1 inch to several feet. The cherty carbonate beds are of the order of an eighth of an inch in thickness.

*Stratigraphy.* These two types of rock alternate with one another on both a small scale and a large scale. The thick, wavy-bedded, coarse-textured, ferruginous cherts are separted by thin groups of the thin and even-bedded, fine-textured, cherty carbonates. There are considerable thicknesses of such alternations which alternate with comparable thicknesses of repeated cherty carbonates. Such thicknesses as the latter seldom contain more than an isolated bed of the thick, wavy-bedded, coarse-textured ferruginous chert. Instead they are alternations of very thin sheets of dense chert, sheets of carbonate of comparable thickness, or sheets of mixed chert and carbonate. On the basis of the proportions of the two types of formation the entire Ironwood has been differentiated by Hotchkiss into 5 members.[1] The first, third, and fifth members are dominantly of the heavier-bedded variety. The second and the fourth are dominated by the thin and fine-textured carbonate. The sequence from top to bottom is indicated in the following column.*

These major divisions are evidently more or less continuous and more or less uniform in thickness along the range. However, there are still finer subdivisions which may be distinguished. Thus, the Plymouth generally has a base of massive red chert or jasper of the order of 5–10 feet thick and characterized by a gnarled or knotted structure. It is succeeded by a comparable thickness of the thin-bedded carbonates. These are recognized in the course of exploration as the "foot conglomerate" and the "foot slate" respectively. The succeeding beds of the Plymouth are the heavy-bedded chert and they are separated by thin groups of the carbonates. Toward the top of the member, the bedding becomes thinner, carbonate richer, and finally it gives way to the base of the Yale, which is dominantly the carbonate type. However, the Yale contains 3 such subdivisions characterized by the cherty iron carbonate alternating with ferruginous cherts, and the uppermost of the cherty iron carbonate subdivisions is succeeded by the Norrie member, which is almost exclusively of the ferruginous chert variety. This in turn is succeeded by the Pence "slates" or thin-bedded carbonates. The Anvil is a composite also. The base is analogous to the main Plymouth and the Norrie, that is, it is ferruginous chert, but the top is the thinner-bedded or "slaty" type.

Thus it is evident that the two types alternate upon a small and a large scale. From one point to another the alternations may vary. Thus the foot conglomerate may be thicker in one cross section than another, and the foot slate may be of considerable thickness in one cross section and a mere marker in another. However, within reasonable distances there are not great variations in the

[1] Engineering and Mining Journal, Sept. 13, 20, 27; Oct. 4, 1919.

* See Stratigraphic Column, p. 159.

| | |
|---|---|
| Anvil | Ferruginous chert |
| Pence | Cherty iron carbonate |
| Norrie | Ferruginous chert |
| Yale | Cherty iron carbonate |
| Plymouth | Ferruginous chert |

sequence. On account of the fact that the sequence in Wisconsin is in detail different from that encountered many miles east in Michigan, the hypothesis which postulates that the two types of formation reflect variation in sedimentary environment becomes complicated. But the hypothesis herewith presented, which postulates that the two types reflect a difference in the concentration of the solutions from which the precipitates were thrown down, readily accounts for the variation in the sequence. In brief, the thin-bedded carbonate slates represent the type of precipitate forming continuously, while the chert beds represent more direct emanations from a magmatic source through vents located along a zone of fissuring. The hypothesis is developed in detail in Chapter VII.

The total thickness of the Ironwood is about 650 feet in Wisconsin. The Plymouth member is around 150 feet thick, the Yale about 135, the Norrie around 100, the Pence around 135, and the Anvil around 120. In Michigan the entire thickness becomes greater and the individual members show corresponding increases.

Figure 13 shows graphically the results of a series of specific gravity determinations on diamond drill core from a hole in T. 46—R. 2E. The entire core had been reduced to supposedly representative specimens in the ratio of 1 foot to every 5 feet of boring, or in some cases 1 foot to every 10 feet of boring. The sample for each thickness of boring represented consisted of fragments varying in length from the order of half an inch to 1½ inches. Each composite sample was weighed in air and then under water and the specific gravity computed from the weights. The results

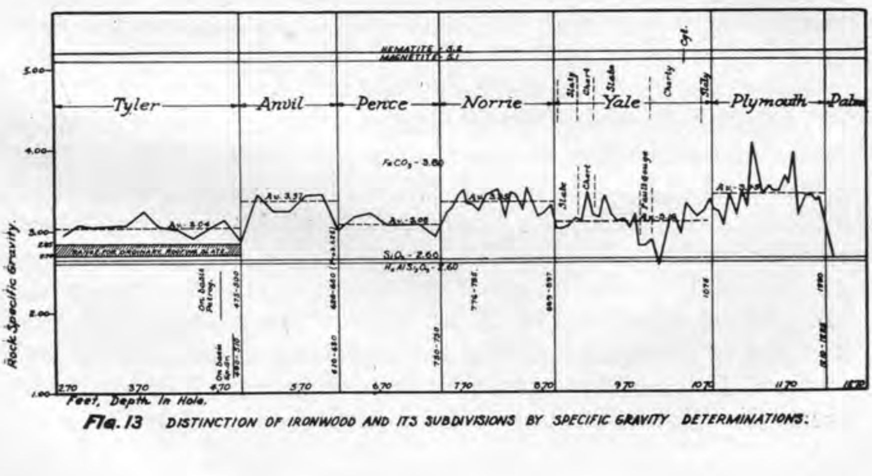



FIG. 13 DISTINCTION OF IRONWOOD AND ITS SUBDIVISIONS BY SPECIFIC GRAVITY DETERMINATIONS.

show that on this basis the formation may be differentiated into the 5 members even more strikingly than on the basis of petrographic study. They show also that as a group the ferruginous cherts are of greater gravity than the carbonates. This is probably due to the fact that the cherts are invariably more intensely oxidized than the thin-bedded carbonates. The results also show that the cherts and the carbonates vary only slightly in net average specific gravity. Thus the cherts of the Plymouth, Norrie and Anvil members have average specific gravity of 3.43, 3.35, and 3.37 respectively. The Yale, Pence, and the Tyler base have factors of 3.10, 3.08, and 3.04 respectively. The base of the Tyler is rich in carbonate and the iron oxides, which appears to account for the gravity values in excess of the usual figure for ordinary slates.

This diagram also reveals some evidence to confirm what is commonly observed in the field and underground, namely, that the slaty carbonate members are far less easily oxidized than the cherts. They are finer-textured, more impervious, and, spite of the fact that they carry abundant iron carbonate, they are universally less readily altered than the cherts.

*Structure.* The formation dips to the northwest at varying angles but in the productive sections at an angle around 65°. This monoclinal structure is simple from Montreal River to a point about 17 miles southwest, where a cross fault approximately at right angles to the strike passes through section 33 of T. 45—R. 1W. Here there is strike folding which is more or less prominant throughout the western end.

Relatively early in its history the formation was thoroughly fractured by a system of complementary joints approximately perpendicular to the bedding planes of the formation. The strikes of these at the time the formation lay horizontally were NE–SW and NW–SE. Subsequently many of these joints were injected by magma of intermediate to basic composition in the form of dikes. On the tilting of the formation to the northwest the intersections of these sets of dikes with the formation pitched to the northeast or to the west.

Subsequent to the injection of the dikes the formation was deformed by a longitudinal fault series. The most prominant of these lies in the middle cherty iron carbonate division of the Yale member. It is roughly parallel to the bedding and it dislocates the dikes. This fault has been located in probably all of the mines of Michigan west of Wakefield, and in all the mines in Wisconsin. It has not been located west of the Iron Belt mine, possibly on account of the scarcity of exposures of the Yale. Nevertheless, there is good reason to doubt that the structure continues far to the west of this point because, as stated above, just west of Tylers Fork the deformation was accomplished by rock flowage rather than by fracture.

*Metamorphism.* In examining the formation west of the Iron Belt one readily perceives a change in the character of the formation. The chert component becomes more coarsely crystallized. The proportion of carbonate decreases. There appear rosettes and tufts of silicate, a green mineral which in many specimens form a felty texture. At the same time there is an increase in the proportion of hard hematite, and as is made strikingly evident by the magnetic instruments, an increase in the proportion of magnetite. The formation is less and less reddened by surficial oxidation and becomes green. The density increases and hardness and toughness multiply, a fact made very real in attempting to take specimens. A short distance west of Tylers Fork there are to be seen the first of a number of close folds in the upper members. Dikes become very rare. And, the formation rises to the height of land reflecting its increase in resistance to erosion as compared to the adjacent formations. As will be shown in later paragraphs, the overlying Tyler responds in a similar fashion.

It is impossible to draw a line to represent where the formation first takes on this different character. The change is gradual and it appears that the resistant character carries on farther to the east in the upper horizons of the Ironwood than in the lower members. This view is based on the magnetic results, which show that in the vicinity of the Montreal Mine and the east, the magnetic attraction is strong only in the very uppermost horizon, that is, the Ironwood-Tyler contact. On proceeding westward from this point, the attraction extends farther and farther toward the base, until at Tylers Fork the footwall, which is to say the contact of the Ironwood with the Palms quartzite, is strong enough magnetically to leave nothing to be desired in the locating of that horizon.

The cause of this gradual change in the formation is approachable only by circumstantial evidence. There has been "work" done on the formation. It has been strike folded, which shows differential movement. The density has been increased indicating a reduction in volume. There has been recrystallization indicating an input of heat units. The only intensive deformation which can be seen in direct evidence was that which followed the outpourings of the Keweenawan lavas. The sole intensive contribution of heat accompanied the injection of the great laccolith of gabbro in the overlying Keweenawan lavas. It is, therefore, considered as the strongest probability that the distinctive character of the formation to the west is correlated with the late Keweenawan events.

As to the increase of these effects from east to west, it may be plainly seen from an inspection of the map, Plate I, that the intensity of the Keweenawan deformation was greatest in the west. That is, the amount of movement on faults and the amount of folding is greater in the west. Furthermore, the great array of intrusives is most voluminous and the "laccolite" of Keweenawan gabbro is normally thickest toward the west. The latter tapers to a sharp nose tangent to a line normal to the strike of the formation at a point just west of the Montreal Mine. Moreover, as the laccolite widens or thickens to the westward, its base carries more and more deeply toward the foot of the Keweenawan flows. At the nose the distance from the base of the laccolite to the Ironwood is about 4 miles. Six miles farther southwest along the strike it is only about 3 miles. Another 6 miles southwest it is only about 2½ miles. At Mellen the distance is only about 2 miles and west of there it decreases until at Mineral Lake it is nothing, the gabbro being in contact with the Ironwood.

The evident responsibility of the deformation and gabbro intrusion for the change in the character of the formation from east to west, and from the upper members of the formation on the east to the lower farther west, suggests that the intensity of the change at any point should be dependent directly upon some power of the measured distance between the base of the intrusive and the Ironwood. This, however, is complicated by the fact that the laccolite of gabbro is not of constant or even regularly varying thickness. The heat factor would be dependent to some degree upon the mass of the gabbro, of which the thickness would be a measure. Hence, the intensity of the metamorphism would be variable indirectly as the distance and directly as some power of the thickness. Thus a greater thickness at a greater distance would accomplish the same comparable results as a thinner portion at a less distance. The significance of these considerations is that the formation from the Montreal Mine to Tylers Fork is of increasingly less promise, that is, so far as the surface is concerned. If it were possible to determine in the dimension of depth the angular relation of the bounding plane at the base of the gabbro with the plane of bedding of the Ironwood, something could be said concerning the probable change in the intensity of metamorphism with depth. On the basis of the apparent structural character of the base of the gabbro, and the belief that such an injection would require a zone of weakness, it is deemed probable that the base of the gabbro is a thrust fault which dips at a more gentle angle than the Keweenawan lavas which it cuts. In short, if the Keweenawan and the Huronian formations were reconstructed, the base of the gabbro would be found to cut into older and older formations toward the west and in coming up the dip. Or, conversely, the base would ride higher and higher stratigraphically to the east and down the dip. On this basis the formation should be less metamorphosed at depth than in the surface. The significance of this is that, granting the validity of the idea, conditions conducive to ore making should be found at greater depth with increased distance toward the west. In other words, the planes of equal change in the formation strike at a greater angle north of east than the formation, and they dip to the northwest at a more gentle angle.

The deformation of the formation approaches a maximum west of section 16 of T. 44—R. 3W., where drag folds with axes striking 10°–15° east of north occur in conjunction with a decided flattening of the monocline. At Mineral Lake an apparently similar fold has been broken and the west limb appears to have been overthrust to the east. Here the gabbro has gained access to the Ironwood and occupied the break in the fold.

*The Extreme Western End.* West of Mineral Lake there is a gap in the exposures of the formation extending to section 23 of T. 44—R. 5W. The Gogebic Range as a topographic feature comes to an end at Mineral Lake. The gap is bridged, however, by the magnetic characteristics of the formation, which also demonstrate the same sort of structure as seen in the exposed drag folds just mentioned. The situation on this west end is covered in detail in Chapter VI. The formation is exposed only in a patch in section 23, T. 44—R. 5W. Another gap then ensues as far as section 16 of the same township, where the formation once more appears in a pair of ridges extending from the center of 16 southwest to the northeast of 19 near Atkins Lake. The pair of ridges are apparently separated by a sill-like intrusion of gabbro. In fact, gabbro can be seen almost everywhere. The southern ridge is underlain by the quartzite of the Palms. The Plymouth member is present and the lower slate of the Yale can be detected in several places. The lower Norrie is also apparently represented. In about this portion of the column the sill-like intrusion of the gabbro comes in and the formation forming the northern of the pair of ridges is slaty formation, probably representing the Pence or Anvil. The entire mass of formation is so completely cut through by the intrusives that there is no hope of finding ore.

In the township to the west, T. 44—R. 6W., there is heavy attraction along two or three lines which are indicated on the map in sections 24, 25, 26, 27, and 34. These lines have been correlated with a formation which is clearly sedimentary. There is, however, basic igneous rock involved, whose relationship to the structure of the sediment cannot be definitely determined on account of the meagerness of the exposure in the several test pits and small outcrops. In this section the magnetic attraction presents a pattern not like that met with anywhere to the east, unless it be that associated with the Atkins Lake exposure. It consists of three lines of attraction striking northeast and southwest, more or less parallel, but considerably contorted. These lines are separated from one another by several hundred paces and the intervening ground shows very weak, normal or even subnormal magnetic readings. If the strike of these magnetic lines be taken as the strike of the formation, which is a justifiable assumption since the exposures are seen to have a general northeasterly strike, and if the surface width of the belt of sediments be taken from the most northwesterly exposure to the southeasternmost line of attraction, it appears that this series is in excess of half a mile wide. With a northwesterly dip averaging around 45°, the thickness would be around 1800 feet. This is abnormal for Ironwood alone. Nor does it appear reasonable to consider sedimentation to have changed so radically in such short distances as between these exposures and those at Atkins Lake. Accordingly, although it appears that the section is abnormally wide for the Ironwood, it also appears that the same has not been thickened by the normal intercalation of other clastic sediments, or of tuffs, such as have been reported for the eastern end in Michigan. At Atkins Lake it is fairly conclusively shown that the two belts of Ironwood are separated by the intrusion of a sheet or a laccolite of gabbro. Furthermore, it appears that possibly the formation was split by a bedding fault along which the gabbro was injected. It is, therefore, considered that the Ironwood of T. 44—R. 6W. may be split apart by intrusions, or by faulting which may have brought sections of the Tyler into alternation with sections of the Ironwood. The width of the formation is abnormally great, partly on account of the inclusion of the Tyler formation, for the outermost exposure to the northwest is most likely of the Tyler slate. The exposures of Ironwood show a universal alteration of the original chert and iron carbonate to a belt of silicates apparently dominated by anthophyllite and indistinguishable in thin section from the basal Norrie of T. 45—R. 2E. It is, therefore, difficult on petrographic grounds to distinguish between altered slates and converted slaty iron carbonate. It is also possible that the Ironwood has been thickened by folding, but of this there is nothing that can be cited in evidence.

The points of significance in this township are that the Ironwood is present in considerable thickness, it is severely altered to silicate schists, and the Tyler is also present, at least in some force. The exposure identified as Tyler is at least one-fourth of a mile northwest across the strike from the nearest attraction. The magnetic intensity on the exposure is practically normal. It would appear, therefore, that there is a considerable thickness of the Tyler lying between the exposure and the attraction. Moreover, the same condition of normal attraction obtains northwest of the exposure of Tyler, in a direction across the strike for at least another half mile. The structure of this exposure was not observed, so that it is impossible to state whether it is located normally with respect to the Ironwood and not separated by significant convergence. It appears that the formation is folded in a broad arc concave to the southeast and having an axis striking in a general northwesterly direction. The Palms is not exposed but there is this very considerable thickness of the Tyler present.

*Contact with the Tyler.* The relationship of the Ironwood to the overlying Tyler is not clearly established. The reason for this is not far to seek because the contact is nowhere exposed. There are exposures of the two formations not far removed from one another, however, and these do not show divergence in dip and strike determination sufficient to suggest angular unconformity. Nor, in diamond drill core is there any suggestion of such a time gap between the two formations.

The base of the Tyler is characterized by an iron content represented by carbonate, or in the western end by magnetite. This iron content amounts to as much as 20–25 per cent through a thickness of as much as 150 feet.[1] It is as much as 15 per cent for another 150 feet and decreases from this to about 5 per cent. This carbonate may be of clastic origin, but since iron carbonate is one of the two outstanding minerals of the Ironwood it cannot be denied that its presence in the base of the overlying formation is strong argument in favor of the idea that this deposition continued for a considerable period following the resumption of clastics to form the Tyler.

In T. 44—R. 3W. diamond drill core shows that the uppermost 100 feet of the deposition of iron formation as represented by chert and iron carbonate was mixed with clastic material. For that particular part of the range, then, there is the very best of evidence of gradational relationships.

In spite of this undeniable suggestion and evidence, there are conglomeratic deposits at the contact between the two formations, at least in a few places and in drill holes. This conglomeratic horizon at the base of the Tyler has been considered as continuous enough by Hotchkiss to carry the name of a distinct member, the Pabst.[2] For descriptions of it the reader is referred to the articles cited. The writer has not had any opportunity to examine this horizon and has nothing to contribute to it specifically. In general, however, there is much that might be said concerning this conglomerate which may be present in some sections and not in others. This is only one of a number of similar "conglomeratic" horizons in the formation. The very basal portion of the Plymouth member is commonly of this character; there is another conglomeratic horizon toward the top of the Plymouth; between the Pence and the Norrie there is a third which is almost ever present and is known in the district as the "Middle Conglomerate"; then there is this at the base of the Tyler.

It is noteworthy that the conglomeratic beds invariably occur at the top of the thick chert depositions. This should be qualified by the statement that there are "pebbles" to be seen in almost any horizon, especially so north of or above the Middle conglomerate.

---

[1] Hotchkiss, W. O., Engineering and Mining Journal, Sept. 13, 20, 27; Oct. 4, 1919.

[2] Idem.

Just why these conglomeratic beds were formed at or toward the close of the deposition of thick cherts it would be well to know. Conceivably an answer to this question would bear directly upon their origin, and hence upon their meaning in the stratigraphic sequence. The writer is inclined to believe that the unusual character of the precipitate should influence one to be cautious in assigning to these conglomerates the sole origin of erosion, unless a definition of erosion be invented which circumscribes all possible modes by which an accumulation of discrete pieces of material can be produced. The writer is not inclined to the idea that these conglomerates were derived through the concerted action of waves and currents during a period in which the process of deposition was inhibited or suspended. Such would be the most simple explanation, and the most natural course to follow, but it is too conclusive.

Within the scope of the hypothesis covering the origin of the Ironwood, it is conceivable that the cessation of chert deposition is a marker of the temporary cessation of magmatic contribution; and it is hence conceivably a reflection of a mechanical stoppage of this emanation from the depths. Such a mechanical stoppage might be a shock such as an earth tremor, and accompanied by a tidal wave. A material such as has been postulated, a gel, subjected to such a shock would be jarred into "clots" or semi-solid "fragments." And the accompanying disturbance of the water would occasion a shifting of these "fragments" over the bottom.

This introduction of purely speculative considerations is induced in the interest of consistent adherence to the magmatic hypothesis of origin. In the event that the iron formation originated in a magmatic source, the terrain would be one of crustal instability. Consistent adherence to the major hypothesis would compel due consideration of the consequences of assuming a close approach of the magma to the surface. From another slightly different angle, the magmatic hypothesis advanced compels consideration of the probability that crustal instability instigated the return of clastics to the basin even before the iron carbonate had been entirely precipitated. Nor is it necessary to hold that the warping movements would bring the clastics over the iron formation uniformly. Whereas in T. 44—R. 3W., the clastics came in to intercalate with the chert and carbonate, it is easily conceived that the same beds of chert and carbonate farther east might be absolutely lacking in clastics.

The writer places greater weight upon the gradation of the clastics with iron formation in the west, and upon the high iron content of the base of the Tyler, apparently representing the gradation of carbonate deposition of the iron formation with the clastics of the Tyler, than upon the conglomerate which is of uncertain origin, of unknown significance, and is "known in few places except in diamond drill holes." [1]

*Development of Ore Bodies.* The development of iron ores in this formation has come about following the tilting of the formation to the north and the erosion of the cover rocks. The surface waters bearing oxygen have gained access to the more ferruginous beds. They have oxidized the ferrous carbonate to oxides and dissolved silica from the cherts. This produced an open, porous texture, and increased the opportunity for the propagation of the process through the opening up of the texture.

In the downward percolation of the waters impervious beds have been met, such as the several slaty members. These have served to concentrate the downward flow and to further the extraction of silica. They have also localized the oxidation of carbonate with the net result of blanket ore bodies on these impervious "footwalls," of which the outstanding one is the base of the Plymouth member.

At the same time, in the percolation and in the more concentrated movements on the "footwalls" the waters have encountered the impervious dikes. From what has been stated in above paragraphs, it should be clear that these dikes cut the bedding in such a manner that their intersections plunge not only downward, but either eastward or westward. Fig 32. Therefore, in moving down the dip, these surface waters are deflected by the dikes to either the eastward or to the westward, effecting a second degree of concentration. In other words, there is a more or less vertical percolation, a deflection of this and concentration on the "footwalls" and a deflection of these footwall movements into pitching troughs at the dike intersections. The more concentrated flow on the footwalls has produced thin blankets of ore upon them, but these generally thicken in the direction toward the dike upon which the ore also generally forms a layer. The net result is an ore body pitching downward and either eastward or westward and having a concave upper surface.

The above statement must not be construed to mean that this

[1] Hotchkiss, W. O., Engineering and Mining Journal, Sept. 13, 20, 27; Oct. 4, 1919.

is the sole mode of occurrence of ore or that all dikes are accompanied by ore bodies. For example, there are numerous instances of the formation of ore bodies in the zone of the bedding fault. There are many occurrences of ore in the form of "chimneys" apparently due to the presence of cross fracturing. When these

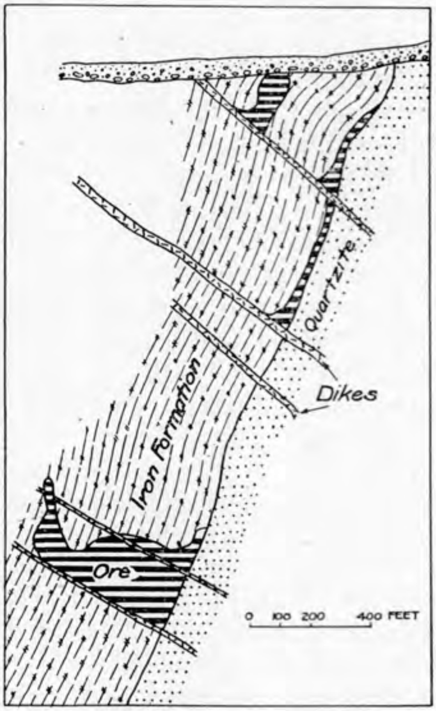



Fig. 32. Gogebic Range. Cross section showing relation of ore, dikes and foot wall quartzite.

erect bodies coalesce with the more common type of dike-controlled body, the aggregate is a huge concentration. Furthermore, there are innumerable instances of ore bodies developed underneath dikes, apparently due to the complete alteration of the dike rendering it permeable, to the dislocation of the dike by faulting, or to other means of leakage of the oxidizing waters through the dikes. Innumerable dikes are known which carry no ore, although oxidation has been intense. Failure of the waters to leach away the silica accounts for this. In other instances the dikes are considered to have been too thin, the waters to have passed through them. The dikes are in other cases said to have been too flat to have accomplished a concentrated flow, or too close to still higher dikes, the latter having protected the lower dikes from the concentrated flow.

In spite of the many exceptions, and the many other contributory factors, such as faulting, the great preponderance of the larger ore bodies owe their presence to the dikes and the oxidizing waters controlled by them.

The lack of ore deposits west of Tylers Fork and the unlikelihood that ores will be found there is made clear by the above outline of the process by which ores are formed. In this denser, decarbonatized, recrystallized portion of the range, the surface waters not only cannot readily gain access to the formation, but find the iron converted to the refractory magnetic oxide, the hard hematite or the silicate, and the quartz in a coarse texture with far less surface exposed to their solvent action. The evidence that this conversion of the formation took place in Keweenawan time was cited. There is no evidence that the Ironwood had been exposed to oxidation prior to the erosion which laid bare the upturned edges of both the Keweenawan and the Ironwood, and hence there is little chance that there can be concentrations of ore formed prior to the metamorphism of this end of the range and converted to the magnetic oxide or to hard hematite by that process.

The map, Plate I, shows the distribution of both the Ironwood and the Keweenawan formations. It shows that the great intrusives of Keweenawan age come to an end in T. 44—R. 6 W. The fact that the intrusives destroy any hope of finding ore bodies in their neighborhood raises the question of whether westward extensions of the Ironwood, beyond the reach of the influences of the intrusives, might not contain ores. This question cannot be satisfactorily answered until the more significant question has been met as to where the westward extension of the Ironwood lies. The maps show all that was ascertained concerning the westward extension. The formation is exposed in section 26 of T. 44—R. 6W., and the attraction associated was traced southward into Lake Namakagon. This is the last known. However, if it is true that the Keweenawan intrusives do not extend west of T. 44—R. 6W., and it is practically certain that they do not occur in the Keweenawan lava series west of that township, then if the Ironwood is in existence to the southwest of Namekagon, it should be free from the metamorphic influence of the intrusives, it should be either carbonate or highly oxidized and hence very weakly magnetic.

### *The Tyler Slate*

The formation above the Ironwood is the Tyler. It is commonly known as the Tyler slate, although it does not meet the requirements of secondary cleavage at an angle to the bedding. This formation is by far the major member of the Huronian series. Its thickness is around 10,000 feet, whereas the combined thickness of the Palms and the Ironwood is around 1,000 feet.

The Tyler is not coextensive with the Ironwood. The westernmost exposure is in section 26 of T. 44—R. 6W. This exposure is not extensive and it is impossible to give any highly precise estimate of its thickness or of its extent. However, from the measurement of the distance between the exposure and the nearest of a series of magnetic lines which correlate with the Ironwood, plus the distance through which the normal magnetic property observed over it can be projected northwest to the first magnetic evidence of the Keweenawan, it appears that there may be several hundred feet of this formation. In Ranges 4 and 5 west the formation is not exposed with certainty because the gabbro intrusives have gained contact with the Ironwood and so badly altered the formations that if Tyler were present it would be difficult to distinguish it from the Ironwood. There is good reason to believe that the formation is present immediately to the east of Mineral Lake, however, the same being that the base of the gabbro is removed from the top of the Ironwood by as much as half a mile. From this point as far as the Montreal River there is no break in the continuity of the Tyler, although there is extreme variation in surface width and thickness. The explanation of this variation in the thickness of the formation is reserved for a later paragraph.

The formation is nowhere exposed in a complete cross section. The more complete sections are found along river courses, particularly the Bad River, the Tylers Fork, the Potato, and the Montreal. From studies on these exposures, plus a nominal amount of work with thin sections, it can be said with certainty that the formation is composed of fragmental or clastic products representing the wasting of older formations that were long exposed to surface agencies of erosion. Quartz is ever present. Almost always feldspars are present. Chlorite or biotite are practically always represented; sometimes both are present in the same thin section. Muscovite is not rare. Iron carbonate or magnetite or both are abundantly present in many specimens which nearly always have been taken from the base of the formation. In T. 44—R. 3W diamond drill core across the contact of the two formations shows that in this gradational zone there is much chert, as well as carbonate mixed with the clastic material.

The proportions of these several minerals vary rather widely. Some beds are actual quartzites, for they are dominantly quartz rocks. Others are composed principally of feldspar and are arkoses. Others are dominantly chlorite, or are sufficiently rich in that mineral to give a distinctive parting and may be classified as phyllites. Perhaps the main body of the formation represents such a mixture as to warrant the name graywacke. In these the lack of bedding is not infrequently observed. At least in the lower 100 feet, but by no means confined to this section, there is a well developed thin and even bedding. This bedding is oftentimes emphasized by the color contrast of adjacent beds, the colors varying from green through straw yellow, to purple.

From east to west there is an apparent variation in composition which in a general way corresponds with the variation in composition of the Archean to the south. That is, between the Montreal River and Penokee Gap, the Archean is largely Kewatin greenstone schist. There are, however, patches of the intrusive Laurentian granites. West of Penokee Gap the Archean is granitic. The Tyler reflects the dominance of the one or the other of the Archean formations in that, west of Penokee Gap, the feldspars are so preponderent that it may be classed as arkosic.

*Metamorphism.* In the discussion of the Palms and Ironwood, it was pointed out that these change in character from east to west. The net effect of these changes is a much greater resistance to weathering. They are tougher, denser and harder formations in the west than in the east. No sharp line can be drawn showing where the changes have been accomplished. But it is clear that in following the formation westward grain becomes coarser, carbonate decreases, magnetite and specularite increase, and silicates become more and more abundant. These changes are summed up in the term "recrystallization." In a similar manner the Tyler reflects similar processes as reflected in similar ways.

In Range 2E. the Tyler lies in the broad valley between the Keweenawan and the Penokee ranges. See cross section, Fig. 14.

The formation is relatively soft; hence poorly exposed, and the profile shows a fairly smooth and regular curve from the summit of the Penokee to the foot of the Keweenawan along which the drainage is concentrated. There are two small hillocks in sections 30 and 31 of T. 46—R. 2E. upon which the Tyler is exposed and which are raised into prominence by reason of the fact that offshoots of the gabbro to the north have here found deeper avenues for injection. Similar conditions are found across Range 1 E. as far as the crossing of the Potato River fault. At this crossing the valley floor to the west is raised about 100 feet, and the topographic profile (see cross section, Fig. 15) shows a gentler slope from the summit of the Penokee ridge. There are numerous blunt hills in the valley which are capped by Tyler. This condition continues across Range 1W. The number of exposures increases, although not sharply. Across Range 2W. the rise of the region of the Tyler into the better drained character of land with drainage both at the south of the Keweenawan and at the north of the Penokee reflects this increase in resistance and also structural abnormalities. There are still greater numbers of exposures. In Range 3W. the Tyler is in contact with intrusive along the north. As far as Penokee Gap fault the intrusive is granitic. West of the Gap it is gabbro. At the fault, the Tyler floor to the west is raised from 100 to 200 feet. This western level is fairly constant at an elevation of 1400 feet above sea. At the fault, however, there begins a subordinate range of hills trending roughly east and west with the strike of the formation. These hills are cored by intrusives. On the east range line the Tyler is about 10,200 feet wide. On the west range line it is about half a mile wide and within half a mile farther west it decreases to zero.

This indication of an increasing resistance to erosion from east to west, the presence of intrusives and of folds in the valley tells the same story as that delineated in greater detail for the Ironwood. Recrystallization has increased the density, the toughness, and the durability. There is an increase in the proportion of magnetite in the base, as indicated by the magnetic observations. Furthermore, it is more strongly indicated that this change has been induced by the dynamic and igneous metamorphic agencies instigated in well advanced Keweenawan time.

*Contact with the Keweenawan.* The question of the relation of the Tyler to the overlying formations, the Keweenawan, once more introduces the element of controversy. As has been stated above, the Tyler varies in width. At or near Mineral Lake in T. 44—R. 4W. it is zero, the gabbro being in contact with the Ironwood. From this point it widens continuously as far as the Loon Lake-Mount Whittlesey cross fault. At the Montreal River, the surface width is again less than at the aforementioned fault. It continues to decrease in width farther east in Michigan. The question is whether this variation in thickness means the intervention of a long period of erosion.

Van Hise and Leith state, "The Keweenawan series reposes upon the Upper Huronian (Animikie group) unconformably. As the two series are nearly conformable in strike and dip, this fact was only slowly appreciated. The proof of the unconformity rests entirely upon broad field relations. In the central part of the district the Keweenawan is upon a great slate formation (the Tyler slate), which has a maximum thickness of at least several thousand feet. At the east and west ends of the district the Keweenawan cuts diagonally across these slates and comes into contact with the iron-bearing Ironwood formation. In the west end of the district this relation might be supposed to be explained by the intrusion of the Keweenawan lacolith, but this cannot apply to the flows. The time gap between the Huronian series must have been sufficient for a widespread orographic movement and deep denudation."[1]

This is, indeed, a clean-cut statement of the situation. Broad field relations show this tapering of the surface exposure of the Tyler to zero at Mineral Lake. But the flows of the Middle Keweenawan below the gabbro are also bevelled off as may be seen on Plate I. The gabbro does contact with the Tyler from Penokee Gap west. From Mellen to the Gap the granite comes into contact with the Tyler.

Nevertheless, from the Loon Lake-Mount Whittlesey cross fault as far as the State Line, the base of the Keweenawan is not confused by intrusives and is regular save for dislocations at cross faults, of which there are many. Here there are no discrepancies in either dip or strike between the Keweenawan and the Tyler. If the width of the Tyler at the Loon Lake-Mount Whittlesey fault be compared with that at the Montreal River, the ratio is as 1.466 : 1.000. If, then, the dips of the Tyler at the two extremes be taken, they are found to be as the average of 30° and 55° or

[1] U. S. Geol. Survey Mon. 52, p. 234.

42.5°, and 80°. The sines of these angles, to which, assuming constant thickness, widths should be inversely proportional, are as 1.000:1.457. In other words the ratio of the computed widths is less than 1 per cent smaller than the ratio of the observed surface widths.

This computation is indicative of a variation of surface width depending upon structural dip. It may be contended that the observed angles of dip are not true representatives. Of this there is a measure of justification because there is known to be a considerable amount of folding. But the same argument holds in contest of the idea of great erosion.

In the chapter on the Structure of the Huronian Series, the evidence is given in support of the fact that the entire series flattens in dip to the westward. There is, therefore, justification for the use of flatter dips at the west than at the east. If, discounted as may be, actual computations using observed dips at the two extremes indicate that the narrowing of the formation is not beyond the probability of structural explanation, at least for a strip of about 25 miles of a total of 65 miles, it becomes necessary to reconsider the evidence upon whose grounds the doctrine of marked unconformability is established. For the 20 odd miles farther west of the strip referred to above, there are strong evidences of thrusting preceding the injection of the gabbro and granites of the Keweenawan. It may have been this thrusting which reduced the thickness of the Tyler, and excepting broad field relations there is no suggestion of any erosion period. We have then fully 75 per cent of the strip of exposed formations devoid of any evidence of marked erosion between the two formations. The incontestable evidence of erosion lies on the eastern end in Michigan; and the sedimentary break in Wisconsin is indicated by the Lower Keweenawan conglomerates.

## THE LOWER KEWEENAWAN

Succeeding the Tyler between the Montreal River and Mellen is a series of sediments whose aggregate thickness is not over 100 feet at the most. It comprises conglomerates, arkoses, and quartzites. The conglomerate contains pebbles of quartz, quartzite, slate, and granular iron formation. It is only about 8-10 feet thick. Succeeding the conglomerate is a comparable thickness of quartzite. In turn, the quartzite is followed by about 6 feet of pinkish feldspathic quartzite.

In Monograph 52 of the United States Geological Survey it is stated, "At only one place in northern Wisconsin is the lower Keweenawan known to be exposed. This is in the southeastern portion of sections 11 and 12, T. 45—R. 1W., west of a small lake. At this point there is a considerable mass of coarse conglomerate, the pebbles of which are mostly white quartz, some of them being 8 or 10 inches in diameter. Flint and black hornstone pebbles are also plentiful. This conglomerate grades up into a coarse quartzite, and this into a fine-grained compact quartzite. Immediately to the north of the latter formation are the basic flows of the Middle Keweenawan, and 400 or 500 feet south of the conglomerate are Upper Huronian micaceous graywackes. The thickness of the conglomerate and quartzite exposed is probably from 300 to 400 feet."[1] To make the description more complete it should be stated that the sedimentation of these quartzites was interrupted by the outpouring of the first lavas.

The statement that as of the date of publication of the Monograph the Lower Keweenawan was known to be exposed in only one place can now be modified. Although the formation cannot be seen continuously, there are exposures at such frequent intervals along the appropriate belt to leave no question as to the presence of the formation all the way from Mellen, at least, to the Montreal River, which is a distance of 25 miles.

As stated elsewhere (Chapt. VII), it is the writer's interpretation that these conglomerates and succeeding quartzites represent the result of the surface manifestations of imminent vulcanism.

## Middle and Upper Keweenawan

The deposition of the arkosic quartzites and conglomerates was interrupted by the outbreak of basic lavas. These probably poured over the sediments from a source out to the north. For a time the lavas alternated with sediments, which indicates intermittent vulcanism. Within a short distance across the strike, however, the sediments come to an end and igneous rocks dominate the section for thousands of feet. The lava pile probably exceeded 20,000 feet in thickness. Individually the flows varied in thickness from a few feet to 100 or more feet. Texturally they varied widely, and in composition they ranged from extremely basic to highly alkalic.

Under the load of this material transferred to the surface, there

[1] P. 376.

was a down-warping as if to compensate. The ultimate situation is that formations dip steeply to the northwest along Montreal River, and less and less steeply along the strike to the southwest. This is interpreted to mean that tilting was initiated to the northeast, or that it was most rapid in that direction, or that it continued longer.

In the structural basin forming as a result of the downsinking, there was accumulated a tremendous thickness of sand, shale and conglomerate. These sediments constitute the Upper Keweenawan formations. They are intercalated between flows of lava representing Middle Keweenawan through several thousand feet. The most conspicuous of the first sediments is known as the Great Conglomerate. This is composed in considerable part of pebbles of alkalic extrusives. It is also associated with flows of similar composition. Incidentally, this fact, plus the very apparent deficit of alkalic flows as compared to the amount of such rock in the conglomerates, is taken as circumstantial evidence or suggestion that the flows came from a northerly source. On account of their probable greater viscosity, these alkalic flows made far less progress in their southward movement than did the basic lavas. Instead they were piled high, thereby increasing the vigor of erosive agents which transported their products to the south. This has been checked by observations of current cross-bedding in T. 44—R. 6 W. and by the occurrence there of andesitic flows occupying gulches cut in the conglomerate.

Following this most prominent of the first of the sediments, basic lavas once more reached surface in a series known as the Lake Shore Traps. These represent the last of the basic extrusives. Upon them are found in succession the Outer Conglomerate, which is from 800-1200 feet thick, the Nonesuch Shale, which is from 120-350 feet thick, the Freda Sandstone about 12,000 feet thick, the Eileen Sandstone, which is said to be 200 feet thick, the Amnicon Shale and Arkose, 5000 feet thick, and an upper group of sandstones aggregating 7000 feet in thickness.

With foundering of the basin, formations at depth were subjected to intense stresses which sought relief by differential movements. As noted above, it is concluded that in the beginning downsinking or tilting was most effective in the east. On this account, with formations holding to horizontality in the west, there were set up stresses of torsional warping. In Chapter VI this is developed more in detail. At a later stage, with foundering over the Lake Superior axis in the west, the structures developed by torsional warping produced complications leading to strong overthrusting. Coincidentally or subsequently the deepest of these were made available to the magmas of the reservoir from which the extrusives had come. These magmas were drawn in and made their way along the thrust which is called, in Chapter VI, the Crystal Lake-Atkins Lake-Keweenaw Thrust. It bevels the underlying formations.

The main body of this injection was gabbro. It is the thickest in the central map region, i. e. in Ts. 44, 45—R. 4W. It made contact with the Great Conglomerate on Davis Hill in T. 44—R. 6W., indicating that the injections were not concluded, at least, until well advanced Middle Keweenawan time, and probably not until much later, since extrusion would have ocurred had there not been considerable cover of Upper Keweenawan sediments.

The present volume is not the place for details of Keweenawan geology. Nevertheless, the events of late Middle Keweenawan time are evidently accountable for (1) the structural deformation of the Huronian, and (2) the metamorphism of the Huronian which has been so profoundly effective in destroying the amenability of the western Gogebic to the processes of ore-making and (3) for the explanation of the stratigraphic breaks of the Huronian succession.

# CHAPTER VI

# THE STRUCTURE OF THE HURONIAN SERIES

## INTRODUCTION

The completion of a study of the Keweenawan north of the Gogebic Range has revealed structural features which have a direct bearing upon the Huronian and which introduce a new factor into the structure of that series. Those who are familiar with the geology of this range and its literature will, possibly, question the justification for any additional views. Accordingly, the writer offers the following as qualifications.

1. A block of 75 townships has been examined in much greater detail than is commonly accorded an area of like size. In this area are the Huronian series on the south limb, and the Middle Keweenawan extrusives and later intrusives on both the south and north limbs of the Lake Superior geosyncline. Traverses have been run on all north and south lines, one-half mile apart, and all possibilities of finding exposures between the lines have been followed out. It is, therefore, held up for consideration that the volume of data forthcoming from such a systematic and detailed field examination is far greater than ever before has been made available.

2. On more than 5,000 miles of traverse, dip needle observations of the magnetic intensity were taken at regular intervals of one-fortieth of a mile. In the aggregate, therefore, there are more than 200,000 such observations. In a region where the ratio of the area of exposures to the total area surveyed is of the order of 1:100,000 it is significant that these magnetic data are available. They have been plotted upon the outcrop map made in the field. They represent a wide range of formations from the Kewatin to the Upper Keweenawan. They reflect as wide a range of structures. The interpretations have been drawn from the collective evidence of outcrops and magnetic data. From a background of 12 field seasons in the drift covered regions the writer maintains that the advantages accruing from his greater volume of outcrop

data are magnified many times by the overprint of magnetic observations.

3. An examination of the Ironwood formation alone, on a scale even more detailed than that described above, and supported by magnetic work in the same detail, has revealed significant facts concerning the structure of the Huronian not heretofore made available.

The writer has directed these surveys in the field, taken an active part in the collection of data, and has been alone in studying the results and drawing the conclusions to be presented herewith. This is of advantage in that the personal equation of a score or more of field assistants has been reduced to one and the familiarity with the numerous intimate relationships between the two series is of advantage in the study of each.

## Current Idea of the Huronian Structure

The structure of the Huronian of the Gogebic range, as it is generally pictured at the present time, is summed up in the following statement.

> " 'The Huronian series has a simple structure. It consists of water-deposited sediments, the origin of which has been for the most part determined. The rocks have simply been tilted to the north at an angle which is convenient for the determination of the succession of belts. They are without folding so marked that the belts do not follow in regular order from south to north. The series is terminated on the east by the unconformably overlying horizontal Cambrian sandstone, and on the west by areas in which it has been entirely swept away by erosion, the Keweenawan series coming directly against the southern complex. It is marked off from the underlying granitic and gneissic rocks on the south and the Keweenawan series on the north by great unconformities.' "[1]

The unconformity along the north of the Huronian, that is, between the Huronian and the Keweenawan, has been described as follows:

> "The Keweenawan series reposes upon the upper Huronian (Animikie group) unconformably. As the two series are nearly conformable in strike and dip, this fact was only slowly appreciated. The proof of the unconformity rests entirely upon broad field relations. In the central part of the district the Keweenawan is upon a great slate formation (the Tyler slate) which has a maximum thickness of at least several thousand feet. At the east and west ends of the district the Keweenawan cuts diagonally across these

[1] U. S. Geological Survey Mon. 52, p. 225.

slates and comes into contact with the iron-bearing Ironwood formation. In the west end of the district this relation might be supposed to be explained by the intrusion of the Keweenawan laccolith, but this cannot apply to the eastern part of the district, for there the lower beds of the Keweenawan are the surface lava flows. The time gap between the Huronian series and the Keweenawan series must have been sufficient for a widespread orographic movement and deep denudation."[1]

In the present paper, this statement of the structure is to be expanded. The folding west of Mellen is to be emphasized, and is to be related to the post Keweenawan deformation. The particular reason for this is that the detailed examination of the Keweenawan series has revealed structures very similar to those in the Huronian.

## Summary Statement

For the benefit of the reader, and hence as an aid in getting the ideas across, the writer submits the following points by way of a synopsis or summary statement. The major elements in the analysis of the Huronian structure are:

1. The deformation of the Huronian on the west end of the Gogebic is similar to that of the Keweenawan and is largely part of that which took place in late Keweenawan time.
2. The deformation was a part of that which produced the Lake Superior geosyncline.
3. The formation of this geosyncline was caused by the downwarping or foundering of the formations into the magmatic chamber whence the Middle Keweenawan lava flows had come.
4. The foundering took place at different rates along the axis of the main fold. It began earlier, or took place more rapidly, or continued longer, off to the northeast of the region under discussion.
5. As a result of the differential foundering, considerable movement having taken place to the northeast while the horizontal position was maintained to the southwest, warping under torsional stresses became effective.
6. One principal result of the torsional stresses was the development of two subordinate, oblique, structures on the south limb of the ultimate structure, a syncline striking slightly east of north (15°–30°) and a monocline or anticline immediately to the west and striking 60°–70° west of north. The comparatively complex

[1] U. S. Geological Survey Mon. 52, p. 234.

folding in the Huronian west of Mellen on the Gogebic was due to this early stage of deformation.

7. Simultaneously with the subordinate folding, the combination of torsional warping stresses and normal compressive stresses incident to the main synclinal development gave rise to strong thrusting up the dip. The Keweenaw Thrust of Michigan was initiated at this time. Its western extension has probably been found in Wisconsin, where it cuts steadily deeper into the series, first bevelling the Lower Middle Keweenawan flows, then farther west cutting out the Lower Keweenawan sediments, then the Huronian. This is apparently accountable for at least a part of the bevelling of the Huronian west of Mellen which was formerly believed to be due entirely to erosion.

8. Upon subsequent foundering along the main axis in the southwest, the development of the major structure was complicated due to the presence of the two subordinate, oblique structures. These latter inhibited the normal differential movements between the lesser units of structure, i. e., the individual beds or lava flows, and themselves functioned as the units releasing the compressional stresses by differential movement up the limbs of the geosyncline.

9. As a result of the accumulation of stresses in larger units of structure, failure took place on a correspondingly large scale. Whereas, in a normal syncline individual beds may move over one another through differentials of distance inappreciable excepting in the net result; in the present instance these differentials were integrated and the movement was great. The movement took place as a second series of major thrusts, of which the Lake Owen Thrust is the outstanding example.

10. During the period of control of deformation by the torsional warping stresses, tensional fractures were developed with a strike approximately normal to the axis of the minor syncline, or parallel to the axis of the anticline. On later adjustments, during the foundering in the region to the southwest, there was movement along these fractures, and the differential tilting took place, in part, by these fault block units.

11. The last stages of deformation were accompanied by, or followed by, the inwelling or injection of magmas along the Keweenaw thrust plane.

12. The inwelling gabbro domed up the hanging side of the thrust in the region between Mellen and Coffee Lake, and fairly well destroyed the subordinate syncline of the Keweenawan for-

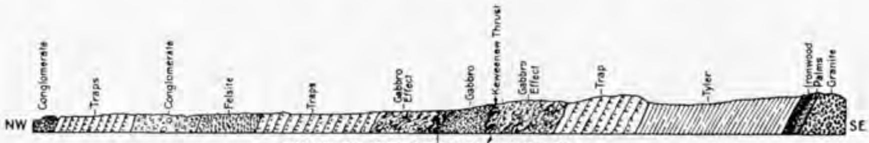
mations in that region. This whole region, however, was later more strongly upthrust, the anorthosite being cut through and upthrust differentially, with respect to the east side of Loon Lake Fault.

13. The final adjustment in connection with the ultimate foundering along the main synclinal axis took advantage of the several cross faults. Two of these, the English Lake—Brunschweiler Mountain, and the Loon Lake—Mount Whittlesey faults played leading parts. The intervening block in the region of the subordinate syncline was thrust southward and up the limb of the main syncline. With this relief of pressure the huge mass of porphyritic granite was welled into the complex which centers in this region. The earlier gabbro was thinned by the thrusting, and the Bad River thrust, whose strike is parallel to the axis of the subordinate syncline, probably experienced further movement at this time.

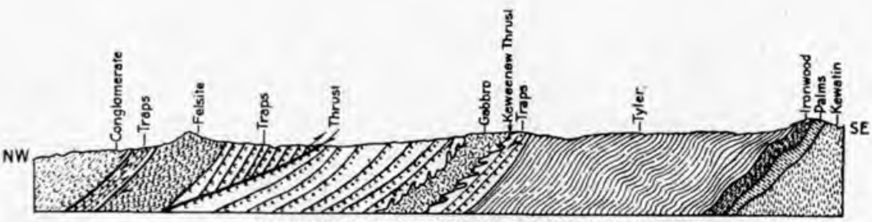
## REVIEW OF THE GENERAL PROBLEMS AND THE STRUCTURAL ELEMENTS

*East of Mellen.* Geologists at all familiar with the Huronian of this range are best acquainted with the region around Hurley and the country to the east and less so to the southwest. This region is also most simple in structure. They also know the Keweenawan best in the region north of the Gogebic, and between Hurley and Mellen. It is perhaps well, therefore, to start the development of the structural hypothesis with some observations in this region.

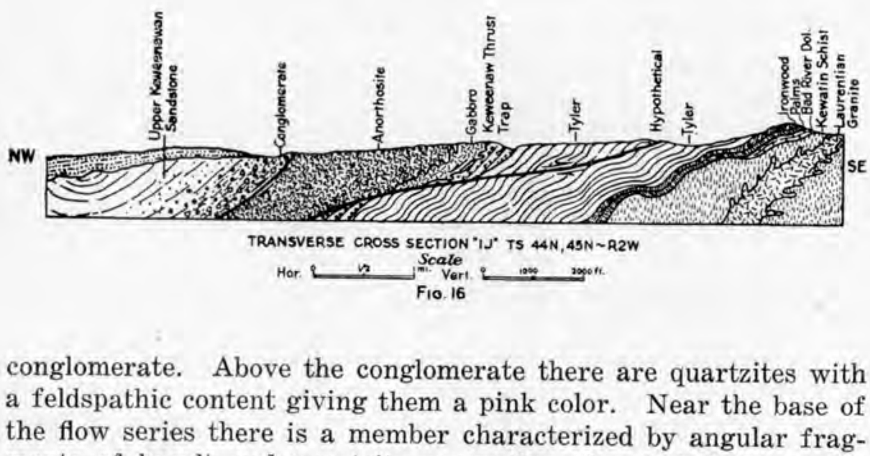
Between Hurley and Mellen, the Ironwood is known to strike northeast and dip to the northwest as a simple monocline. The overlying Tyler formation which is about 10,000 feet thick, has the same attitude. The basal flows of the Keweenawan conform in strike and dip with the Tyler and they alternate with sediment through a considerable thickness. As a first approximation, therefore, the conclusion could be drawn that the Huronian sediments gave way gradually to lava flows and the whole pile was then simply tilted to the northwest. (See cross sections Figs. 14, 15, 16) It should be noted, however, that about 200 feet below the basal lava flow there is a conglomerate about 8 feet thick. This contains chiefly quartz pebbles, but some slates and jaspillites. In the Tyler below, quartzitic rock is characteristic, and in this there are also pebbles of quartz in every way similar to those in the




TRANSVERSE CROSS SECTION, "MN" T-46N, R2E
*Scale*
Hor. 1 in = 1 mile Vert. 1/20 in = 100 feet
FIG. 14




TRANSVERSE CROSS SECTION "KL" T'S 44N, 45N-R2W
*Scale*
Hor. 0 1/2 1 mi. Vert. 0 1000 2000 ft.
FIG. 15




TRANSVERSE CROSS SECTION "IJ" TS 44N, 45N-R2W
*Scale*
Hor. 0 1/2 1 mi. Vert. 0 1000 2000 ft.
FIG. 16

conglomerate. Above the conglomerate there are quartzites with a feldspathic content giving them a pink color. Near the base of the flow series there is a member characterized by angular fragments of basalt and quartzite suggestive of a link between the sedimentary Huronian and the volcanic Keweenawan. It is succeeded by more of the quartzite before the first flow is encountered.

The presence of the conglomerate, at least, indicates a change in the source from which the sediment was derived. And although there is no proof of cessation of sedimentation throughout the stratigraphic section, this change in the source of sediment is indicative of a significant break in the sequence of events. It marks an unconformity. These sediments can be found at such closely spaced intervals, throughout the 25 miles of contact between Hurley and Mellen, as to indicate continuity. The first conclusion, that the sediments and flows succeeded one another, must be modified by the statement that some condition was introduced between the two series which changed the source of the sediment. This might mean that somewhere in the basin movements had taken place that exposed earlier members to erosion. In Michigan, at a point some 15-20 miles east of Hurley, it is apparent that the Ironwood had been eroded in this interval. Across this stretch of 25 miles west of Hurley, however, there is no known evidence of local erosion. If the width of the Huronian be measured at Hurley, and if the average dip be used in computing the true thickness, it will be found to be practically identical with the true thickness, computed in the same way just east of Mellen. So far as direct evidence here goes, therefore, there has been no bevelling in the horizontal dimension. Furthermore, the dip of the base of the lavas is always parallel to that of the upper Tyler, so that neither is there any evidence of bevelling in the vertical dimension.

*West of Mellen.* An examination to the west of Mellen reveals irregularities sharply in contrast with what is seen to the east. The Ironwood is well folded, though not so complexly that the belts do not follow in regular order from south to north. Across T. 44—R. 3W. are a number of folds striking N. 15° E.; they continue to show themselves in the east of T. 44—R. 4W.; and in the southwest of the last township they culminate in a major synclinal fold. West of this axis, namely at Coffee Lake, also at Atkins Lake and at Trappers Lake, the Ironwood reveals an anticlinal structure with suggestions of minor drag folds.

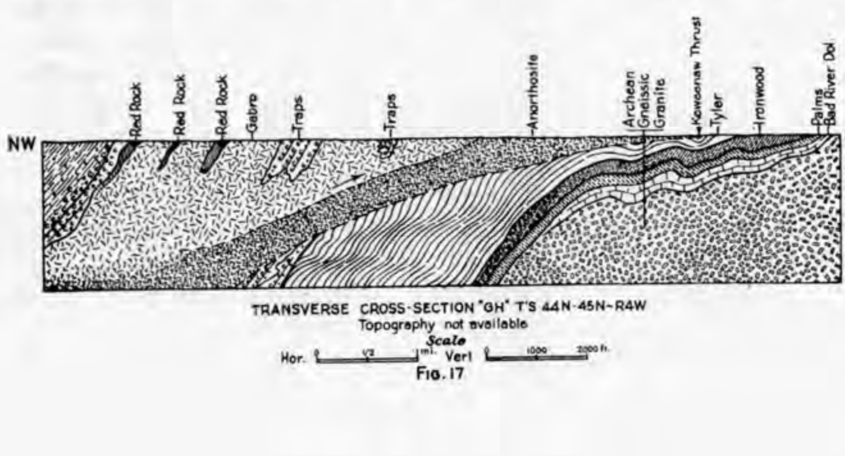
Immediately west of Mellen, the Keweenawan is represented by a large mass of intrusive granite, and observations relevant to the present consideration cannot be made. West of the English Lake-Brunschweiler Mountain cross fault, however, although complicated by gabbro intrusions, the Keweenawan lavas are again found. These, when followed westward, have at least a suggestion of the synclinal structure corresponding to what was seen on the Ironwood to the south. Still farther west, the Keweenawan lavas are folded into a clean cut anticlinal structure again corresponding to the anticline in the Ironwood to the south.

The first conclusion has, therefore, to be modified further. The series of sediments and lavas not only did not succeed one another without a break, but the tilting to the north was not simple. Instead, there was folding. Furthermore, the folding in both series is very similar. This suggests that the folding took place in post Keweenawan time, since it included the Keweenawan.

The Ironwood has thus far been employed as if it were representative of the entire Huronian series. So far as structure is concerned, this is probably permissable, but in connection with the question as to how long the period of unconformity continued, it is necessary to examine the Tyler.

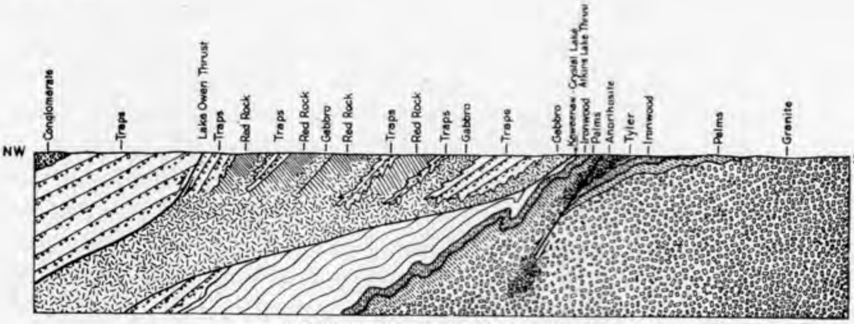
It is found that, beginning at Mellen, the Tyler is reduced in thickness from some 10,000 feet at that point to zero at the east end of Mineral Lake, some 8 miles west. Farther west, even the Ironwood and the Palms have been eliminated. These observations can be interpreted to mean that the unconformity was so long that the formations are missing through having been eroded away. This is the region too, where the Huronian is folded. The tendency is, therefore, to think that the folding was what accelerated the erosion. If this is a true conception, then the similarity of the Huronian structure to that of the Keweenawan cannot permit its explanation under a hypothesis based on the Keweenawan observations.

On further examination of the Keweenawan flows north of this belt where the Huronian is bevelled, it is found, however, that these formations too have been bevelled. But the bevelling has taken place at the base of the series, and not at the top. At Hurley, the lava series is found to be some 4 or 5 miles thick. The same series which has been folded into the anticline in the extreme west of the map area is also between 4 and 5 miles thick. But immediately north of Trappers Lake in T. 44, 6W. the same series is only about 2½ miles thick. The top of this series, consisting of the typical

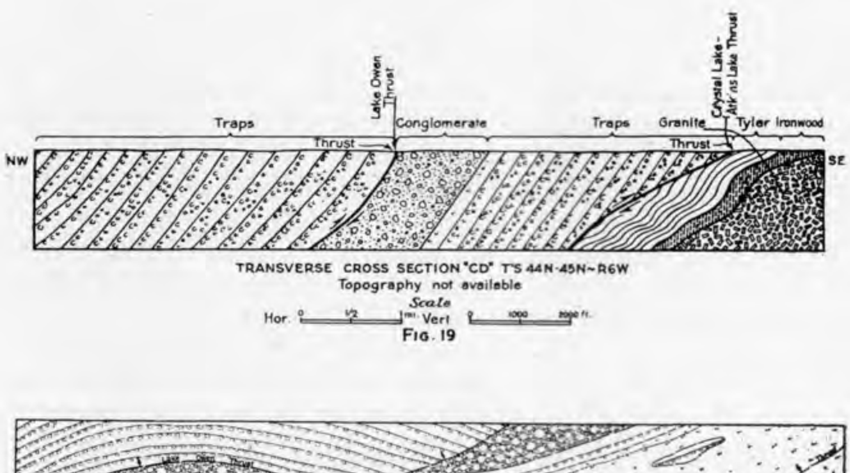



TRANSVERSE CROSS-SECTION "GH" T'S 44N-45N-R4W
Topography not available
*Scale*
Hor. 0 1/2 1 mi. Vert 0 1000 2000 ft.
FIG. 17

upper Keweenawan conglomerates, is in place. The bevelling of the base of the Keweenawan cannot be explained by erosion. Thrusting is the probable cause. (See cross sections figs. 17, 18, 19, 20).




TRANSVERSE CROSS SECTION "EF" T'S 44N, 45N–R5W
Topography not available
*Scale*
Hor. 0 — 1/2 — 1 mi. — Vert. 0 — 1000 — 2000 ft.
FIG. 18




TRANSVERSE CROSS SECTION "CD" T'S 44N-45N–R6W
Topography not available
*Scale*
Hor. 0 — 1/2 — 1 mi. Vert. 0 — 1000 — 2000 ft.
FIG. 19


FIG. 20 LONGITUDINAL CROSS SECTION "OP" T44N-Rs 4,5,6W.

This thrust can be followed from Crystal Lake in the south of T. 44—6W. north and east through Trappers Lake, Atkins Lake, and north of the Ironwood exposures north of Coffee Lake. From this point it swings more to the north of east across T. 44—R. 4W. and T. 45—R. 4W. as far as the English Lake-Brunschweiler Mountain cross fault, where it is cut off and the trap series gives way to the porphyritic granite or red rock. Throughout its course, the thickness of the overlying traps is of the reduced order. From Coffee Lake east, the thrust is bounded along the south by anorthosite. This is about 2 miles thick, and is bordered along its south by gabbro. It is the gabbro which makes contact with the Huronian. These anorthosites and gabbros are injections dating only from late Keweenawan time. If they are eliminated from the picture, then the northern traps will be continuously in contact with the Huronian along the surface which had been heretofore thought of solely as an erosion surface. Incidentally, the synclinal development of the Keweenawan would be more clear with these injections of gabbro, anorthosite, and granite out of the picture.

The necessity to conclude that the surface which bevelled the Huronian had been wrought solely by erosion is now seen to have been only apparent. There is an alternative hypothesis to entertain. This contact between the two series is on the one hand a thrust plane, and on the other an erosion surface. The problem at hand is to give weight to these two processes. The thrust could have accomplished the removal of the Huronian as well as the elimination of the base of the Keweenawan. The erosion could have been responsible only for the Huronian bevelling. It could, therefore, have accomplished part of the work, and the thrust could have done another part. There is no way to prove that the thrust is wholly responsible, although in considering the area farther east it will be shown that the probable eastward extension of this thrust very probably did accomplish at least a part of the Huronian bevelling.

In attempting to give weight to one or another of the two processes, the question arises as to why, with all the erosion, there is no trace of the products of the erosion, along the contact. The gabbro might be held responsible. Another question is why there is no trace of the 200 feet of lower Keweenawan sediments and conglomerates west of Mellen. One answer is that there was none of this sediment deposited west of Mellen and that it was the region whence the lower Keweenawan derived its sediment. The other answer is that the thrust eliminated the base of the middle Keweenawan, the entire lower Keweenawan, and then the Huronian.

There is apparently, no question about the fact that there is an unconformable relationship between the Huronian and the Keweenawan. However, the discovery of the thrust weakens the idea that this was a major break in this particular region. The writer is inclined to the idea that the break in the record which is evidenced by the conglomerate east of Mellen, was a relatively minor one, and was connected with surface manifestations of the approach to the surface of the Keweenawan magma.

*The Keweenaw Thrust.* In Michigan, along the south boundary of the Keweenawan series on Keweenaw Point, there is a thrust long since determined. This has never before been detected in Wisconsin. It has been projected westward to intersect the Wisconsin line in the northwest of section 3, T. 46—R. 2E.[1]

The probable westward extension of this thrust in Wisconsin has been discovered by the following line of attack. In the central part of the Keweenawan lava pile east of Mellen is a laccolithic body of gabbro. The base of this body cuts diagonally across the underlying flows. In other words, the gabbro bevels the underlying flows in such a manner that following westward these lavas are found to become progressively thinner. Just west of Mellen the lavas are finally reduced to zero. The general trend of this base has been projected north and east by means of the magnetic method. Although there are no exposures to bear this out, there is a continuation of the same type of attraction which accompanies the main gabbro mass. This projection apparently meets the supposed position of the Keweenaw thrust at the point to which it was projected by the Michigan geologists.

On general principles, it is considered that the gabbro laccolith would take advantage of a thrust plane as the line of least resistance in injecting itself into the lava pile. The apparent coincidence of the base of the mass with the westward projection of the Keweenaw thrust favors that assumption. So, also, does the observation that the base does not follow bedding but cross cuts it. The occurrence, at frequent intervals along the base, of rocks of fine-grained basic composition and schistose structure impregnated by platy plagioclases between the planes of schistosity, is taken as evidence of earlier thrusting. In further qualification of these

[1] Annual Report Michigan Geological Survey, 1909, Plate VIII.

rocks as evidence, it is cited that on the Douglas County thrust, which is a well established structure, there are rocks of identical description with the gabbro minerals injected along the schistosity. In the field, these rocks were designated as "basic injection gneisses." No such rocks have been seen elsewhere in the region than along these thrusts.

Upon the evidence thus recounted, it is concluded that the western projection of the Keweenaw Thrust has been found. This can then be introduced into the structural hypothesis being developed.

The point at which the Keweenaw thrust completes the process of bevelling the underlying flow is that at which the bevelling of the Huronian is begun. The contact between the Tyler and the granite here is along the projection of the base of the gabbro or the thrust. There is no reason to consider that the thrust ends here, and there is no other known course for it to follow. Along the contact between Mellen and Mineral lake there are breccias with the igneous rock forming the matrix. This is further suggestion that the contact was controlled by thrusting and followed by magmatic injection.

Here, as in the case of the Trappers Lake situation, the contact between Huronian and Keweenawan is on the one hand a thrust and on the other an erosion surface. It is not known, however, that there are any conglomerates along this surface such as one might expect in view of the deepness of the assumed erosion. The Lower Keweenawan conglomerates are gone, if they ever were deposited here, and an overthrust from the north could have carried them away. As before, the fact of an unconformity cannot be denied, but the presence of the thrust, in position to have accomplished all or any part of the elimination of both Keweenawan and Huronian, tends to discount the length of the time gap which is indicated in the commonly accepted description of this situation.

Up to this point, in two different areas, and with two distinctly independent lines of approach, we have come face to face with the probability of a thrust at the contact between these two series of formations, and in each case the thrust has major proportions. The question arising is whether these two thrusts may not be one and the same.

There can be no definite proof that the thrust at Trappers Lake is continuous with the one along the base of the gabbro to the east. Their position at the top of the Huronian suggests that they are identical. One line of reasoning favors such a conclusion. From the vicinity of the Ironwood north of Coffee Lake to the English Lake cross fault, the base of the Keweenawan traps is the anorthosite. (See fig. 17.) From the English Lake fault to the southwest end of Mineral lake, the top of the bevelled Huronian is gabbro about half a mile thick. The gabbro is succeeded by the anorthosite, which is about 2 miles wide. If the base of the traps and the top of the Huronian were in contact along the thrust plane and the gabbro, and later the anorthosite came in along that plane and domed up the overlying traps, we should have exactly what is found in the field. In other words, the base of the large injection is the foot side of the thrust plane, and it is the connecting link between the two thrusts that have been discovered. Then the Keweenaw Thrust of Keweenaw Point can be carried from horizons high up in the Keweenawan series in Michigan to low horizons in the Upper Huronian 150 miles southwest.

*Other Examples of Thrusting.* The Keweenaw Thrust just described is the outstanding example of thrusting in the map area. There are other examples, one in the western third of the area, the others in the eastern.

Across the north of T. 44—R. 6 W. there is a prominent ridge striking east and west. There are abundant exposures here, and they show Keweenawan traps standing on edge and striking east and west. The south boundary of these is marked by a steep escarpment. South of the escarpment is a valley suggesting the Tyler Valley over east. The south slope is more gentle. On this slope are exposures of typical Upper Keweenawan conglomerate with interbedded sandstones. Incidentally, these sediments are gullied, and in the gullies are andesitic flows. The strike of these sediments is about N.60°E. Their dip is to the northwest at an angle of 55°. Thus, the conglomerates and sandstones are in structural convergence with the traps to the north. South of the sediments are more traps, and these are conformable with the sediments. The northern traps have been traced in detail by the magnetic method, and they prove to have been folded into an anticline or arch which has already been referred to. The base of these has also been followed magnetically, and between it and the top of the underlying traps there is a belt of practically normal magnetic attraction. The strike of the structure of the lower series is always at an angle to that of the upper. This upper series has been folded and then, as a unit, has been upthrust over the conglomerate, which is probably the counterpart of the Great Conglomerate of Keweenaw Point. Lake Owen lies in the fault zone, and from it the structure has been named the Lake Owen Thrust.

In the eastern third of the map area, it is noticed that the formations converge toward a focus at Mellen. In the block just east of the Loon Lake-Mount Whittlesey cross fault, and immediately north of the thin gabbro lens, the traps have a strike approximately parallel to the Huronian contact. The next series of flows appears to have a steeper strike to the north, and to bevel across the end of the underlying series. Farther north, and just below the confluence of the Bad River with the Tylers Fork, there is an exposure which shows the conglomerate (probably the Outer Conglomerate, since the exposures down stream are all sedimentary) cutting across the Chippewa Felsite by means of a thrust. This is designated on Plate I as the Bad River Thrust. It is concluded from this that probably the overlap of other formations in this sector was brought about by the same sort of thrusting. The movement appears to have been up the dip, and to the east. This appears to have been part of the adjustment due to the oblique synclinal structure.

*Cross Faulting.* Excepting that cross faults have been referred to for purposes of location, these elements in the structure have not been considered. There are a number of them, and all strike more or less perpendicular to the strike of the formations. From east to west some of the more prominent ones are as follows:

1. West Branch of the Montreal. This is clearly marked in the footwall of the Keweenawan series, and it is probably reflected in the sag in the Ironwood through which the stream crosses the range. The exact location underground has not been determined, but there is an obvious change in the character of the formation between the Montreal Mine and the Ottawa Mine. There is much cross fracturing here but no pronounced dislocation.

2. Plumer Mine. This also is well marked in the offsetting of the footwall of the Keweenawan series. It is shown up in the magnetic work of the Ironwood and on the underground maps of the Plumer Exploration.

3. Potato River or Upson. This fault is clearly shown in the Ironwood and was described many years ago. It is even more clearly shown up in the offsetting of the base of the Keweenawan just east of Little Lake. The gabbro also reflects its crossing.

The floor of the Tyler Valley, west of this fault, is higher by about 100 feet.

4. Tylers Fork. This is perfectly shown in the offsetting of the base of the Keweenawan. It produces an offset in the gabbro, and well up in that formation a large dike apparently occupies its course. The fault is not particularly well shown in the Ironwood, although the gap in the range through which the stream flows is just west of the break.

5 & 6. Loon Lake-Mount Whittlesey and Reservoir Faults. These two faults form a block across Ironwood, Tyler, and Keweenawan which is distinctive. (See fig. 16.) In the Ironwood, which contains the property known as the Berkshire Mine, the formation is more strongly folded by differential movements up the dip than is to be seen at any other point along the range. In spite of this, the formation on either flank is not markedly deformed. In the footwall member there is a synclinal fold pitching to the west. The high point in this block is Mount Whittlesey, one of the highest points in the state. The Tyler block is well set out topographically. This formation is narrowed appreciably. The footwall of the Keweenawan, within this block, is set south by more than a quarter of a mile, showing strong movement from the north or down the dip. This, plus the folding in the Ironwood, and the narrowing in the Tyler, are all believed to be related to the strong, up-dip thrusting and folding. The foot of the Keweenawan lavas is only about a quarter of a mile wide. The gabbro north of it is also about the same width, whereas, on either flank it is more than a mile wide. This, again, gives the impression of a "punching" upwards from down the dip. To complete the impression, the gabbro is succeeded on the north by a block of anorthositic gabbro, which is without connection on either flank. It would appear that this had been literally forced up the dip through a die into the place formerly occupied by the gabbro. This also correlates with the the observations in the formations to the south. The conglomerate and the thrust at its base are projected southwestward from the last exposure upon the felsite, across the path of the Loon Lake fault, and as far as the Reservoir fault, even though no exposures were seen. It cannot be carried farther because of granite outcrops west of the Reservoir fault. The movement along the thrust was a rotary one, the axis being off to the northeast. Thus there was an up-dip component of movement from the northwest to the southeast at all points on the thrust plane southwest of the axis,

and as may be readily seen, such movements become greater and greater as one progresses toward the southwest. Because of this, and because of the fact that the lower formations in the fault block under discussion were subjected to the strongest up-dip movement of any block, these two strong up-dip movements were deemed to be related. In this connection it is to be pointed out that on the property of the Berkshire Mine, which is on the Ironwood within this fault block, there are a great number of huge blocks of Keweenawan conglomerate. The number and size of these are greater than is to be found anywhere along the range,. The extraordinarily strong thrusting within the fault block is considered to be the reason for these great conglomerate blocks. In other words, their presence in this particular place tends to confirm the idea that the conglomerate probably passes through the Loon Lake fault and as far as the Reservoir fault.

A summary of the observations within this block is as follows. Within this block there was the greatest amount of up-dip movement; the block lies at the focus of the convergence of the formation to the east; it lies approximately at the point where the folding in the west ceases; it also lies at the point where at one and the same time both the bevelling of the flows east by the Keweenaw thrust and the bevelling of the Huronian, probably by the same thrust, respectively ends and begins. In other words, it has the appearance of lying in the cross section of maximum torsion. In this there is probably the answer to why the folding in the west ceases so abruptly, why the bevelling of the Huronian is so abrupt, and why in general the formations in the east with their regularity of structure contrast so sharply with the irregularity in the west.

7. Penokee Gap. This, too, is well known in the literature. It was first described by Col. Charles Whittlesey. It is, in reality, a broad zone of dislocation, or a series of cross slices, which is probably true of most of these faults. Its course is well shown on the topographic sheet, even well out into the Keweenawan. It is to be noted that at the contact between the Huronian and Keweenawan this fault divides granite on the east from gabbro on the west. The Tyler valley is elevated on the west side of the fault.

8. English Lake-Brunschweiler Mountain Fault. This is best seen in the Keweenawan. Brunschweiler Mountain is the landmark in sections 14 and 15, T. 45—R. 4W. The fault is marked by a strong escarpment plainly visible from State Trunk Highway 13

in its course south of High Bridge. It divides the complex of traps, gabbro, and red rock in the north, and anorthosite on the south, from the porphyritic red rock on the east. Even were there no exposures in the vicinity, a thrust would be called for by the magnetic observations. The complex on the west is highly magnetic, while the red rock is without expression. The course of the fault is marked topographically in the Tyler and Ironwood. The amount of offset in the Ironwood is not great, and a fault would not be established on these grounds alone. But the magnetic attraction comes into service here. On the east the width of the belt of attraction is much narrower than on the west, and on the west the dip of the formation becomes much more gentle to account.

9. There is apparently one more fault on this end which strikes northwest from the northeast end of Mineral Lake. It offsets the Keweenawan markedly, but it is not clear that it passes through the Huronian.

Many other cross faults are shown on the map, and others are known to exist but cannot be traced completely through Huronian and Keweenawan. There are several at close order along the main Montreal River. These have controlled the course of that stream. The faults, in general, are without exception shown up in the magnetic work; in fact the magnetic method is responsible for the first clue to faulting in every case. There is not the slightest question about their crossing the footwall of the Keweenawan. In fact, most of them can be shown to cut well into the central pile. Some cut through the gabbro, and the Penokee Gap fault apparently cuts the granite porphyry. There can be no doubt, therefore, that they are one and all of post-Keweenawan age.

The most interesting thing about these cross faults has been shown up on the graphical plotting of the magnetic attraction. The attraction over the Ironwood forms a belt parallel to the formation but of greater width. The footwall, as indicated on the magnetic chart, is exact within a foot. The underlying formations are without expression. The Tyler is similar. But the attraction due to the Ironwood carries out over the Tyler for a considerable distance. This is because the dip of the formation carries it out under the Tyler. If now, on a series of north and south traverses across the formation at intervals of half a mile, we mark the footwall points, and also the points out over the Tyler where the attraction finally gets down to zero, we find these form two parallel lines. At least, over short distances they are essentially parallel. The distance between the lines is the width of the magnetic belt. The width of this belt increases to the westward. There are two very good reasons for this. The first is that the gabbro out in the Keweenawan has metmorphosed the Ironwood, and magnetite is one of the principal products of the metamorphism. Hence, as the gabbro approaches closer and closer to the Ironwood from east to west, the amount of magnetite increases. Hence, the greater volume of magnetite will have its effect at greater depths than a smaller volume. The horizontal projection of this greater effective depth is a greater width. The other reason is, that the dip is gentler in the west. With gentler dip the magnetite is not so rapidly carried beyond the "feel" of the dip needle, and hence the belt is wider.

The most interesting feature of this is that the width of the belt of attraction changes abruptly at the cross faults. There is certainly nothing about the metamorphic changes which varies abruptly in this way; hence the only conclusion is that the dip angle changes abruptly at the faults. In other words, when the final tilting took place the eastern fault blocks were tilted more steeply. From this, plus the fact that the faults cut the Keweenawan completely, the conclusion is drawn that the final tilting did not take place until the Keweenaw Thrust had taken place, until after the gabbro had filled it, until after the anorthosite had crystallized, and not until during the introduction of the porphyry, and possibly after. It was clearly of late Keweenawan age.

## FORMULATION OF THE ELEMENTS OF DEFORMATION

The major elements of deformation have now been reviewed. The problem at hand is to combine these factors or elements into an expression which will relate them as factors in one single episode of deformation.

The first consideration is that the formations were lying more nearly horizontally when the last of the flows was poured out. These flows, by the way, thicken down the dip, as has been shown by determinations in the mines in Michigan. Therefore, there is perhaps some objection to the use of the term "horizontal" as applied to the series as a whole. In the west the series is more nearly flat today than, for example, off to the northeast along the Montreal River. The dips are respectively 30° and 80°.

At least to some degree, all the formations have been tilted to the northwest. On account of the steeper dip in the east, it may be considered that here the tilting began earlier, it went on more rapidly, or it continued longer. The essential fact is that there was differential tilting.

The behaviour of a series of formations subjected to differential tilting can be studied crudely, and in a homely way, by twisting a flat eraser. Take an eraser 2 inches long, an inch wide, and one-quarter of an inch thick. Orient the long dimension parallel to the formations on the map. Then hold the northwest, the southwest, and the southeast corners approximately rigid. Depress the northeast corner to imitate the steeper tilting off to the northeast. Three things of significance in this consideration take place. The first is that a synclinal fold tends to develop through the center of the eraser, pitching toward the northeast. The axis of the fold makes an angle of about 45° with the edge of the eraser. The second point is that an anticlinal fold also tends to develop. The axis of this also makes an angle of about 45° with the edge, but it strikes to the northwest at right angles to the axis of the syncline. The third point is that by increasing warping in this manner there develop tears or tension cracks cutting approximately normal to the flat side of the eraser, but parallel to the anticlinal axis.

The experiment seems to reproduce what we have observed as structural deformation in both Keweenawan and Huronian. Aside from the breaking and injection of the syncline in the Keweenan, the structures have the same relationships as shown up in the twisting of the eraser. The tension cracks appear to represent the cross faults. And if the tendencies to tear in the eraser were aided somewhat by cutting with a knife, it would be found that the successively adjacent blocks move differentially, taking on different dip angles.

One difference, at least, between the eraser model and the problem in hand is that the formations discussed are but one limb of a major syncline. In the development of a syncline there is compression in the upper beds along the axis. This compression is relieved by differential movement of one bed, or series of beds, over the underlying ones and in a direction up the dip of the limb. This movement has to be taken into consideration. In the present case it would have to find relief in buckling of the beds or in thrusting up the limbs. In the Upper Keweenawan formations there are subordinate folds produced in this way. The main Keweenaw Thrust, which we have projected across the map area, is probably a response to the same stresses. It was apparently one of the first elements of deformation to effect the two series.

The several elements of structural deformation can, therefore, be formulated into a single simple expression. The two series were downwarped along the axis of the Lake Superior geosyncline, as we now know it. The compression attendant upon the synclinal folding produced strong, longitudinal thrusting. The strongest foundering was to the east, and torsional stresses were set up which produced the subordinate, oblique, synclinal and anticlinal structures. These were in process of development when the first thrusting—the Keweenaw Thrust—was produced, and they affected its position from point to point. Later downwarping in the west, and the normal compression along the axis, was complicated by the presence of the two minor structures. The lateral relief of the compression along the axis took place in a second period of thrusting, of which the Lake Owen and the Bad River thrusts are examples. With final stages of downwarping, the gabbro and red rock injections were drawn or forced into the thrusts and planes of weakness between beds, such as the gabbro and anorthosite along the Keweenaw thrust, and in the belted complex of T. 44—R. 5W. and T. 45—R. 5W. The many cross faults are the result of post intrusion movement along the tension cracks produced in the period controlled by torsional warping.[1]

## THE REFLECTION OF THE STRUCTURE IN THE PHYSIOGRAPHY OF THE REGION

There are a great many direct reflections of the structure of the region in the physiography. This is brought out on the diagram, figure 21, which is based upon it.

The main axis of the Lake Superior syncline "comes ashore" southeast of Ashland. It then turns more to the west for a distance before returning to the northeast-southwest strike. The position of the trough is thus well illustrated in the diagram.

The lowland south and east of Ashland, and, in a general way, extending west as far as a line drawn between Grand View and Iron River, appears to reflect the northeastwardly pitching, synclinal, oblique structure. Its eastern boundary strikes more or less parallel to the Bayfield Peninsula, and approximately parallel to the axis of the subordinate syncline.

[1] Mead, W. J. Notes on the Mechanics of Geologic Structures. Jour. Geol. Vol. xxviii, No. 6, Sept.-Oct. 1920, p. 513.

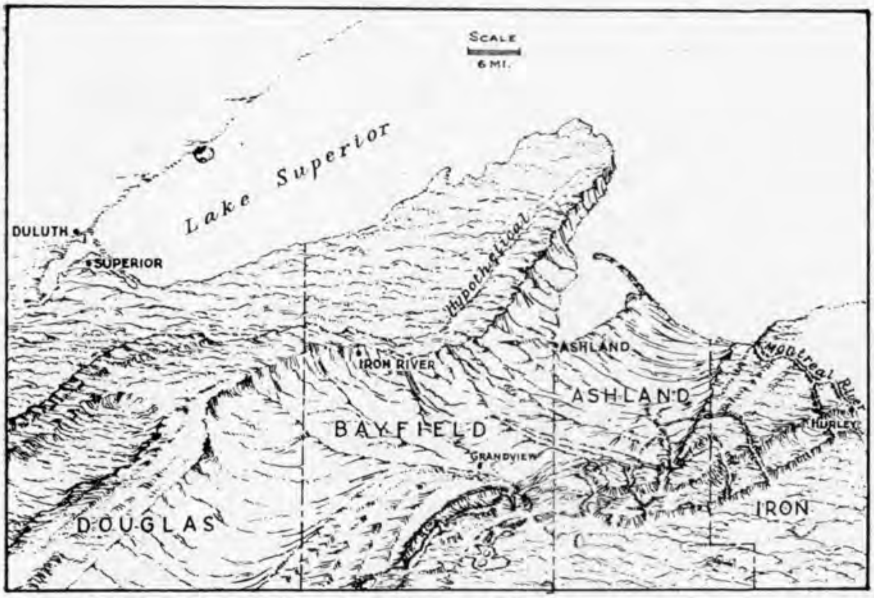



FIG. 21 ~ DIAGRAM SHOWING STRUCTURAL CONTROL OF PHYSIOGRAPHY

The belt of high land crossing the trough in western Bayfield County, with its eastern boundary along the line from Grand View to Iron River, is apparently a reflection of the anticlinal fold in the west of the area under discussion. This belt is the locus of a terminal moraine deposited by a lobe of the glacier that occupied the Chaquamegon embayment. The top of the belt is between 600 and 700 feet above the surface of Lake Superior. In this physiographic situation there is suggestion that the arch that crosses the trough was the barrier which retarded the advance of the ice lobe. The moraine was built on the eastern flank of the barrier ridge when the debris in the ice was deposited by the balance between continuous melting and steady ice advance. In the northern limb of the trough, and in line with the axis of the arch, there is an apparent reflection of the emergence of this cross structure. This inference is wholly derived from a study of the magnetic attraction, for the region is well covered with glacial drift.

In connection with this physiographic reflection of the arch crossing the trough it is perhaps appropriate to note that the great intrusions, so far as they have been brought to light, all lie on the east flank. The west end of the so-called Bad River gabbro, the west end of the gabbro on the Douglas County fault, and the southwest end of the Duluth gabbro all lie approximately on the north limb of this structure. The significance of this observation is unknown. It is an interesting point for speculation, however.

The Douglas County Thrust is well shown in the physiography. So also is the Lake Owen Thrust. Thus there is a certain amount of symmetry in the thrusting. It would be of interest, also, to speculate upon the possibility that the base of the Duluth gabbro, like the base of the gabbro in Wisconsin, is a thrust and the counterpart of the Keweenaw Thrust.

With the main elements of deformation strongly reflected in the physiography of the region, there is suggested a possibility that the Bayfield Peninsula may also be a reflection of structural control. On the north limb of the syncline the traps were followed east of the Brule River almost entirely by means of the magnetic instruments. These formations have an east-west strike across T. 48—R. 9W., and in the west of T. 48—R. 8W. the strike turns slightly south of east. They were lost, probably on account of the heavy drift, at about the center of T. 48—R. 8W. In view of the close parallelism of the Peninsula with the strike of the east side of the lowland and with the axis of the minor syncline, it is suggested that the Peninsula is controlled by the same structure developed in the traps. This, although only a suggestion because there are not known to be any outcrops of trap on the Peninsula, is strengthened by magnetic traverses run recently by the writer employing the sensitive Hotchkiss Super dip.

# CHAPTER VII

# THE ORIGIN OF THE IRONWOOD AND THE DEVELOPMENT OF ORES

## INTRODUCTION

The origin of the Lake Superior Iron Formations in general has been studied at great length by Van Hise and Leith and their associates. The conclusions reached have been summarized as follows:[1]

"Ordinary processes of weathering, transportation, and deposition of iron salts from terranes of average composition were as effective in the pre-Cambrian of the Lake Superior region as in other times and places, but these processes account for only thin and relatively unimportant phases of the iron-bearing rocks; for instance, the lenses of iron carbonates associated with graphitic slates of the upper Huronian, probably deposited in lagoons and bogs of a delta. For the derivation of the unique thick and extensive iron-bearing formations of the Lake Superior region it is necessary to appeal to some further agency. This is believed to be furnished by the large masses of contemporaneous basic igneous rocks. The association of sedimentary iron-bearing formations and basic igneous rocks is known in many localities outside of the Lake Superior region. The iron salts have been transferred from the igneous rocks to the sedimentary iron-bearing formations partly by weathering when the igneous rocks were hot or cold, but the evidence suggests also that they were transferred partly by direct contribution of magmatic waters from the igneous rocks and perhaps in small part by direct reaction of the sea waters upon the hot lavas."

During the study of the Ironwood nothing has been discovered which in any way detracts from the general conclusions stated above. The idea is introduced, however, that the essential factor which accounts for the many detailed differences between the two types of formation, was the concentration of the solution from which precipitation took place. The heavier chert beds are believed to have been thrown down as highly aqueous gelatinous masses from solutions of high silica and carbonate concentration, while

[1] U. S. Geological Survey, Mon. 52, p. 516.

the slaty cherty carbonates were precipitated from more dilute solutions. In this higher concentration there is suggestion of the magmatic environment which tends to emphasize the direct magmatic contribution phase of the igneous hypotheses given above.

The description of the details of composition, texture, sedimentary features, and later alteration, by which the two types of formation are strongly in contrast, is based upon "green" drill core from the Plumer exploration in section 6, T. 45—R. 2E. Here the extreme oxidation characteristic of the formation to the east is not effective and the extreme recrystallization characteristic of the region to the west has not been important. Because of these conditions, it is believed that the formation comes much closer to representing the original minerals than at most other places on the range. It should be distinctly understood, then, that the descriptions do not apply to the formation most commonly met with in the course of mining but they may be suited to the more unoxidized portions such as in the region between Cary Mine and the old Ashland, and elsewhere.

## The Ironwood: Its Leading Original Constituents and the Processes of Their Original Deposition

### *TYPES OF ROCK*

The Ironwood, in its original state, comprised two distinct types of rock. Both types were chemically precipitated silica minerals and iron carbonate. They differ compositionally in ratio of silica to carbonate, in regard to the original depositional unit, in mode of occurrence, texture, bedding characteristics, and metamorphic response. In Table IV the contrasting features are tabulated for ready reference and as an introduction to the detailed description.

#### *The Wavy-Bedded Cherts*

In the photographs, figures 22, 23, and 24, some of the characteristic large scale features of the wavy-bedded cherts may be seen.

*Mode of Occurrence.* These beds always occur singly. In figure 25 may be seen a single bed amongst many feet of the thin-bedded slates. In figure 22 several such single beds are seen separated by very thin groups of the slates or thin laminae which differ essen-

TABLE IV

THE CONTRASTING FEATURES OF THE TWO TYPES OF FORMATION

| Feature | Type I<br>Wavy Bedded Cherts | Type II<br>Thin Laminae | Type II<br>Even Bedded Slates |
|---|---|---|---|
| Mode of occurrence | Single beds. Repeated to form distinct members; stray beds in Type II | Repeated to form ¾ inch beds separating beds of Type I* | Repeated to form distinct members |
| Bedding thickness | Variable (1″–6′); average around 3″ | Least—fairly constant at 1/10″ | Intermediate—fairly constant at ⅛″ |
| Bedding regularity | Extremely irregular— thickening and thinning—non-parallel | Pronounced—straight and parallel | Pronounced—even and parallel |
| Composition | Quartz dominant | Carbonate dominant | Carbonate dominant |
| Clastic material | Apparent only at very base—quartz grains | Not apparent—probably little | Extreme—both clastic silicate suspension and carbon |
| Original texture | Amorphous | Fine particles—a mud | Fine particles—a mud |
| Original depositional unit | Carbonate oolites<br>Silica amorphous gel | Fine particle—both carbonate and quartz | Fine particle—both carbonate and quartz |
| Present texture | Extremely coarse and irregular; oolites | Fine and uniform | Fine and uniform |
| Degree of metamorphism | Complete re-organization of silica, metasomatic replacement of carbonate. Thickening and thinning with disruption of thin laminae | Oxidation only. Mashed by Type I beds | Partial oxidation only |
| Ore making preference | Maximum | Indirect | Very slight |

*When occurring in this manner they are referred to as "separators".

FIG. 22 Wavy Bedded Cherts—Type I With Type II as "Separators"

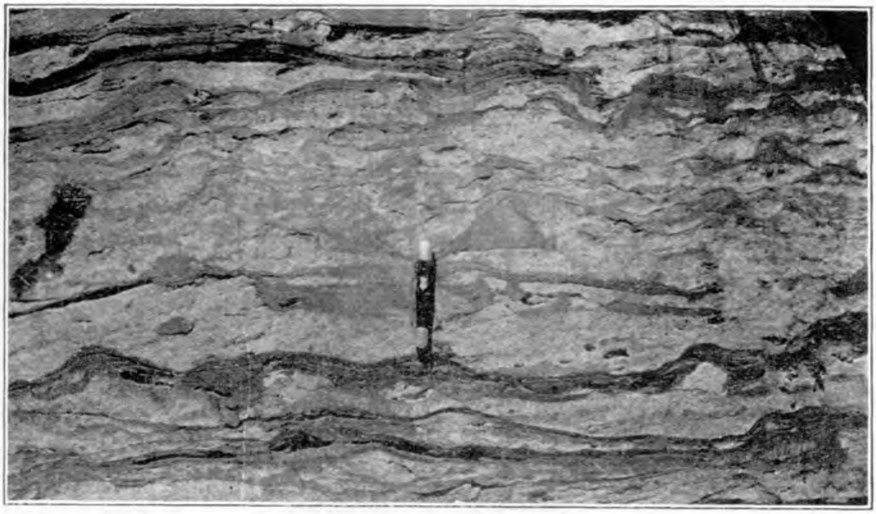


FIG. 23 Wavy Bedded Cherts—Type I With Type II as "Separators"

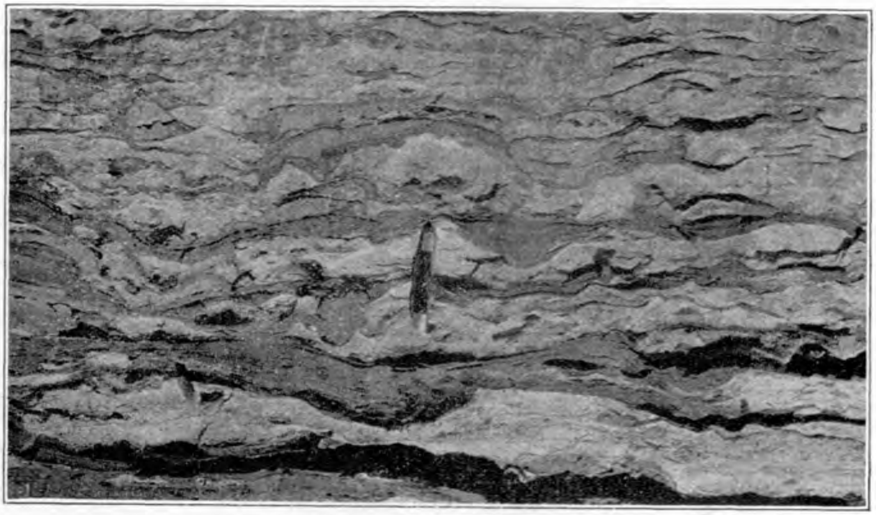


FIG. 24 Wavy Bedded Chert—Type I

tially from the slates only in regard to this illustrated mode of occurrence. In figure 25 it is clear that the conditions controlling deposition of this type of rock were not repeated whereas in the first three they were repeated many times. This recurrence with great frequency characterizes three portions of the column so prominently that they may be considered as distinct members.[1]

*Bedding Thickness.* Beds measure in thickness from an inch to several feet. In figure 25 the bed of this type of formation is about 1 foot thick. The average thickness is about 3 inches.

*Bedding Regularity.* The photographs tell the story of bedding regularity of these cherts. They thicken and thin without the slightest regularity. Furthermore, their tops and bottoms are not parallel. Many cases are seen where the beds lens out or even split into two.

*Composition.* The essential minerals in these cherts are one or more of the silica minerals. Carbonate is important in many and oxides derived from carbonate are also of consequence. In the western portions silicates have been formed from the combination of silica with lime and magnesia as well as iron.

*Clastic Material.* Excepting for a considerable proportion of quartz sand grains in the very base of the lowest member composed of this type of formation, Plate II, Figs. E. F., Plate III, Figs. A. B., there is probably no appreciable amount of clastic material. The transition zone at the base of the lowest member measures 5–10 feet in thickness.

*Original Texture.* The siliceous constituents of these beds vary in texture from a dense, massive, condition which is too fine-grained for even the high-powered microscope to resolve, to a grain size visible to the naked eye. The finest type has been examined by the X-ray method and it proves to be crystalline in spite of the apparent isotropic character indicated by the microscope.[2] The coarser textures always occur in connection with replacement of carbonate by quartz. In this case the silica must have been in true solution when it took the place formerly occupied by the carbonate. When it forms dense masses, it is believed to have been precipitated in a gel condition from which it has changed to the solid form by simple dehydration. The occurrence of this type at the base of the formation mixed with the sand grains is taken as proof of primary deposition.

The carbonate too forms masses that are very dense. These are evidently crystalline, but no crystal boundaries can be discovered.

[1] See Stratigraphic Column, Fig. 27.
[2] Personal Communication from Dr. A. N. Winchell.

*Original Depositional Unit.* From the above it is concluded that the silica precipitated as voluminous masses or clots of gel. From the occurrence of carbonate as small ellipsoidal bodies which are scattered through the chert similar in all respects to the common oolites of limestones, it is concluded that carbonate also precipitated in amorphous form as globules in the silica masses.

*Present Texture.* As indicated above, the silica varies widely in present texture from the dense condition, thought to be practically unchanged except by dehydration, to a size visible to the naked eye. When a thin section of the latter is examined under the microscope, it is practically always seen to be full of elliptical bodies like the oolites of carbonate and these are colored with an impalpable black or brownish dust. The crystals of silica cut indiscriminately across these areas as well as the interstitial space. The carbonate occurs in beds practically pure but massive, as well as in oolites. Here and there carbonate too has recrystallized, even within the oolites.

*Degree of Metamorphism.* From the photographs it is seen that the irregularity of the bedding planes is related to a crumpling, wedging, breaking, and reincorporation of the thin laminae. They thicken and thin typically. The silica has been completely reorganized and has replaced carbonate on a stupendous scale.

*Ore Making Preference.* At first thought it seems paradoxical that members typified by these beds richest in silica should generally be most effective in the making of ore, yet that is the case. The real reason is that in parts of these members the chert beds are thin and the highly ferruginous separators slump together following leaching of the chert beds. True, some of the carbonate slates make ore, in fact, in some mines, especially in Michigan, the whole formation has been converted to ore.

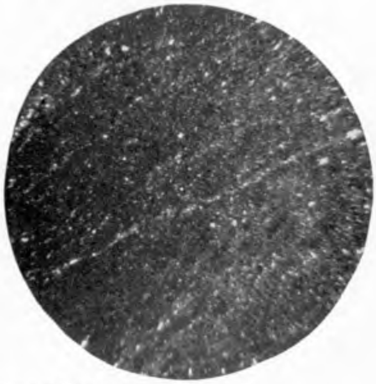
Photomicrographs on Plates II to VI show the principal features of these wavy-bedded cherts.

### *The Even-Bedded Slates*

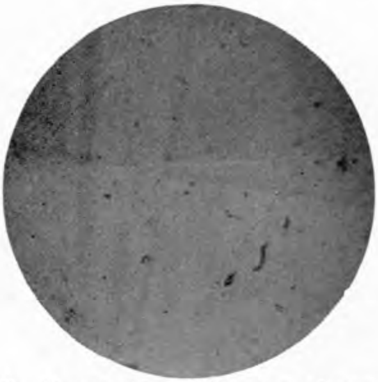
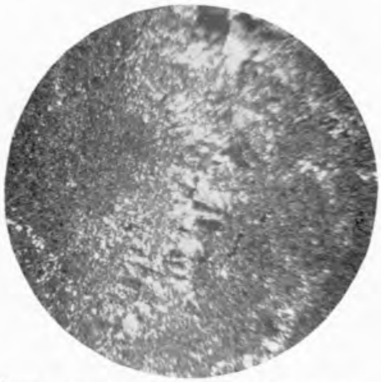
Photograph, figure (25) p. 141 shows these slates in typical occurrence. Figures (22), (23), and (24) p. 137, 138 show them in their thinner groups between cherts.

*Mode of Occurrence.* These never occur singly. The repeated beds may be in the aggregate only about three-fourths of an inch

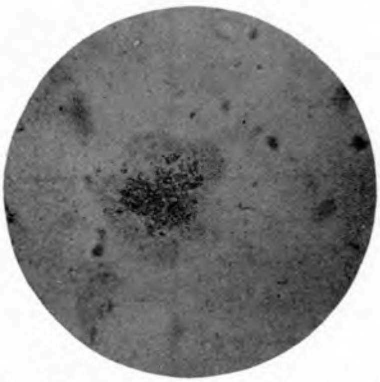
PLATE II. DENSE CHERTS

A. Dense Chert. Without analyzer × 40.
B. Same with analyzer.

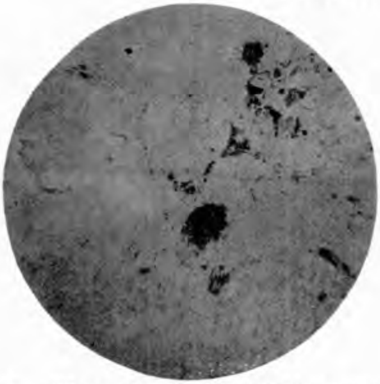
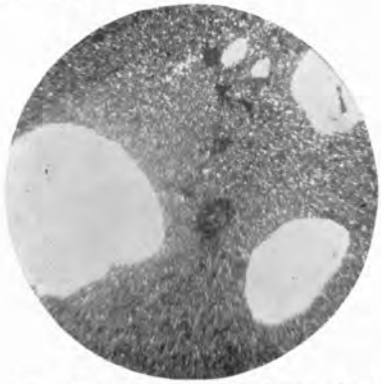



C. Dense chert, Without analyzer × 40. Shows traces of incipient fracturing.
D. Same with analyzer. Shows rehealing of fractures and gradation of grain from dense, original, chert to coarse secondary quartz.

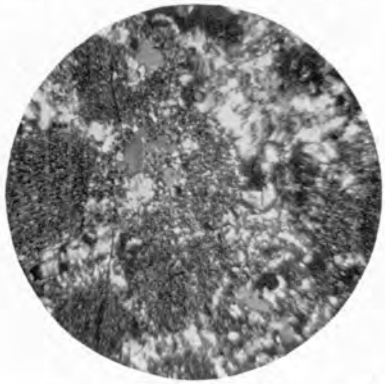



E. "Sweeping bed". Without analyzer × 40. Quartz grains in dense chert.
F. Same, with analyzer. Shows dense chert surrounding rounded quartz grains. Note that there is no enlargement of quartz grains.

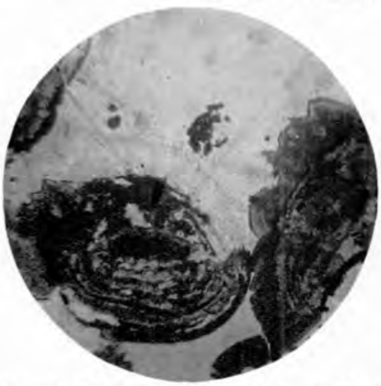
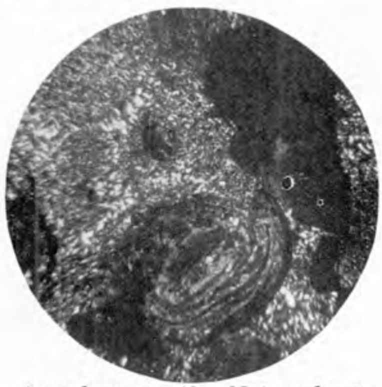
PLATE III. DENSE CHERTS

A. "Sweeping bed." Without analyzer × 40. Quartz grains in dense chert.
B. Same with analyzer. Note that there is no quartz enlargement.

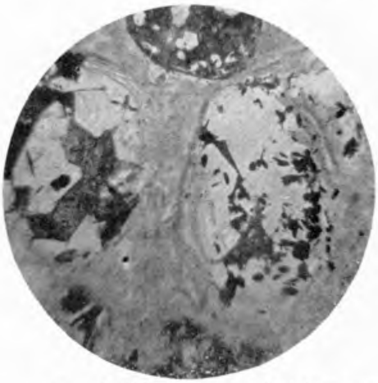



C. Granular, dense chert in matrix of coarser texture. Without analyzer × 40.
D. Same with analyzer. Note that granules are of dense chert and that they are separated by chert of coarser texture.

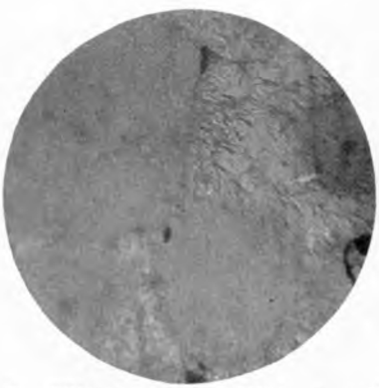



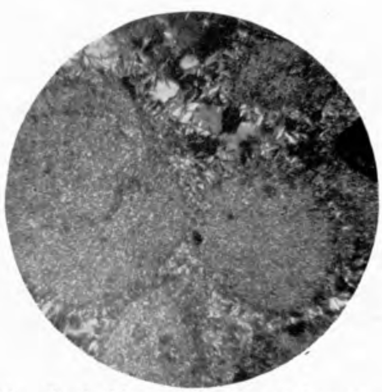
E. Carbonate oolites in dense chert. Without analyzer × 40. Note enlargement of oolites by secondary carbonate, and partial replacement by quartz and iron oxide.
F. Same, with analyzer showing dense chert matrix around oolites.

PLATE IV. OOLITIC CHERTS



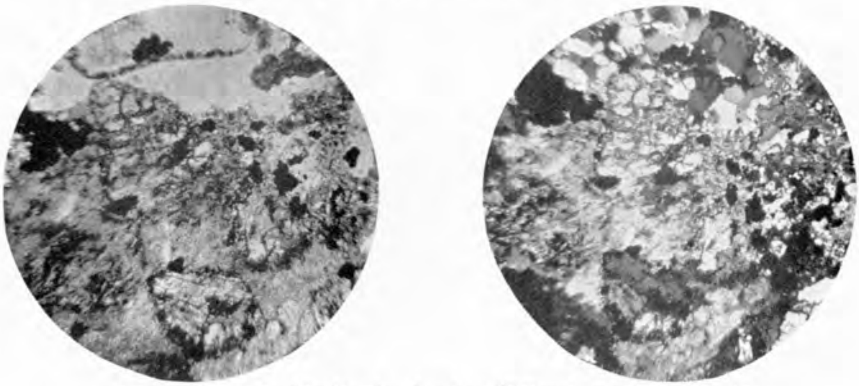
A. Oolitic chert. Without analyzer × 40. Carbonate replaced by quartz and magnetite.
B. Same, with analyzer.





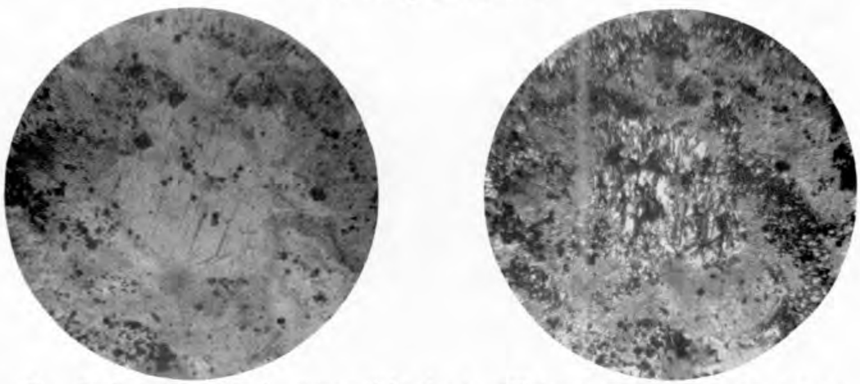
C. Silicate oolites. Without analyzer × 40. Probably originally carbonate. Amphibole needles in interstices. Secondary carbonate at right edge.
D. Same, with analyzer. Shows coarse quartz and amphibole in interstices between oolites.

PLATE V. OOLITIC CHERTS



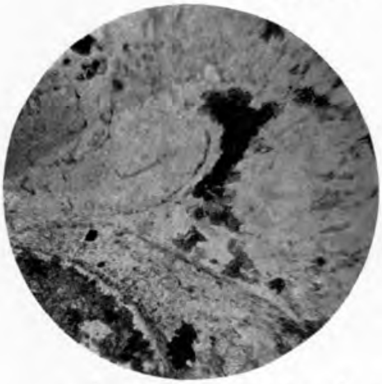
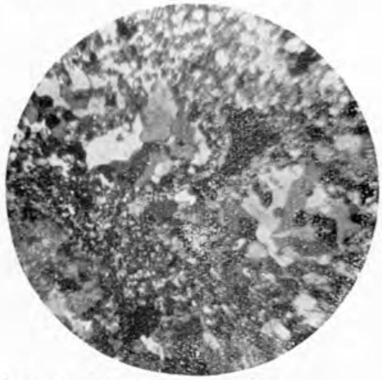
A. Oolites of siderite in chert. Without analyzer × 40.
B. Same with analyzer. Shows coarse quartz in interstices.

C. Oolitic chert. Without analyzer × 40. Shows coarse quartz in interstices.
D. Same with analyzer. Note dense chert around rhombs of secondary carbonate.

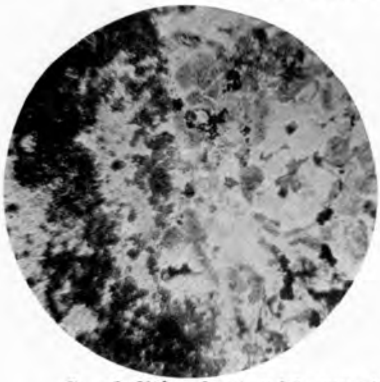
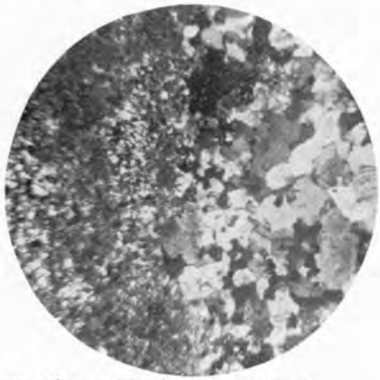


E. Carbonate oolite in magnetitic chert. Without analyzer × 40. Note cleavage in oolite.
F. Same with analyzer. Note preservation of carbonate cleavage by quartz which has replaced carbonate oolite.

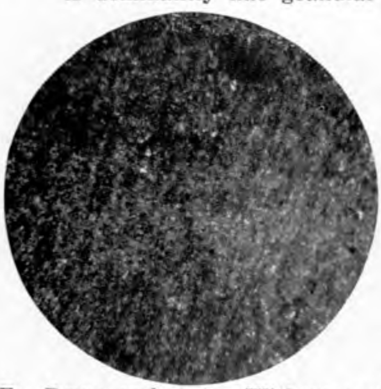
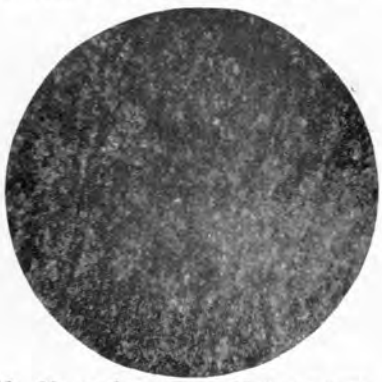
## PLATE VI. OOLITIC CHERTS

A. Oolites of carbonate replaced by quartz and magnetite. Without analyzer × 40.
B. Same, with analyzer. Note coarse texture of the secondary quartz. Cf. dense textured cherts on PLATE II.

C. Oolitic chert with quartz and magnetite replacing carbonate. Without analyzer × 40.
D. Same with analyzer. Note coarse grain of secondary quartz. Left half is dominantly fine granular carbonate with quartz replacements.

E. Dense carbonate. Without analyzer × 40. No replacement. Note texture.
F. Same, with analyzer.

FIG. 25 Even Bedded Slate—Type II With Stray Bed of Chert Type I

or so in thickness, when they appear as "separators" between chert beds, or they may recur with great frequency through a thickness of a 100 feet or more forming distinct members*. In fact, there are three members that are composed of these beds more or less exclusively except for a stray bed here and there of the chert like in figure (25).

*Bedding Thickness.* These slates are but a fraction of an inch thick. The average thickness where they occur as distinct members is about one-eighth of an inch. When they occur in the "sep-

* See Stratigraphic Column, Fig. 27, p. 159.

arator" capacity, they seem to average less, perhaps one-tenth of an inch. The thickness of a single bed seems to be fairly constant also.

*Bedding Regularity.* The regularity of the bedding planes is exceedingly striking. Moreover they are parallel and may be followed along the entire length of an outcrop. The thin laminae or "separators" have been badly crumpled and variously deformed.

*Composition.* Carbonate is the principal mineral. Oxides are invariably present. Silica is generally subordinate when mixed with carbonate but forms thin laminae.

*Clastic Material.* In these slates there is almost always some fine silicate material which may be of clastic origin. Conceivably there should be some fine suspensions making their way out to the depths where iron formation was depositing. Probably these beds accumulated more slowly as will be shown later in which case the fine suspension would be relatively more important. There seems to be none of this in the thin laminae, that is, the separators intercalated with thick cherts. Carbonaceous material is also found abundantly in the middle division of the lowest slate member, the Yale. The origin of this is unknown and an explanation has not been attempted.

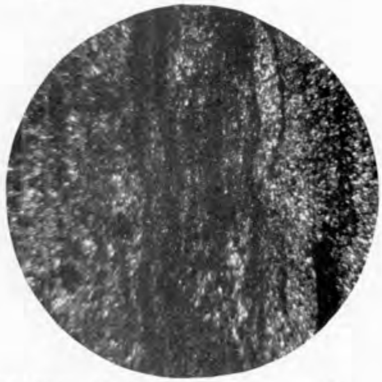
*Original Texture.* The microscope reveals a very fine aggregate of carbonate. When silica is present, it is usually intimately mixed with carbonate, although there are thin beds of nearly pure silica. As the trend of metamorphism is to increase grain size, it is concluded that these beds were originally no more coarsely grained than at present and possibly much finer.

*Original Depositional Unit.* There are no oölites in these slates and no secondary units of deposition of any other type. The original depositional units, therefore, appear to have been fine discrete particles or flakes.

*Present Texture.* So far as evidence has suggested, the present texture is not greatly different from the original texture, uniformly fine-grained.

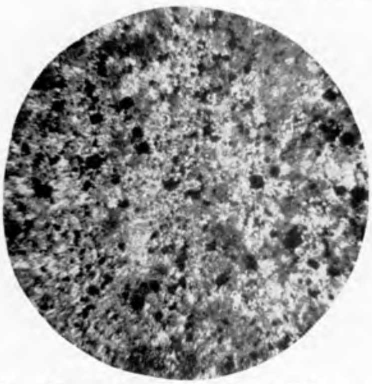
*Degree of Metamorphism.* Excepting the formation of oxide which is generally present there seems to have been no metamorphism. The bedding is unmodified, there is no recrystallization, and only rarely is there replacement. The thin laminae have been

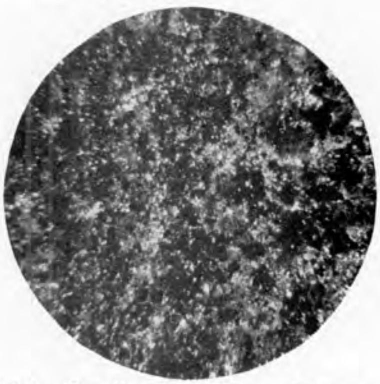
## PLATE VII. SLATES



A. Typical jaspery "slate". Without analyzer × 40. Some magnetite disseminated. Dark bands are jasper.
B. Same, with analyzer. Note texture of chert.

C. "Slate". Carbonate—chert mixture. Without analyzer × 40. Note texture and absence of oolites or granules.
D. Same, with analyzer. Note texture.





E. Magnetitic "slate". Without analyzer × 40. Banding indistinct. Mixture of carbonate, fine chert.
F. Same, with analyzer. Note granular mixture and absence of oolites.

referred to as badly crumpled and broken. In many cases the frayed ends of these fragments have been replaced by silica.

*Ore Making Preference.* Only in localities of intense oxidation do these beds generally make ore. Exceptions are found, but in general they appear to be inhospitable to the processes of ore making. Indirectly the thin laminae or separators make ore when the cherts are altered.

Photomicrographs on Plate (VII) illustrate the principal features of these evenbedded slates.

### *The Source of the Silica and Iron Minerals*

Faced with a formation of this sort, and hoping to determine its origin, a geologist has little upon which he can safely depend as a starting point. It is impossible to match such a formation against any other whose origin is known through observation of its deposition. There can be no doubt about its chemical sedimentary origin, but among the long list of sediments there is hardly a one which in any essential respects strongly resembles the Ironwood, excepting the other iron formations of similar age.

The main difficulty lies with the very uncommon composition. Here is a formation obviously formed as a chemical precipitate in a body of water on the surface of the earth and, therefore, one which should be the passive product of surficial environment. However, a very comprehensive study of surficial processes has revealed[1] no circumstances under which a solution of these two substances, silica and iron, may be mutually segregated from the other elements of ordinary rocks and in such enormous quantities. The uniform habit of iron and silica in surface processes is to part company, that is, one is removed and the other remains insoluble and fixed.

The escape from this difficulty has been seen only in the concentration of the silica and iron in an extra-surficial environment. In short, these materials were created in solution by a subsurface environment, a magma.[1] This turn to magmatic sources is compelled not alone by the elimination of more immediate sources. Wherever similar formations occur there are ample evidences of magmatic activity if not contemporaneously at the surface, at least imminently below surface, for not long subsequent to the deposi-

[1] Van Hise, C. R., and Leith C. K., The Geology of the Lake Superior Region: U. S. Geological Survey, Mon. 52, p. 516.
Moore, E. S., Maynard, J. E., Econ. Geol. Vol. XXIV #5, p. 527, Aug. 1929.

tion there is surface volcanism. In the present case it is but a matter of observation that on the Michigan end there was contemporary vulcanism throughout Upper Huronian time as shown by intercalated tuffs and surface flows.[1] Furthermore, in Keweenawan time the whole vicinity was deeply and completely buried by 5 miles of lava flows. The reservoir of this lava could not have been far below the surface even in Ironwood time.

The magmatic origin of the silica and iron which makes up the Ironwood is therefore believed to meet the requirements of the formation. It is not possible to indicate the exact method by which this transfer of material from the depths to the surface was accomplished, but it is necessary to accept one or both of two possibilities. Either[2] the silica and iron were dissolved in a solution and the solution was poured into this surface basin, or there were deliveries of molten lava at the surface and sea waters or meteoric waters extracted the silica and iron salts from these hot masses.

The doctrine that the Ironwood materials originated in an extraneous or subsurface environment throws no light upon the environment into which these were introduced. The latter as read from the formation itself was at least one of quiet and poorly oxygenated waters. The fact that the waters were quiet follows from the observation of the perfect evenness of the bedding in the slaty type of formation. No such evenness could have been developed if the sediment had been agitated by strong wave action. In all probability, then, the water was deep enough so that the bottom was below the reach of ordinary wave action. The absence of oxygen is proved by the ferrous state of the original iron minerals. This, of course, also goes to show that the magmatic contributions were subaqueous. Moreover the deep water environment was constant. This is indicated by an hypothesis which accounts for the contrasting features listed and described in detail above.

### *The Cause of the Contrasting Features of the Two Types of Formation*

The two types of rock comprising the Ironwood were obviously composed of the same minerals and hence originated in an identical source. The problem at hand is to determine the reason why such materials assumed such contrasting features on de-

[1] U. S. Geological Survey, Mon. XIX p. 360–361.
[2] U. S. Geological Survey, Mon. 52, p. 513.

position and during subsequent stages. There are but two recognized possibilities, either the environment changed thereby effecting different modes of aggregation of a constant type of precipitate or else the environment remained constant and the character of the precipitate itself varied on account of some inherent factor.

The change of environment does not appear probable. In the first place as shown in the photographs, particularly in figure 25 p. 141, the wavy-bedded chert with all its contrasting features came down obviously under the same environment as the slate. In figures 22, 23, and 24, it is seen that the chert came down periodically between thin groups of evidently the same sort of slate beds representing evidently the same sort of environmental conditions. Unless the bottom virtually vibrated with frequent oscillations, water depth could not have varied widely enough to account for these differences. In the second place such features as greater bedding thickness, oolitic structures, recrystallization, and replacement, cannot be positively correlated with an environment distinctly different from that of the slates. The waviness of the chert bedding has been ascribed by Hotchkiss to wave action and implied rippling.[1] Disapproval of this idea is based on the belief that the original chert was a coherent semi-fluid mass in which ripples do not form, and also upon the observation of a close relation between the waviness of bedding and the later crumpling and wedging of the separators and apparent injection of oolitic chert material between their beds.

On the other hand, a difference between the nature of the original precipitate in the two types of formation has been shown. In the cherts there is evidence of precipitation as voluminous masses of silica that have been preserved without intense coarse recrystallization.* In the slates the units of deposition were clearly discrete particles of silica and carbonate in intimate mixture. The cause of these differences is believed to have been a higher content of water in the chert precipitate as compared to that of the slate precipitate. It is seen also that the wavy bedding is related to deformation of the thin laminae, a feature absolutely unknown in the slate members. Oolitic chert has been squeezed around the broken mass of thin laminae and even injected between its beds. This plastic deformation indicates a fluid property not

[1] Engineering and Mining Journal, Sept. 13, 1919, p. 446.

* The formation is described in its condition where the oxidation and metamorphic affects of the gabbro are a minimum.

inherent in anhydrous quartz or in carbonate and evidently not present in the ruptured laminae. It indicates a fluid medium which probably would be water. The recrystallization so prominent in cherts but never seen in slates also predicates the presence of water in the former. In close association with the recrystallization is metasomatic replacement of carbonate by quartz which also proves the presence of water. For these reasons the probable character of the original solutions as well as their precipitates must be considered.

*Precipitates of Silica.* Solutions containing silica in concentration tend to form jelly-like half solid masses when they are exposed to the influence of salts. This coagulation often occurs spontaneously, closely resembling the crystallization of a very soluble salt from a supersaturated solution by inoculation with a tiny crystal. In dilute solution amorphous precipitates are obtained instead of jellies. Once precipitated the solution cannot be reformed either by dilution with water or by warming.[1]

Given this information not only does the explanation of the many differences in the two types of formation become simple, but we have a theory adding weight to the probable magmatic origin of the silica and carbonate.

Under this explanation, the chert beds are interpreted as gelatinous precipitates from highly concentrated solutions. The slates were precipitated as fine aggregates of silica and carbonate from more dilute solution.

Possibly there is no environment so conducive to extreme concentration of solutions as the magmatic. These concentrated solutions from a magma entered the basin subaqueously. In the contact with sea water the bulk of the silica and carbonate was thrown into colloidal emulsion, but convection currents, the force of emission, and basin currents would produce a certain amount of dilution from which separator beds of slate were precipitated and distributed.

Correlation of the several contrasting features with these differences of precipitates is very simple and direct. Before proceeding to make the demonstration, however, the attention is called to the physical properties of gels.

In the present connection the four most significant properties of the gels are (1) water content which may be as high as 98 per

[1] Zsigmondy, R., Spear, E. B., The Chemistry of Colloids, (1917) p. 8.

cent, (2) physical properties correlating with water content, (3) resistance to dehydration under pressure, (4) change of volume with dehydration under pressure.

Water content may be as high as 98 per cent. Change of physical properties with water content is shown in the following table.[1]

| Per cent water by weight | General character |
|---|---|
| 92-90 | Gel may be cut |
| 85 | Fairly stiff |
| 75 | Brittle |
| 65 | May be pulverized and the powder is apparently dry. |

The change of volume with water content is shown in the following table.[2]

| Per cent water by weight | Volume |
|---|---|
| 97.3 | 29 |
| 95.8 | 18 |
| 93.1 | 11 |
| 87.4 | 4 |
| 77.2 | 3 |
| 45.6 | 1 |
| 39.7 | 0.86 |
| 33.7 | 0.75 |
| Transition | |
| 23.0 | 0.73 |
| 10.4 | 0.73 |
| 8.2 | 0.73 |

These two sets of figures are shown on the graph Fig. 26. The changes of volume and physical properties with water content are correlated.

The resistance to dehydration under pressure has been studied by Lenher.[3] Starting with gels containing 90 per cent of water dried between cloths he subjected these to pressures increasing from 230 kilograms per square inch to 272,700 kilograms per square inch. Dehydration proceeded fairly rapidly to about 50 per cent under pressures up to 900. But from this degree of hydration and down to 12.5 per cent, pressures as great as 272,700 kilograms per square inch were required. In the experiments the water was absorbed by filter paper or canvas filter cloth. The question might be raised whether the absorption of water did not

[1] Zsigmondy, R., Spear, E. B., The Chemistry of Colloids, p. 138.
[2] Idem. p. 139.
[3] Jour. Am. Chem. Soc. Vol. XLIII No. 3, March 1921, p. 391 et. seq.

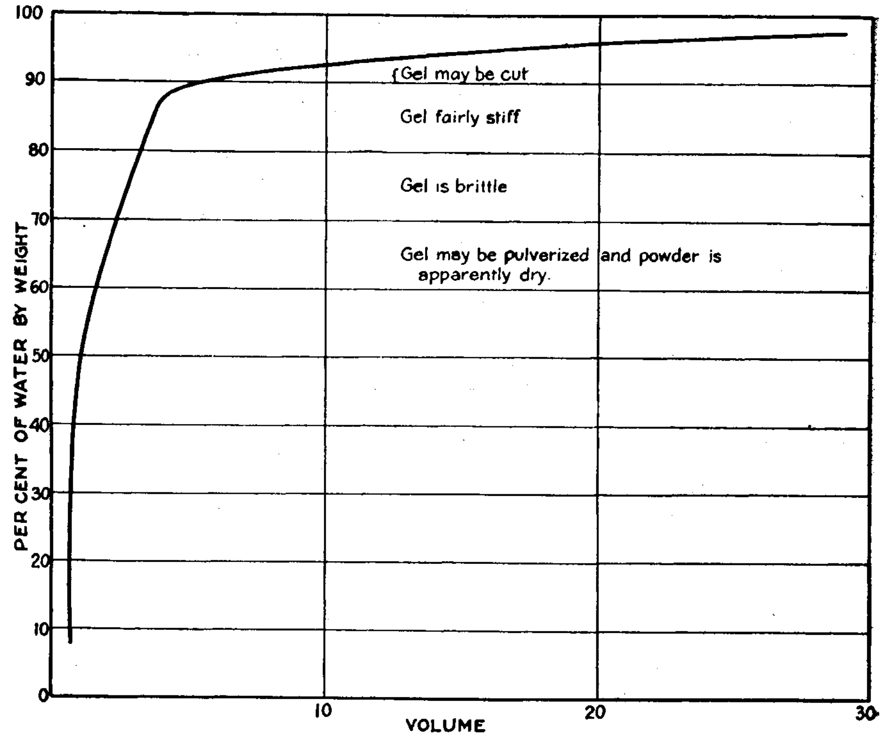



FIG. 26

accelerate dehydration. Under natural conditions in a body of water there would be no agents to assist in this way.

"The dryer the gel becomes the more difficult it is to press out the water."[1]

*Explanation of the Contrasting Features on the Basis of Variation in Character of the Original Precipitate*

The contrasting features are summarized on Table IV which has been discussed. In the light of the data concerning the variation of the character of the precipitates of silica with concentration of the corresponding solutions and the data on the physical properties of the precipitates from concentrated solutions many of these features are readily explained.

[1] Zsigmondy, R., Spear, E. B., Chemistry of Colloids, p. 138.

*Mode of Occurrence.* The two different types of rock alternating with different frequencies in different portions of the formation are explained as due to variation in the concentration of the precipitating solution, the sedimentary environment remaining constant.

*Bedding Thickness.* Thicker beds represent voluminous direct precipitation from more concentrated solutions, thinner beds indicate more leisured precipitation from solution rendered more dilute by seawater.

*Bedding Regularity.* The thick beds are extremely irregular. This irregularity is associated with rupturing and general deformation of the thin laminae. It has been ascribed to a plastic property predicating a water content. The gels forming from concentrated solutions may carry down as much as 95 per cent of water and tend to retain as much as 44.5 per cent even under pressure comparable to the load of Ironwood plus Tyler and as much as 35 per cent even under pressures equal to the entire column through the Upper Keweenawan. The plasticity and resulting deformation of the cherts is explained by their original gel constitution. Under pressures with slight differentials here and there the gel would be variously moulded and injected. The thin laminae or separators being relatively more competent broke and were incorporated by the plastic mass.

*Clastic Material.* The greater concentration of fine clastics in the slates is due to their slower rate of deposition.

*Original Texture and Structure.* The slates were precipitated from the waters of the basin as aggregates of fine discrete units which were spread in uniformly thin beds. The cherts were precipitated directly from the magmatic solutions on their arrival in the basin as semi-fluid coherent masses. As there were no discrete particles ordinary stratification was inhibited. The slates had the texture of an aggregate of fine particles. The cherts were gels which, if unaffected by later metasomatic processes, simply dehydrated and crystallized as cryptocrystalline dense masses.

*Original Depositional Unit.* The slates, to repeat, were precipitated as fine particles showered upon the bottom. The cherts were precipitated as semi-fluid clots which settled gradually and flattened out and ran together to form large lenses on the bottom.

The silica and carbonate alike were fine aggregates in the slates. The original condition of the carbonate in the gel of the cherts can be looked upon this way. Carbonate occurs as oolites abundantly in these cherts but never in the slates. The origin of oolites has never been satisfactorily explained. The most acceptable statement of their origin is that of Bucher[1] who states that the assumption is justified "that most if not all oolitic and spherulitic grains were formed by, at least, one constituent substance changing from the emulsoid state to that of a solid; that the spherical shape of the grain is due to the tendency of the droplets formed during this process of separation to coalesce; and that the difference between radial and concentric structure depends on the amount of other substance thrown out simultaneously with, and mechanically enmeshed in the growing structure." Twenhofel[2] comments, "As bearing on this problem, it is to be remembered that oolites formed in this manner would appear as if floating in the associated sediments." This appearance of "floating" is an exact representation of the occurrence of the oolites in these cherts. In all accounts oolite growth is related to supersaturation or high concentration. According to the idea that the cherts were precipitated as gels from concentrated solutions the carbonate too would be concentrated, if not supersaturated, probably to be thrown out as an emulsoid dispersed and protected by the silica gel. Later the finer globules coalesced to form oolites. The absence of oolites in slates would be explained by the absence of gel and absence of supersaturation.

*Degree of Metamorphism.* As stated elsewhere, the cherts are replete with evidences of solution activity while slates are practically free. The silica is recrystallized in large part and the carbonate oolites have been largely replaced by silica. Both processes indicate presence of water and are explained in the proposed theory.

Water was retained in the gel as it originally formed. With mounting pressures and temperatures due to superimposed sediments, dehydration was effected. As shown by the evidence presented, water is eliminated very slowly p. 147. When the pressure finally accomplished this removal, the water closely associated with the fine silica effected its solution. The carbonate was in part perhaps decarbonized due to pressure, becoming hydrous oxide,

---

[1] Bucher, W. T., On Oolites and Spherulites: Jour. Geology vol. 26, pp. 593, 603, 1918.
[2] Twenhofel, W. H. Treatise on Sedimentation, p. 543, 1926.

but in large part was dissolved and replaced by the silica which crystallized as quartz. There seems to be little doubt that a tremendous amount of carbonate has been removed from the oolites by this means. The net volume of the small rounded bodies that comprise the oolitic or granular cherts is highly important. That these were originally carbonate is shown by a residuum of finely divided oxide curiously distributed in the same way as in the carbonate that still remains. The silica embracing these is coarse and its crystals cut across the boundaries of the rounded bodies indiscriminately. In some, silica is present only as scattered crystals with outlines forming rhomb-shaped areas indicative of replacement of rhombohedral carbonate. In others, though few, the rhombohedral cleavage of carbonate is perfectly preserved in a mosaic of fine quartz. Plate V. Figs. E F.

In many cases the frayed ends of dislocated thin laminae have been partially replaced by silica. This metasomatic silicification of carbonate is evidenced on a tremendous scale. While it is perhaps probable that there also has been a complementary replacement of silica by carbonate, thereby enriching the carbonate beds, there is no known direct evidence of this. The slates show little or no recrystallization or replacement which is in keeping with the idea that in their original precipitation there was no absorbed water and hence no metamorphic agency.

### *The Environment of Ironwood Deposition*

The environment of Ironwood deposition is concluded to have been constant throughout. The water was deep enough so that the bottom was below and out of reach of the agitation by ordinary wave action. The iron salts and silica probably were introduced below the surface of the water as indicated by the fact that the original minerals were retained in the ferrous state. There is the possibility, however, that the atmosphere at this time was deficient in oxygen and rich in carbon dioxide.[1]

*The Surrounding Land Mass.* The composition, relief, and climate of the surrounding land mass can be approached through consideration of the character of the Palms sediment.

The lower palms is poorly assorted sediment containing feld-

[1] Lane, A. C. Lawson's correlation of the Pre-Cambrian Era: Am. Jour. Sci., Vol. 43, 1917, pp. 42–48. MacGregor, A. M. The Origin of Sedimentary iron ores: Ec. Geol., Vol. 20, 1925, pp. 195–197.

spar and quartz which have been identified[1] with the granitic masses out to the south of the outcrop. In some places the basement is green schist and this is reflected locally in Palms composition.

The feldspathic detritus is poorly decomposed. From observation it is known that moisture, products of the decomposition of organic matter which ultimately form carbon dioxide, and high temperature promote decomposition, lack of decomposition suggests deficiency in one or more of these agents. The apparent deficiency of decomposition would seem to correlate well with the evidence of lack of vegetation in Huronian times. The usual effect of high temperature is to promote oxidation, but these rocks are outstandingly low in primary oxidation. As acidic rocks are low in iron they are not particularly amenable to oxidation. Hence, it might be concluded that temperatures were not excessively high. On the other hand, wide variation of temperature is conducive to disintegration on account of the differential expansion and contraction of minerals which set up breaking strains. Continued disintegration is promoted by prompt removal of the products. If anything can be deduced from these observations, it would seem to suggest moderate relief, a relatively low temperature, but wide range of variation, moderate rainfall, and absence of vegetation.

*Size and Shape of the Basin.* The estimating of the size of the basin can be approached only through consideration of the area covered by its sediments. The last outcrops to the west are in T. 44—R. 6W. of Wisconsin, the most easterly are in T. 47—R. 43W. of Michigan. Hence the basin was at least 75 miles in this dimension. Farther west there probably had been greater extension because there are evidences that the formations come to their end by erosion or by overthrusting followed by intrusion. For similar reasons it may be held that an easterly extension increased the total dimension. In fact, it has been considered by some geologists that the Ironwood may have been connected with the Marquette district formations. Thus, along the dimension represented by the outcrop, the basin was at least 75 miles long, and possibly 3 or 4 times that figure. An attempt to estimate the transverse dimension finds little basis. Mines only extend a few thousand feet down the dip. From structural data the formation appears to be a monocline. Its surface thickness is around 500-600 feet in

[1] U. S. Geological Survey, Mon. 19, 180.

Wisconsin but increases beyond 1000 feet in Michigan, hence a reconstruction of its extent to the south permits of the idea of at least several miles before it tapered off to nothing or merged with the other deposits. If the minor ranges, the Marinisco, Turtle (Messembria), and Manitowish, with their ferruginous rocks represent outliers of the Gogebic formation, then the basin may have extended from the present outcrop 50-60 miles or more. If, as will be developed later, the axis of the Lake Superior syncline was the locus of magmas, and if it was centrally located, then the two halves of the basin may have been 160 miles or more in width. The dimension across the strike thus appears to have been about half the longitudinal measure.

A consideration of the apparent control of the present day northeast structure, which is tied in with the igneous hypothesis, suggests a long and elliptical trough-like basin. In this case the ratio of the two dimensions may have been greater than 2 to 1. At all events the data at hand suggest the elliptical proportions rather than the circular.

*Conditions within the Basin.* Data on the depth of water and degree of agitation during Palms deposition would be particularly valuable for use in checking the above conclusions as to conditions of Ironwood deposition. The data available for interpretation are not voluminous but an analysis is attempted.

The Palms has been differentiated into two types of sediment. The lower 300 feet are composed of poorly assorted fine-grained detritus from granitic sources. The upper 50 feet or so are composed of almost perfectly assorted quartz grains, possibly from identical sources. Thus even here two distinctly different environments are indicated although it is necessary to be cautious lest these be thought of as obtaining at the locus of deposition, that is to say, two sorts of sediment created by distinctly different environments were deposited at different times at the same spot. This variation does not postulate any change whatsoever in the environment of that spot. It may equally well mean that environment had changed elsewhere in the basin and from it the corresponding product was moved to the locus of deposition. Accordingly, the two types of Palms deposition may have gone down under constant conditions of depth and tranquility.

The lower Palms has the most clean-cut features. For example, it is poorly classified which means either rapid burial inhibiting the washing process or dead water. It shows cross bedding in which the foreset beds are relatively steep and short which thus correlate with relatively slow deposition and weak velocities.[1]

These two observations, therefore, suggest depth because in a basin of this area, waves must certainly have been set in motion to stir up the bottom if the water were reasonably shallow.

### THE RELATIONSHIPS BETWEEN PALMS AND IRONWOOD

Before the conditions under which the Palms was laid down can be applied to Ironwood deposition, it is necessary to show that there was no period elapsing between the two of such length that the Palms environment could have been completely reorganized.

The conclusion has been reached from a weighing of evidences that the Ironwood deposition began under probably identical conditions which governed the deposition of the Palms. The evidence is as follows.

*Evidence on the Question of Erosion.* Nowhere can one observe dip and strike on one formation at significant variation with observations on the other. There is no evidence of regional convergence of strike and dip.

Nowhere is there any evidence of gullying or scouring such as would have been accomplished by streams had there been subaerial erosion. There are very few stretches of the quartzite exposed for more than 100 feet. West of Potato River exposures are more abundant because there all formations of the sedimentary series have been thoroughly anamorphosed through recrystallization and their resistance has been greatly increased. There has been flexing also in consequence of which the strike does not carry across country as a "bee line." The contact is wavy and any attempt to distinguish slight erosion channels from irregularities due to folding and faulting, is hazardous. Nowhere has the quartzite been cut out, in fact, Irving[2] laid particular emphasis upon the "extraordinary persistency of this quartzite horizon." He had just commented upon the unassorted character of the lower Palms and the above observation of persistency he held to be very interesting in connection with the change from unassorted to perfectly assorted material.

Just what occupied Irving's mind as he laid emphasis on the

---

[1] Twenhofel, W. H. Treatise on Sedimentation, p. 443.

[2] Irving, R. D.. and Van Hise, C. R., The Penokee iron-bearing series of Michigan and Wisconsin: U. S. Geol. Survey, Mon. XIX, p. 180, 1892.

persistent, coextension of the quartzite and Ironwood weighing as he did the change in Palms sedimentation, it would be interesting to know. It may be noted in addition, however, that Palms and Ironwood are not only coextensive along the strike but in thickness they vary more or less together. In connection with the present endeavor to obtain evidence concerning conformability, it is well to note that these similar behaviors on the part of two successive formations are strongly suggestive of the deposition of the two under the same controlling factors. That is, if the factor controlling thickness in these formations is the distance of deposition from line source, and if the two consecutive formations vary in thickness at the same rate along the strike this would be strongly suggestive of derivation from identical line sources. This would indicate derivation under common physiographic conditions and discount the idea of an intervening episode of warping, erosion, and lapse of deposition. If progressive foundering of the bottom determined thickness, it would seem that this downwarping began in Palms times and continued at a similar rate through the Ironwood period.[1]

The main thread of the discussion of evidence for or against regional erosion may be reengaged with observation of the Palms-Ironwood contact east of Potato River. Excepting in the mines there are no exposures of the contact. Here it is customary to follow the contact with footwall drifts. These are commonly crooked, but from this it may not be inferred that the Palms surface was gullied. On the contrary, the usual reason is that the miners have not followed the contact any too efficiently. They broke erratically into quartzite on the one hand and up into the Ironwood on the other. The situation is complicated by the fact that here the quartzite is frequently found to be a rather loose sand. It breaks readily under blasting and even runs like ordinary sand. Still farther, although the engineers have observed "bumps" on the quartzite similar to minor elevations on an old surface, these same men recognize innumerable cross faults of slight throw that produce minor irregularities. Irving observed this situation writing[2] "In places the upper part of the quartzite appears to be no more than a coarse sand, and occasionally blocks of it are contained in the basement layers of the iron formation.

[1] W. O. Hotchkiss, Bull. G. S. A. Vol. 34, pp. 669–678, 1923.

[2] Irving, R. D., and Van Hise, C. R., The Penokee Iron-bearing series of Michigan and Wisconsin: U. S. Geol. Survey, Mon. XIX, p. 175, 1892.

This would seem to indicate that here and there the quartzite was somewhat broken before the beginning of the deposition of the overlying member or else by dynamic movements." The part that dynamic movements have obviously played discounts any attempt to prove original irregularities.

In view of the above considerations the writer can only conclude that there are no positive evidences of local erosion. Hotchkiss writes,[1] "Its (the Ironwood) contact with the quartzite below is abrupt, and is noticeably irregular in such a manner as to indicate conclusively that an erosion period intervened between the deposition of the quartzite which forms the footwall and the deposition of the Ironwood formation." Although the writer does not agree with this statement, the resultant views may not be far apart because in a later paragraph Hotchkiss writes,[2] "The unconformity between the footwall quartzite and iron formation is not marked by a large amount of erosion so far as facts are available at present." Evidently he did not see a time break of such length as to weaken the deduction that Ironwood deposition took place under conditions like those of the Palms.

With the one additional observation that nowhere are any products of Palms erosion to be found, the decision is reached that there was no great period intervening between deposition of the two formations.

*Evidence on the Question of Lapse of Deposition.* The second phase of the question concerns evidence for or against lapse of deposition between the two formations. The questions are whether time intervened between the last sand deposition of the Palms and first chert deposition of the Ironwood; whether chert deposition interrupted sand deposition; or whether the sand deposition had just ceased when the chert deposition began.

The examination of the contact is the proper procedure. Here the first observation is that there is a zone of 5-10 feet comprising a mixture of chert and sand grains.* This zone of apparent transition at once throws weight to the idea of the continuous deposition. Hotchkiss calls this the "sweepings" bed and explains the

[1] Hotchkiss, W. O., Geology of the Gogebic Range and its relation to recent mining developments: Eng. and Min. Jour., vol. 108, p. 502, 1919.

[2] Hotchkiss, W. O., Geology of the Gogebic Range and its relation to recent mining developments: Eng. and Min. Jour., vol. 108, p. 506, 1919.

* See Photomicrographs.

sand in this zone as wind blown,[1] saying that its occurrence "suggests the *probability* that they were wind-borne rather than washed in by currents and waves, as are ordinary sands."

The mere fact that the top of the Palms was originally a coarse clastic might suggest that the environment of its origin was so unlike that which would account for the chemical precipitation of the Ironwood as to require a long time interval for the reorganization. During this period the sand at the top of the Palms might have been cemented by silica. Erosion surfaces very commonly become silicified.[2] However, the chemical precipitation apparently did not take place from solutions created by surficial processes, and hence there was no occasion for the environment of the Palms deposition to have changed. The fact that the iron solutions did not percolate down into the top of the Palms does not necessarily mean that the latter was tightly cemented. It may be the reflection of the fact that the iron solutions were protected by the gelatinous precipitate of silica which could not percolate itself and would seal off the porous Palms. There is a complete silicification of the Palms, Ironwood, and Tyler throughout the west end of the series and to a certain extent throughout the entire formation which took place later and probably was superinduced by the Keweenawan gabbro intrusions. This could have accounted for the cementation of the top of the Palms.

The writer considers it a valid contention that the Palms was still a loose sand when the chert came down as the base of the Ironwood. To add weight, the reader is referred to the fact cited above that in the mines the quartzite is oftentimes but a loose sand. On the one hand this may indicate a leaching of silica cement contemporaneously with the dissolution of the chert in making ore. Just why these solutions would preferentially extract silica of the second generation rather than take indiscriminately of silica of the first and second is unexplained. In view of the evidence that silicification on a broad scale took place in post Tyler time, at least, from Potato River west, it may well be that these loose sands never had been thoroughly silicified in the productive region. The Ironwood east of the Potato exhibits little or no effects of the extreme induration process and very likely the Palms escaped for similar reasons.

---

[1] Hotchkiss, W. O., Geology of the Gogebic Range and its relation to recent mining developments: Eng. and Min. Jour., vol. 108, p. 449, 1919.

[2] Leith, C. K., Silicification of Erosion Surfaces; Economic Geology, Vol. 20, pp. 513–523, 1925.

The sands scattered through the basal chert member of the Ironwood constitute the best evidence that deposition continued at least for a time.

With this citation of evidence indicative of continuous deposition it is held that the Ironwood began deposition under the surface environment of the late Palms.

### THE DEPOSITION OF THE IRONWOOD

From the examination of the Ironwood itself and the Palms, it has been concluded that the water in the Ironwood basin was deeper than the prevailing depth of wave action. The two distinct types of formation have been shown to depend for their contrasting features upon the concentration of the magmatic solutions, and not upon variation in environment.

The first appearence of iron formation consisted of voluminous gel which precipitated from concentrated solutions welling out through vents. This gel became mixed with sand grains which were carried down as if floating in the gel. The same sort of material without the sand continued to deposit and it shows abundant concentric structures measurable in inches which have been likened to present day structures called "water biscuits." When they are colored brilliant vermillion with iron oxide, they are called jasper. These two portions of the column have been called respectively the "sweepings" bed and the foot "conglomerate" and are respectively 5–10 and 1–5 feet thick in the Wisconsin part of the formation.

Succeeding the foot "conglomerate" and with a thickness of around 10 feet in Wisconsin are carbonate slates called the "foot slate." Throughout the entire column, as shown elsewhere, the gel deposition was followed by and alternated with slate deposition. With the first description of the occurrence of the slate this alternation may well be accounted for according to the hypothesis.

According to the hypothesis the concentrated solutions must have been primary, that is, they were concentrated as they formed in the magmatic reservoir. There is no way apparently by which they could have been concentrated after they reached surface. The dilute solutions, however, may have been diluted in depth or after more concentrated solutions had been emitted into the waters of the basin. Under the momentum of more vigorous emission the concentrated solutions would produce an action similar to that

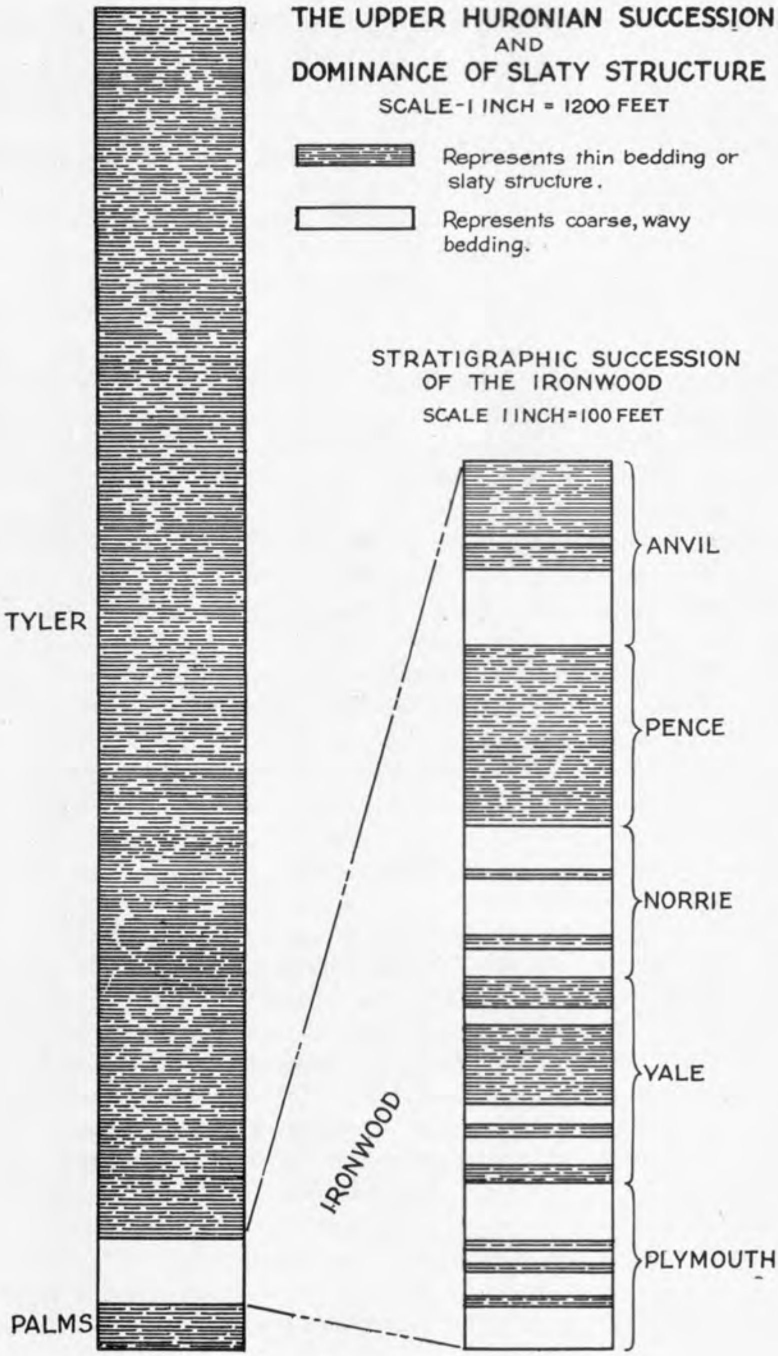

THE UPPER HURONIAN SUCCESSION
AND
DOMINANCE OF SLATY STRUCTURE
SCALE-1 INCH = 1200 FEET
Represents thin bedding or slaty structure.
Represents coarse, wavy bedding.
STRATIGRAPHIC SUCCESSION
OF THE IRONWOOD
SCALE 1 INCH=100 FEET
TYLER
PALMS
IRONWOOD
ANVIL
PENCE
NORRIE
YALE
PLYMOUTH

Fig. 27

of boiling. By convection and diffusion they would be diluted to some extent by sea water, the carbonate more so than the silica for the reason that it is more soluble. From these more dilute solutions the discrete amorphous precipitates would form.

The gels forming from the concentrated solutions are pictured as highly aqueous clots with comparatively low density which floated about but finally settled to the bottom where they ran together into more or less coherent lenses. These were covered by the thin laminae of discrete particles of carbonate. If the time elapsing before other lenses of gel settled was long then the number of laminae of carbonate was greater than if the first was more immediately covered. The thicker gel beds are most commonly found near the base of the chert members, the Plymouth, Norrie, and Anvil. They indicate a superabundance of gel and periods of more voluminous contributions of concentrated solutions. In the aggregate they compose these chert members. When magmatic contributions became weaker, or more dilute, or when they possibly ceased entirely for a time, the carbonate slates and the fine clastics accumulated the slate members such as the foot slate, the Yale slates and the Pence and Anvil.

The foot slates then would mark the first cessation of concentrated emission and the first leisured precipitation from dilute solution. Following them the concentrated solutions again resumed their surface occurrence. For 100 feet or more in thickness there was piled up a succession of thick gels and thin groups of carbonate laminae. This entire pile above the Palms quartzite, including sweepings bed, foot conglomerate, foot slate, and the succeeding 100 feet or more of alternating chert and carbonate has been named the Plymouth Member, Fig. 27 p. 159.

In a general way the whole formation is but a repetition of these processes, concentrated contribution, corresponding immediate gel deposition, dilution, and more leisured carbonate deposition. With dying out of the vigorous magmatic contributions gel beds became gradually thinner and gave way to exclusive carbonate accumulation except for an erratic gush now and then to produce a stray lens of chert such as that pictured in figure 25 (p. 141). On a large scale there are three alternations of gel and carbonate deposition. The first pair includes the Plymouth chert and Yale slate, the second the Norrie chert and the Pence slate, the third the Anvil chert and Anvil slate. Within each such major alternation, however, there are minor alternations of different order of importance. For example, the foot conglomerate and foot slate, both included within the Plymouth member have been described. Within the Yale there are three alternations of this order; the base is carbonate slate followed by a thin chert, in turn it is followed by a second or middle slate and an upper chert, and finally by a third slate. The Norrie succeeds with chert deposition. On a finer order the thin laminae between chert beds represent the same sort of thing. These were undisturbed by any vigorous water action and retained their remarkably regular bedding planes. The source of the precipitate was the supernatant water of probable uniform composition and hence the accumulation was uniform in thickness over great areas. Eastward in Michigan the succession is reported to be more complicated there being a much greater proportion of slate but if the extrusions were from vents along a fissure rather than from a continuous vent, variations might well be expected.

Deposition took place without contact with free air in consequence of which oxidation was a minimum. The jasper of the foot conglomerate is possibly to be explained as due to the oxygen available in the water at first. The first gels forming would probably have absorbed or exhausted this oxygen by oxidation of its carbonates so that subsequent precipitate was practically unoxidized. Aside from this occurrence jasper is almost exclusively associated with slates, which suggests that the fine amorphous silica and absorbed carbonate remained suspended in surface waters long enough to be oxidized by atmospheric oxygen. Moreover, there is far more jasper in the Michigan end perhaps indicative of greater aeration due to the shallower waters and greater wave action in the vicinity of the local volcanic vents.

In the gels the carbonate was disseminated as an emulsoid. During subsequent time this carbonate coalesced to form the oolites which floated in the gelatinous masses.

In the carbonate slate beds little or no change took place excepting compacting and consolidation.

*Subsequent Changes of the Deposit.* The changes referred to in this paragraph do not include the extreme oxidation whose end product was the making of ore, nor those more intense reorganizations and recrystallizations which are more properly considered as metamorphism. These are discussed separately in other places. The changes to be discussed are those which have to do with the rupturing of the thin laminae between gel beds, the formation of the oolites and the replacement of carbonate by silica.

Lenher's results show that if a gel containing 95 per cent of water is subjected to pressures of 340 kilograms per square inch, the gel would still retain as much as 71–73 per cent of water. This pressure is comparable to a column of rock equal to the present thickness of the Ironwood assuming specific gravity to be three. If pressures had increased to 4540 kilograms, the water retained would still be about 60 per cent. This pressure is comparable to the weight of the Ironwood and the Tyler. Therefore, although Lenher's results were gotten from the application of pressures for short time intervals, and therefore it has to be considered that lower pressures maintained for vastly longer periods might have caused even greater degree of dehydration, nevertheless, the tendency is established that the gels hold tenaciously to their water. Also, of course, it is not a proven fact that these gels of the Ironwood originally contained as much as 95 per cent of water. It is evident that they contained much more water than the slaty beds and for their strongly contrasting features water is responsible.

The gels with their water were on that account plastic. They functioned much as a fluid because of the abundance of the water and the fineness of the solid phase. On original precipitation it is deemed probable that the carbonate was thrown down as an emulsoid protected by the silica gel. Subsequently, the carbonate coalesced to form the tiny droplets or oolites. With the increase of pressure and temperature, the water of the gel was slowly driven out. It was saturated with silica and carbonate. The probable tendency would be for the two materials to segregate. The only process in evidence is that by which the silica concentrated itself by replacing the carbonate in oolites and elsewhere. It is perfectly possible, apparently, that the carbonate migrated to larger units of carbonate and reprecipitated thereby enriching these masses. The so-called granular cherts of the formation owe their texture to the replacement of carbonate oolites by silica.

The movement of the escaping waters cannot be traced. Possibly they percolated their way slowly through the overlying formations. Since the slaty beds are much more impervious than the cherts through which the solutions could diffuse at a speed comparable to that of diffusion in solutions, it is believed that a greater component of the movement would be along the beds. This would also bring them toward the joints which are the only avenues of escape.

The plasticity of the gels was apparently not lost until after the thin laminae had become indurated. These latter were broken off, as if very brittle, by the plastic flow of the oolitic gel about the fragments. Slight differentials here and there evidently caused the differential flow of the plastic mass. This flowage is probably responsible for the wavy bedding.

## Events Following Ironwood Deposition

Following the deposition of the Anvil slate, the second member of the third and final gel-carbonate slate couples, according to the succession now recognized, unassorted, unoxidized fine clastics accumulated to a depth of at least 10,000 feet. They constitute the Tyler slate formation, the highest member of the Upper Huronian succession in this district.

This formation followed the Ironwood with but a minor break at best. The question of this relationship and the conclusion reached involve the examination of the contact between the two with view to determining whether there was long erosion or even a lapse of deposition. These questions are identical with the ones raised in connection with the Palms-Ironwood contact and are treated in the same way.

By way of introduction to the analysis of the evidence, it is to be pointed out that the Tyler is in many respects the counterpart of the Lower Palms. It may, therefore, be considered as the resumption of Palms deposition. The sediments of the two formations as well as their textures and sedimentary structures are practically identical. Even bedding, although not invariable, is characteristic of both. They were apparently deposited under like conditions. And if the evidence that the Ironwood was deposited under like conditions be considered, despite the fact that its materials were largely of extra-surficial origin, it is then apparent that the same sort of sedimentary environment persisted from the beginning of Palms time until the close of Tyler time. In fact, the extraneous origin of the Ironwood and the presence of fine clastics in its more leisurely deposited members indicate that the same type of sediment was undergoing deposition although masked by the superabundance of the magmatic precipitate. A great area had begun to sink in early Palms time, and except for minor warpings possibly wholly within the basin itself, and having axes related to those of the basin, this sinking had persisted throughout the Upper Huronian. These warping movements are believed to have been related to the rising of the Great Keweenawan magma.[1]

The first question to consider in connection with the relationship of the Ironwood to the Tyler is whether there was a long erosion period between the two. A decision is difficult. Exposures are not numerous along the zone of contact. Relief is generally slight, and as the slope is toward the contact, it is generally well covered. Irving wrote,[2] "In the few localities in which the transition from the iron-bearing to the upper slate member is exposed the change is quite gradual". Later Hotchkiss wrote,[3] "The longest period of erosion is that between the deposition of the Anvil member and the beginning of the deposition of the Pabst. . . In other words, the greatest unconformity at present known between the base of the Palms and the base of the Keweenawan." Here is a possible conflict of ideas although this could be the greatest unconformity known between the given limits and still not be great. So far as the writer has been able to view the situation in the field, the transition would appear to be gradual, and it seems to be a fact that in the field there is no evidence of regional convergence of strike or dip, and no evidence of local gullying. Hotchkiss based his contention upon underground data and he writes,[4] "The transition of the Anvil member to the overlying Pabst member is almost invariably an abrupt one. In the eastern end of the range, where the Anvil member is thickest, it is usually followed by a thin carbonate slate, but in the western portion, where the formation has nearly all been eroded away, the transition is usually marked by the beginning of the conglomerate and the granular jasper associated with it." In another place he writes,[5] "On referring to figure 17 it will be noted that this formation is present in sections 3, 4, and 5, and is missing in section 7, is again present in sections 8 and 9 and then does not appear again until section 13 is reached, from which point it is continuous to the Mikado Mine."

---

[1] Hotchkiss, W. O., The Lake Superior Geosyncline. Bull. G. S. A., Vol. 34, pp. 669–678, 1923.

[2] Irving, R. D., and Van Hise, C. R., The Penokee Iron-bearing Series of Michigan and Wisconsin: U. S. Geol. Survey, Mon. 19, p. 297, 1892.

[3] Hotchkiss, W. O., Geology of the Gogebic Range and Its Relation to Recent Mining Developments: Eng. and Min. Jour., vol. 108, p. 506, 1919.

[4] Hotchkiss, W. O., Geology of the Gogebic Range and its relation to recent mining developments: Eng. and Min. Jour., Vol. 108, p. 507, 1919.

[5] Idem, p. 505.

On checking this statement with the diagram it is found necessary to add that the latter indicates also that the formation is also missing in section 6. The checking process also brings to light the matter of fact that indeed very few of these sections actually penetrated the contact and hence they do not support any idea of a significant time break.

The second phase of the problem of relationships concerns the question of lapse of deposition. Here, as in the case of Palms-Ironwood relationships, the very best evidence is that materials characteristic of the lower formation continue on up into the upper, at least for a distance. Carbonate of iron sufficient to give 15 per cent of iron, occurs mixed with the Tyler for several hundred feet above the base of that formation. This transition would appear to be very good evidence of continuous deposition.

Further evidence of continuous deposition is seen in thin sections made from core from a diamond drill hole in T. 44—R. 3W. Here there is a zone nearly 125 feet thick of mixed iron formation and clastic detritus. Some beds are fairly clean iron formation, principally carbonate, others nearly pure clastic, and others are good flinty chert. This transition is taken to indicate continuous deposition; clastics came into the basin before iron formation had finished.

Accordingly, from these analyses of the available evidence on erosion and lapse of deposition, the writer concludes that the Tyler succeeded the Ironwood with but a minor break.

*Conglomerates.* In connection with the conglomerate which Hotchkiss[1] describes in connection with his description of the Ironwood-Tyler unconformability, it may be well to recognize the more general occurrence of such formations.

In the Ironwood, conglomeratic material is seen not infrequently in the chert members. There are at least three fairly persistent conglomeratic horizons. These are at the tops of the chert members, from base up, at the top of the Plymouth, the Norrie, and the Anvil.

The idea is offered that the formation of these conglomerates by the breaking of earlier beds is related to movements or shocks caused by the magmatic movements. In developing the hypothesis to account for the differences between the cherts and the slates, the former were related to periods of vigorous and voluminous mag-

[1] Hotchkiss, W. O., Eng. and Min. Jour., vol. 108, p. 449, 1919.

matic contribution. The slates were related to periods of weaker contribution and more leisured precipitation. It is conceivable, therefore, that the former periods were brought to a close by or accompanying some shock or movement due to a subsurface event. Such a shock with a consequent reflection upon the water in the basin, such as what might be likened to a tidal wave, might well be responsible for the occurrence of these conglomerates as the closing record of these periods of rapid deposition. In all cases the conglomerates were covered by the slowly deposited slates.

The conglomerate at the top of the Ironwood which was followed by the Tyler clastic deposition is interpreted as a reflection of the temporary collapse of the magma following its emission of the materials of the Ironwood.

## Clastic Deposition of the Tyler

Unassorted clastics carrying fine silicate flakes, angular quartz grains, and feldspars make their appearance in the iron formation 125 feet below its top, as shown by drill core from a point west of Penokee Gap. There are no available data on such a thick transition zone elsewhere in Wisconsin, but, as stated above, carbonate slates continue on into the Tyler for several hundred feet, and analyses run as high as 25 per cent iron. The inference from these facts is that the muds returned to deposition in this basin not at the same time nor with equal volume over the entire area, but irregularly. Thus, in the west they entered even before the chert of the iron formation had finished precipitation and in the central area perhaps not until after chert had finished but before carbonate had concluded its deposition. It is reported that in Michigan there are bands of iron formation out in the Tyler which would seem to reflect local rejuvenations of magmatic activity.

Just what is responsible for return of clastics is difficult to determine, but presumably differential warpings should be considered. The clastics certainly came from sources outside the portion of the basin in which iron formation had deposited. They may represent a shifting of detritus that had been going down outside of the portion of the basin accumulating iron formation, or they may have been first-hand sediments from off the surrounding land mass. Throughout this whole period this basin appears to have been sinking and outside there must have been a relative uplift. If, as suggested, the basin floor had been warped by the upthrust of an arch over the wedge of magma below and complementary thereto downwarped to form a trough serving as a catchment area for iron formation, and the normal clastics had been thereby restrained shorewards, the return of muds may have coincided with the subsidence out to the north. Sediments then spilled over onto the iron formation. Just as it is conceived that the appearance of magmatic solutions at the surface would have produced an uparching, so it would seem likely that dying out of this volcanic activity would result in differential settling. At all events, immediately following the cessation of magmatic contribution the longest period of continuous clastic accumulation and foundering was initiated. The muds which had been held in abeyance were then shifted into the trough in tremendous volumes.

## Events Following the Tyler Deposition

Tyler deposition was brought to a gradual close by the warping of the central basin along an axis approximately parallel to that of the basin. The actual close of the deposition was caused by the outbreak of Keweenawan lava floods. This view of the situation is extreme, however, and requires some observations in its support.

There are no continuous sections across the Tyler but there are several places where the portion closest to the Keweenawan is fairly continuous. One such in sections 11 and 12 of T. 45—R. 1W. of Wisconsin may be taken as a type. This section is located about midway between Mellen and Hurley and a brief description follows:

Near the S¼ of section 12 quartzites occur containing half inch subangular pebbles of vitreous quartz. These pebbles give the rock a conglomeratic appearance and suggest a change in the source of the sediment from that which had been supplying the main mass. They do not, however, indicate any lapse of deposition. Farther north are more slates. Still farther north by 150 paces is an exposure of conglomerate about 8 feet thick. This formation contains a variety of pebbles up to 6 inches in diameter and as small as one-fourth inch all thoroughly cemented by a coarse-grained quartzite. The pebbles consist of milky quartz, quartzite, and iron formation, which latter includes both red and black banded jaspillites. The larger boulders are of quartz and quartzite. The iron formation pebbles are generally the smaller and they are seldom as well-rounded as the larger boulders. This is, however, probably explained by the fact that the iron formation is generally of the slaty variety. This conglomerate grades up into a similar thickness of quartzite containing well-rounded grains of quartz as well as subangular pebbles of the same. This is much like the conglomeratic quartzite seen south of the conglomerate and suggests a similar origin and hence no lapse of deposition. Above the quartzite is feldspathic quartzite 6 feet thick containing angular pink feldspar. This is succeeded by an amygdaloidal lava flow which in turn is overlain by thin beds of fine-grained micaceous quartzite and a white calcareous chert about 2 feet thick. The succeeding flow has a thin brecciated base and an ellipsoidal structure suggesting subaqueous extrusion. Cementing the ellipsoids is a mixture of coarse feldspar and quartz.

The conglomerate may be seen at such frequent intervals between Mellen and Hurley, and according to reports, for some distance east in Michigan, as to indicate its continuity. Throughout, so far as there is any record, the formation is of the same approximate thickness. Across the strike there is no direct evidence of lapse of deposition until the lava floods overwhelmed the basin. The presence of the sediment between flows for a distance of 400 feet up into the Keweenawan, and the ellipsoidal and brecciated bases of flows indicate that water deposition was going on when the lavas made their appearance.

If we were to apply this evidence which appears to represent the central part of the basin to the basin as a whole, it would appear that an uplift had occurred more or less parallel to the axis of the basin so that the thickness of the new deposits was approximately constant along the outcropping edge. It would appear moreover, that the uplift had occurred at some time previous to the deposition of the conglomerate, being responsible for the alternation of the more slaty phase of the Tyler and the quartzites.

There is an objection to the application of this simple picture to the basin as a whole for the reason that west of Mellen there is no conglomerate and in Michigan east of Sunday Lake the conglomerate is found lying directly upon the Ironwood. The latter indicates that there was no Tyler for the conglomerate to be deposited upon, which means either that there the Tyler had not been deposited or that it had been deposited to at least some thickness but was subsequently eroded. In view of the fact that erosion is indicated at this horizon in most places around the lake, it must be considered that the Tyler had been deposited at least to some thickness. But not much farther east it is evident that throughout the Upper Huronian time there had been local volcanic vents which may have produced local warpings not parallel to the main axis of the basin. Here, during the uplift reflecting the imminent appearance of the Keweenawan magma at the surface, erosion may have gained rapid headway toward exposing the Ironwood. From it the pebbles of iron formation in the conglomerate farther west may have been derived.

The situation west of Mellen is different. In 8 miles the Tyler is reduced in thickness from 10,000 feet to nothing. It is not seen for certainty again until we get to the Trappers Lake vicinity some 15 miles farther west. The Ironwood is partially or wholly missing in several places in the interval. The whole Huronian sequence has been folded in this region and the strongest suggestion is that the erosion interval preceding the Keweenawan was long enough to have embraced orogenic movement. This would hardly explain why the conglomerate should be missing, however, an erosion period to account for the removal of the conglomerate would have to be even later, and it too should have left a conglomerate.

The explanation which has been offered in some detail in Chapter VI on the structure of the Huronian is that the Lower Keweenawan conglomerate, the Tyler, and part of the Ironwood in this region was carried away by a strong thrust fault which also carried away apparently some 10,000 feet of the base of the lava series. The presence of the unconformity across the region from Mellen west cannot be denied, but with the evidence that there was a thrust along the same line of contact, the depth of the erosion that had formerly been believed to be great must be somewhat discounted. Thrusting could have accounted for the entire bevelling. Moreover, the folding in this region which is a strong suggestion of erosion, has been found to be identical with that of the Keweenawan which lies above. It, therefore, appears to have been of post Keweeenawan origin.

It is possible, therefore, to apply the idea of an uplift parallel to the axis of the basin to the western two-thirds of this district. It seems probable that the uplift took place out to the north, parallel to the axis of the Lake Superior Syncline, and due to the rise of the Keweenawan magma.[1] In other words, therefore, it appears

[1] Hotchkiss, W. O., The Lake Superior Geosyncline, Bull. G. S. A., Vol. 34, pp. 669–678, 1923.

that the closing events of the Huronian period were also the opening events of the Keweenawan period, or, the sedimentary record is somewhat broken but the volcanic record takes its place.

In passing, it is to be noted that the thickness of the Tyler need not necessarily mean great length of time. If the subsidence following the Ironwood deposition permitted sediments to be moved farther north into the basin, the thickness would be increased by this secondary factor. And if later in Tyler time the center of the basin was uplifted, and the sediment over this were shifted south, then the total thickness in a relatively narrow trough would represent far less time than if the 10,000 feet had been accumulated over a greater area.

With the last of the sedimentary tendencies of this basin finally overcome by the flood of lavas, there ensued continuous extrusion until a depth of some 3–4 miles of these lavas had been accumulated. There is evidence to show that the lavas came from the north. Briefly, the flows thicken as they are followed down the dip in the Michigan mines. If they were poured out from vents to the north, they would normally thin out or wedge off toward the south. The tops of pipe amygdules in the bases of flows have been observed to be bent up the dip. While this might be due to differential movement during the formation of the syncline, there seems to be no evidence of breaking across these structures. The cross-bedding in conglomerates intercalated with flows near the top of the Middle Keweenawan series shows movement of sediment from north to south. The cross sections of intrusives that have been upthrust are wider or thicker than those of portions which have been stationary. This indicates that the source of the injections was down the dip.

The lava floods finally gave way to a return of sedimentary conditions and the later flows are intercalated with sediments. These are for most part alkalic or acidic. In fact the conglomerate in T. 44—R. 6W. is accompanied by andesitic flows which occupy gorges cut in the conglomerate. These andesites are fragmental on top and have suggested that the materials of the conglomerate were derived in considerable part from the brittle, glassy flows. In this connection, it has been observed that there is more acidic material in the conglomerates than is indicated in the outcropping of flows of this composition. The reason has been advanced that this is because the acidic flows were more viscous, they did not flow so far, but instead were piled up near the vent. The evidence that the currents carrying the sediment came from down the dip or to the north suggests that the vents are also in that direction. Hence there would not be a balance between the visible supply and the amount of acidic material in the conglomerates.

These sedimentary conditions were overcome temporarily by a rejuvenation of volcanism and the so-called Lake Shore traps were poured out. Following them, however, the basin continued to subside and there was laid down some 5 miles of conglomerates, shales, and sandstones. At some time during the Upper Keweenawan period the development of the Lake Superior syncline began. The Upper sedimentary series took part in this as is proven by the folds described by Thwaites.[1] When tilting of the series of flows and the underlying Huronian began cannot be stated but it probably began on a small scale quite early to allow for a gentle southward slope of the lavas.

The origin of the structure of the Lake Superior syncline has been discussed briefly in a paper by Dr. W. O. Hotchkiss[2] in which he embodies the general view given here. "The gradual foundering of the roof of this bathylith is believed to offer the most plausible explanation of the origin of the present structure."

The writer, from an analysis of the structural evidence offered by the Keweenawan of Wisconsin, has carried the origin of this structure to a more extreme view. The evidence that the formations in the vicinity of Hurley dip more steeply to the north than those to the west, has been taken to mean that there was an earlier, greater, or longer continued tilting toward the axis of the syncline in the region to the northeast than in the region to the west. This differential tilting would have set up torsional warping stresses, and if these be analyzed as has been done in the chapter on structure, then we should get the results observed in the field.

The first of the developments would be a minor synclinal structure striking at an angle to the axis of torsion. Such a syncline is believed to be the one that strikes about N. 15° E. through the southwest of T. 44—R. 4W. and out through Chequamegon Bay. This structure is not so clearly reflected in the Keweenawan because of the later injections. We should also get a complementary anticlinal structure striking at right angles to the minor syncline. This is represented by the Huronian between Coffee Lake and

[1] Wisconsin Geol. and Nat. Hist. Survey, Bull. XXV.
[2] Bull. G. S. A., Vol. 34, pp. 669–678, 1923.

Trappers Lake, and by the great fold in the Keweenawan between Marengo Lake and the southwest of the map area. Plate I.

These minor structures are the result of the early stress conditions in the formation of the main Lake Superior syncline. The stresses of the major structure were compressional along the axis of the trough. These resulted in the movement of upper beds away from the axis and up the limbs of the structure. The great Keweenaw thrust was developed in this way during or following the development of the minor structure just referred to. This thrust has been found to follow across the map area from the Montreal River to the southwest of the map area. That part of it which occurs west of Mellen was described on an earlier page. Briefly, it is the contact between the Huronian and Keweenawan west of Mellen. The Keweenawan flow series above has been thinned by the thrusting away of some 2½ miles of its base. The Huronian below was either eroded away earlier or carried away by the same thrust.

East of Mellen the thrust climbs up into the series so that in the 25 miles between Mellen and Hurley, the thrust gains about 2 miles stratigraphically. Farther east it has been mapped by the Michigan geologists.

Contemporaneously or subsequent to the formation of this thrust, there was an injection of gabbro along the thrust plane. This is clearly defined on the map and is discussed in connection with the thrust in Chapter VI. Its western extent within the fault plane is delimited by the east limb of the subordinate anticline west of Coffee Lake. It extends farther west but not in the thrust plane, and it does not appear to get farther west than the axial plane of the subordinate anticline.

This gabbro is responsible for the metamorphism of the Huronian formations. The Tyler in the east is less siliceous than in the west, and it is represented by chlorite in the east and mica in the west. Its base is fairly rich in carbonate to the east and in magnetite to the west. The Ironwood near Hurley is markedly magnetic in the upper horizons only. Going west, it becomes more and more magnetic in deeper horizons until at Tylers Fork its footwall may be readily detected magnetically. From that point west there is little additional increase in magnetic intensity. Near Hurley the formation is well oxidized. Going west the intensity of oxidation decreases and west of Tylers Fork it is apparently negligible. The texture of the cherts also changes from east to west. In the east it is commonly very fine, but with distance west it becomes coarser and coarser. The specific gravity also increases to the west. Also, in tracing the formation west, there appears a steadily increasing proportion of amphibole and other silicates.

All these changes in texture and mineralogy are of the sort described as due to the increase in energy. There has been an input of heat in the combining of the silica and iron to form silicates, in the elimination of the carbon dioxide and the formation of magnetite, and in the reduction of volume by the increase in density. The one great source of energy in the region is the great gabbro out to the north. On general principles this would appear to be responsible for the metamorphism. It may be pointed out, however, that the increase in these changes from east to west correlates with the decrease in the distance between the gabbro and the Ironwood from east to west. It has been shown that the base of the gabbro bevels the underlying formations in this direction and the increase in metamorphism is a reflection of this. It can be pointed out further that the eastern limit of the gabbro mass lies upon a line, which, if drawn perpendicular to the Ironwood would pass through the western edge, approximately, of the Montreal Mine. Although there have been ore bodies mined west of here, they were not of the size found in the Montreal. In other words, the western limit of complete oxidation seems to be coincident with the eastern limit of the large laccolite of gabbro.

Some doubt has been expressed by geologists that the gabbro which is 12,000 feet or more above the Ironwood could have been responsible for its metamorphism. The distance is too great according to them. The suggestion is offered here that the water content of the formation according to the theory advanced in this chapter may have been the special condition offsetting this great distance. The solutions would greatly increase the metamorphic changes by promoting chemical change and by their greater heat conductivity. Furthermore, the presence of these solutions is possibly responsible for the flow of rock represented in the folding from Tylers Fork west. East of that point, there is no evidence of deformation by folding. In short, the recrystallizing of the formation and the folding are probably of simultaneous origin. These siliceous solutions are probably also responsible for the silification of the top of the Palms.

At some point in time during this period the Ironwood and Tyler had been jointed along direction NE–SW and NW–SE. These were then injected by the dikes that are so important in the formation of ores. Furthermore, there is a bedding fault of considerable importance which shears off the dikes. The fault lies mainly in the Yale member of the formation and the movement[1] was such that west of the Tilden Mine in Michigan, upper beds moved up the dip and east, while east of that mine the upper beds moved down the dip and somewhat to the west.

This bedding fault has not been seen west of the Atlantic Mine in T. 45—R. 1E. At Tylers Fork there is no evidence of it. On the other hand, here is where we first see the up-dip folding. Within a distance of 6 miles then, the movement on the bedding fault evidently becomes a maximum and disappears, and the first of the up-dip folding occurs. The suggestion is that at Tylers Fork or near by, the synclinal stresses combined with the torsional stresses and produced up-dip movement of the upper beds. This was relieved east of the Forks by the gliding on the bedding fault, and west of there by the folding and recrystallization. The latter has been found to correlate in time with the injection of the gabbro which was coincident with or preceded by the great Keweenawan thrusting.

There appears to have been this sequence of events. The Huronian was jointed. The Keweenawan thrust was begun. The magmatic injections came into place gradually filling the joints of the Huronian. Then movement on the thrust was accelerated and under these movements the Ironwood was deformed by up-dip movements. West of the Forks, where the gabbro was much closer, the Ironwood recrystallized and folded. East of the Forks the Ironwood broke along the Yale member and the bedding fault was formed. This sheared the dikes.

The cross faults may be accounted for in the theory of torsional warping as developed in Chapter VI. According to this theory the faults are tensional cracks formed during the torsion and they should strike to the northwest along the beds as they lay horizontally. The movement upon them probably did not occur until later in the course of tilting. West of Mellen there is evidence that movement on these faults took place late in Upper Keweenawan time. Farther east it is apparent that the movement did not take place until after the gabbro injection. These faults cut Huronian, Lower Keweenawan, Middle and Upper Keweenawan. The

[1] E. and M. J., Vol. 108, p. 540, 1919.

movement upon them was rotatory as shown by the fact that the magnetic attraction changes in width abruptly at these faults.

*The Formation of Ores.* Following the development of the Lake Superior syncline the outer rim of the formations was subjected to more vigorous erosion. If the folding had not been effective far from the present outcrop, then to the south there was a more or less flat-lying series. This has been eroded away. With advance of the erosion the folded portion or monoclinal portion was exposed.

With their bevelled edges exposed to the atmospheric processes, there was an opportunity for oxidizing waters to gain access to the formation which was rich in ferrous carbonate. Joints, the bedding fault, and the innumerable cross faults, were perhaps the largest of the openings through which water gained access. However, the original pore space in the aggregate probably functioned in the most important manner in letting the waters into the formation. These waters carried oxygen to the ferrous carbonate, and oxidized the latter to hydrous oxide. The elimination of carbon dioxide and the increase in density of the oxide over the carbonate provided an additional porosity. The waters also took silica into solution thereby adding further to the porosity. In these various ways waters made their contact with the formation and continued deeper and deeper down the dip. In some beds there was probably greater porosity than others. If these were originally richer in iron carbonate there was a greater conversion of carbonate to oxide.

The principal factor in the making of ore was thus the infiltration of oxidizing waters. Of second importance was the factor of concentration of the underground flow. Certain of the beds, for example the slaty type, were more impervious and waters did not pass through them readily, but instead passed deeper along them. Thus the flow was concentrated in more pervious members or beds. By far the most important factor controlling circulation was the dike. These have been described as occupying joints that are essentially perpendicular to the bedding of the formation and when the formation lay horizontally they had strikes either northwest or northeast. With the formation tilted to the north these dikes dip to the south or southeast and the intersections pitch to the west or to the northeast. Therefore, the waters percolating through the porous beds or flowing in sheets on impervious beds eventually met dikes. The dikes, therefore, deflected circulation along themselves gathering the waters from steadily increasing depths and concentrating their flow to greatly restricted channels. The impervious beds diverted downward flow to the northward in the direction of dip. The dikes deflected it southward. The intersections were, therefore, the principal channels. The dikes also deflected movement eastward, and accordingly, the channels pitch eastward and northward, and down the plane of the dipping formation. Ultimately, the intersection of the dikes and the quartzite top of the Palms became the main channel. There was, therefore, a universal concentration of waters along the footwall and here with oxidation of all the carbonate and the extraction of all the silica, there was formed the blanket of ore which characterizes that formation as the leading ore making horizon. In some mines this is practically the sole ore producing horizon.

The intersections of other impervious beds with the dikes have also functioned in concentrating the flow of water and here ores have been formed. There are thus many permutations and combinations of the several factors which make for ore deposition. Original high iron content is of possibly first importance although obviously with long continued exposure to solution activity beds with lower iron content have made ore. Opportunities for the ingress of waters is also of importance and close fracturing without appreciable movement is favorable to ore making. Concentration of this flow is of equal importance. Instead of dissipating their activity over a large mass of formation these waters are focussed upon smaller volumes by the impervious beds and by the dikes.

The main ore deposits are on dikes. There are some which lie upon the intersecting dikes and in the intersection there is naturally a huge concentration of ore. There are ore bodies in the zone of the bedding fault and also in the zones of cross fracturing where flow has been restricted. The intersection of such a zone with a thick dike is, of course, attended by wholesale concentration. The breaking of a dike offers a constriction through which the waters have to pass and by thereby concentrating the flow the oxidation and leaching of the formation is locallized and ores have developed.

There are 6 horizons most amenable to ore making according to Hotchkiss.[1] These are:

[1] E. and M. J., Vol. 108, p. 579, 1919.

1. In the lower part of the Plymouth member.
2. In the upper part of the Plymouth member.
3. In the bedding fault horizon—either in the Yale member or basal part of the Norrie.
4. Near the contact of the Norrie and Pence members.
5. In the Anvil member.
6. In the Pabst.

In Wisconsin numbers 1–4 inclusive are most important in that order. Of these number 1 and 2 are most productive. Number 3 was the locus of the bulk of the production from the Atlantic and Iron Belt mines. Number 4 is the locus of the great hanging ore body of the Montreal Mine but it has not been found to be productive elsewhere in Wisconsin.

# PART II

## MAPS AND DETAILED DESCRIPTIONS OF TOWNSHIPS

## TOWNSHIPS 45 AND 46N., RANGES 2 AND 3E.

The surveyed area in these townships comprises the southern 4 rows of sections in 46—2E., the fractional sections 30 and 31 of 46—3E., the northern row of sections in 45—2E., and section 6 of 45—3E.

### SURFACE FEATURES

This area lies entirely within the Lake Superior Highland Physiographic Province. Underlying formations control the surface features. In the northern part of the area the topography reflects the steeply northward-dipping Keweenawan lava flows. See figure 14. Here the topography is rough, with ridge-like tendencies following the strike to the northeast. Naked knobs and ridges of diabase and basalts abound. Transverse valleys which cut through the series can be identified as faults along the southern boundary of the series which is the most prominent topographic feature in the area. This is a precipitous escarpment extending continuously, excepting for the dislocations produced by the transverse faults, from the northwest of section 30, 46—2E. to the northeast of section 14 of the same township. The escarpment is no less than 150 feet in height and is known locally as the Trap Range.

South of the escarpment lies a broad inter-range valley some 2 miles wide. Relatively soft slates and graywackes, the Tyler formation, structurally conformable with the hard iron formation to the south and resistant traps of the north have been eroded away producing this intervale with an assymmetric profile. Along the foot of the trap range the main drainage flows parallel to the structure. From this to the south the slope is a gentle rise for upwards of a mile, succeeded by a steeper ascent to the crest of the Gogebic Range which roughly follows a line from the west quarter of section 6 in 45—2E. to the south quarter of section 24 of 46—2E.

The principal exception to this regular ridge and valley topography is the series of low but prominent hills in the Tyler valley in sections 30 and 31 of 46—2E. On these intrusive gabbro offshoots from the larger laccolite to the north are exposed.

The Gogebic Range is here controlled by the Archean granites and the Palms quartzites and schists. The Ironwood lies beneath the steeper north-facing slope of the Tyler valley. This southern ridge is serrated on account of several transverse faults which correspond to those of the Trap Range. In the eastern portion of the area the relief of the Gogebic is around 50 feet. In the west it is closer to 200 feet.

South of the Gogebic Range granites and greenstones abound. In direct response to this the topography is a gently undulating terrain of subdued relief. Locally steep slopes on bare rock are to be seen, of which the most notable example is the knob of crystalline intrusive on the east side of Lake Lavina in section 25 of 46—2E.

The influence of the glaciers in fashioning the topography of the area is not deemed to have been great. It appears that a local interridge tongue occupied the Tyler Valley and moved southwestward along the trench. Scouring, grooving, and plucking in the Trap Range have been observed. The granites of the Archean have suffered somewhat similarly. Ground moraine generously representing the traps of the Keweenawan series and Tyler slate is the dominant mantle. This varies in thickness but excepting for filling the pre-glacial valleys is probably not generally excessively thick. Along the West Branch of the Montreal, in section 21, is a deposit of gravel which is apparently an esker reflecting the probability that glacial drainage followed the fault zone which, at present, governs the course of the West Branch. In the southwest of 27 and the northwest of 34, on the west bank of the West Branch of the Montreal is a large deposit of sand and gravel which is probably to be classified as outwash related to the glacial antecedent of the stream.

The drainage of the area is controlled by the rock structure. The ultimate drainage is by way of the two main streams, the Montreal River and the West Branch of that stream. These flow northwest across the Gogebic and the Trap ranges in courses perpendicular to the strike of the ranges and under the direct control of the transverse faults. Tributary to these are creeks which flow parallel to the strike of the formations, which is northeast. The beds of the main streams are nearly everywhere boulder-strewn, but the minor creeks are usually sluggish and in places are scarcely more than marshes.

The area is practically all clear of timber. Second growth, largely poplar and hardwood brush, makes traversing difficult in a large part of the area. Approximately a quarter of the area is cleared and small farms have been developed, more especially close to Hurley.

Hurley is the county seat of Iron County. It is a prominent city in the region and the source of supply for the mining companies. Two railroads make contact, the Soo Line extending along the Range from Mellen, and the Northwestern, which is a main line between the south and Ashland. Ores are shipped to the lake at Ashland over both these lines. Other communities are Gile, Montreal, and Pence. In these the principal occupation is mining but there are small enterprises to supply the necessities for the miners' families.

One first-class road, State Trunk Highway No. 77, is the main travelled route between Hurley and Mellen, 25 miles west along the range, where it makes a junction with State Trunk No. 13, an important artery for north and south travel across the state. U. S. Highway No. 51 enters Hurley from the south and U. S. Highway No. 2 runs north and west out of Hurley.

## General Geology

### *Archean*

The oldest formations in the area are crystalline rocks forming the floor upon which the Huronian sediments were deposited. At this place a general statement is made and excepting for the significant details it will not be repeated for the townships farther west.

These ancient crystallines are not possessed of even the slightest trace of evidence of remains of life. There are variations in composition from highly basic "greenstones" to acidic granites. The former as a group are definitely older and are invaded by the granites. The former have been assigned to the Kewatin and the latter to the Laurentian.

The Kewatin formations are dominantly greenish and characteristically schistose. Variations are structural and mineralogical. For most part the essential minerals are chlorite, biotite, or hornblende. As a group they appear to represent basic extrusions, intrusions, and possibly some sediments. The former is deduced from the presence of amygdaloidal structures with various mineral fillings. The intrusive character of others is attested to by the field relationships, crystallization, and structure. The possibility that some are sediments is suggested by a well developed banding and the folding of these into intricate patterns. Schistosity of the group wherever it is pronounced is striking roughly north and south and dipping eastward.

The granite of the Archean is evidently a major intrusive. It is usually very coarse-grained and is not conspicuously gneissic. It exhibits variation in composition, texture, and structure, as well as the usual accompaniments such as pegmatites. The type specimen is pinkish gray containing quartz, pinkish orthoclase feldspar, and hornblende. The pegmatitic phases are generally pure feldspar or quartz.

The granite occupies the southeastern corner of the area, that is, the southeastern 9 sections or fractional sections of the map area. It continues on to the eastward as the formation immediately beneath the Palms. To the west the area below the Palms is greenstone, excepting for small areas, for example, in section 5 of 45—2E., where evidently the granite is merely an offshoot of stock-like or dike proportions, as far as Penokee Gap in 44—3W.

### *Huronian*

The Huronian of the district in Wisconsin is represented by four formations, from oldest to youngest, the Bad River dolomite, the Palms quartz slates and quartzite, the Ironwood iron formation, and the Tyler slates and graywackes. The Bad River lies unconformably upon the Archean, and is unconformably overlain by the Palms. The Palms-Ironwood relationship has been discussed in detail in chapter VII, where it is maintained that the two formations are conformable. Similarly, there is much to be desired in regard to the relation between the Ironwood and the Tyler. In the chapter referred to, this relationship is described as probably conformable. The Tyler is considered as unconformable beneath the overlying Keweenawan. The Bad River dolomite is, therefore, considered to be of a lower Huronian than the Palms, Ironwood, and Tyler.

*The Bad River Dolomite.* This formation does not occur in the township, so far as can be learned. It is not exposed in outcrop, and the mine openings, such as the shaft crosscuts from the vertical shaft of the Montreal Mine to the Ironwood, penetrate greenstone and then Palms.

*The Palms.* This formation is only sparsely exposed in the townships. The best section available is along the West Branch of the Montreal River. The rock is a straw colored aggregate of feldspar and quartz. The feldspars are not badly altered, which fact suggests that they were derived from a granitic rock undergoing disintegration rather than decomposition. The formation is thin-bedded with layers varying in thickness from about one-fourth of an inch to about 1 inch. The top of the formation is capped by a nearly pure vitreous quartzite whose thickness varies from 20 to 50 feet thick along the range. The thickness is not known to vary greatly within short distances. Toward the base of the Ironwood, and between it and the vitreous quartzite, is a bed varying in thickness from 5 to 10 feet. This bed is a mixture of quartz grains and very fine-grained chert. It represents the gradational relationships between the two formations. In Chapter VII this transitional bed is given great weight as indicating the conformable relationships. The more unclassified portions of the Palms sometimes show ripple marking and cross-bedding, which indicate a general southwesterly movement of the materials. The relation of the Palms to the Archean is shown in an exposure in the southwest of section 32. Here the base of the Palms consists of a 6-foot bed of conglomerate comprising pebbles of quartz, chert, granite, and green schist, with a matrix of fine, dark-colored clastic. Most of the pebbles are granite. They are well rounded and about 1½ inches in diameter. The largest pebble noted measured 9 inches by 5 and was also granite. Immediately below the conglomerate is greenstone but this has been intruded by granite to within a couple of feet of the conglomerate contact. The conglomerate is succeeded by 6½ feet of quartzite. The Palms is here about 400 to 450 feet thick.

*The Ironwood.* The Ironwood is poorly exposed across these townships. However, here the most extensive underground workings are located, there are hundreds of test pits, and there have been thousands of feet of diamond drill holes sunk in scores of locations. These fairly well settle the question as to the possibility of finding ores at least to a depth of a thousand feet. Plate VIII.

Section 24 of 46—2E. has been explored at various times and by various companies. Two properties, the Germania on the southwest quarter and the Minnewawa on the southeast, now long since abandoned, produced in the neighborhood of half a million tons of ore. The ores lay along the footwall quartzite in thin blankets bottoming upon dikes. The section is well supplied with dikes, but the upper horizons are poorly oxidized and leached. The ore bodies die out to the westward and appear to have been influenced to no slight degree by the several transverse faults which control the course of the Montreal River.

Section 26, east half, is known as the Windsor Mine. This exploited thin footwall ore bodies and operations were abandoned at a depth of 1500 feet. The main ore body was areally extensive upon the footwall and was an erect chimney coming to the grass roots.

The west half of section 26 and the adjacent eastern quarter mile of section 27 are known as the Cary Mine. The western portion of this ground has been far more productive of ore. The bodies are thin footwall blankets carried by dikes and influenced obviously by cross faults. In the lower levels the tendency is for ore bodies to widen out. In part, at least, this can be accounted for by strike faults which have duplicated the formation, but also oxidation and leaching appear to be more vigorous at depth. The block of ground between the Windsor and the Cary has not until recent years been looked upon with favor by the operators, but present developments at intermediate levels look somewhat promising.

Adjoining the Cary Mine on the west in section 27 is the former Ottawa Mine of the Montreal Iron Mining Company, and now known as No. 6 shaft of the Montreal Mine. Workings here are quite similar to those in the Cary. The ore bodies are 10 to 15 foot seams along the footwall. The property has been developed to the greatest depth on the Range. In 1928 the lowest level was 2700 feet below surface or 1000 feet below sea level. The projection of the mine workings upon a vertical plane parallel to the formation outcrop shows the most thorough exploration of the ore-bearing horizon conceivable. The ore bodies are definitely in control of dikes but the largest mined area shows that the ore passed through successively deeper dikes like an erect chimney. This indicates the presence of a sheared zone which functioned as the adit for oxidizing waters. In the deeper levels ore bodies are showing tendency toward greater width. This mine has produced large tonnages of ore carrying up to 5 or 6 per cent of manganese.

In sections 27 and 33 are the workings of the Montreal Mine. This is one of the 3 ranking properties of the Range, during the period from the first shipments. Here alone among the Wisconsin producers the ore bodies are not confined to footwall blankets. The main control is with the dikes, although the largest body yet mined was in considerable measure related to a zone of cross-fissuring, which also produced a chimney-like ore body.

In the main ore bodies at present the enrichment extends through the Plymouth, the Yale, the Norrie, and well into the Pence. In a few instances the ore carries from foot to hanging, a width of between 400 and 500 feet.

The projection of these workings on the vertical plane shows the dominance of long bodies of ore lying on the eastward-pitching dikes. The presence of the bedding fault in the Yale may have played a part in the extensive oxidation. This was a later event than the dikes which are offset. In consequence of this there are in reality two ore-bearing horizons, a lower or foot and an upper or hanging.

In connection with the presence of the two ore-bearing horizons in the Montreal and the absence of such in the properties east, it is interesting to note that there is a cross fault of considerable magnitude in the region immediately west of the West Branch of the Montreal River. This fault is interpreted from the magnetic observations along a belt of high attraction in the hanging zone. It is confirmed by the observations along the base of the Trap Range. It also is indicated by the change in the character of the ground in passing from the Montreal to the Ottawa Mine. There seems to be no concentrated dislocation but instead a broad zone of adjustment. On the property maps the fault is indicated to be of opposite throw from that established by the magnetics. An explanation is not to be undertaken other than that the magnetic attraction represents aggregate or net effects of adjustments, whereas the mine map merely expresses the situation and the conditions observed at one or two known points. The question arising from the situation is whether or not the extreme oxidation and ore-making processes in the Montreal Mine will carry on across the fault zone into the ground to the east. The future of the Montreal and the Ottawa and the Cary hangs upon the answer to the question. From the tendency for the Ottawa ores to widen in the lower levels there is some cause to deem it likely that they will take on the characteristics of the Montreal bodies at greater depths.

West of the Montreal, in section 32 and 31, as well as section 6 of 45—2E., production has been but nominal. Nevertheless, there has been extensive pitting, there have been many diamond drill holes sunk, and underground exploration has been carried on upon a large scale. The most extensive of these explorations was but recently concluded unsuccessfully in section 6 and vicinity. The Plumer shaft was sunk to a depth of about 2000 feet and drifting and crosscutting total many thousands of feet. The ground was well supplied with dikes. In the west side of the property is a broad zone of cross faulting which was first detected by magnetic surveying on the surface. Oxidation was apparently good but the silica remained high and the ore bodies were lean. In this connection it is of interest to note that there is an unusual quantity of silicate in the drill cores from the exploration. The basal Norrie and the Yale are particularly noteworthy in this respect. At the same time it is of interest to remark that there is a series of low hills not over a mile and a half directly north in the northern of which are extensive exposures of gabbro. In the hills farther south there is suggestion that the gabbro is also present under the cover of the Tyler slates. These gabbros locally more than 2 miles farther south than commonly are probably tongues from the main laccolite of gabbro out in the Keweenawan. They force the suggestion that their proximity to the Ironwood, where the silicate is relatively abundant, is responsible for this recrystallized, unpromising ground.

In the course of the magnetic work in these townships, the preliminary traverses along the north and south section and quarter lines showed that the lower horizons of the Ironwood were but very slightly more magnetic than the underlying formations. On this account the Ironwood-Palms contact could not be as definitely shown as in the townships west. It also meant that the proportion of magnetite was not so great. But whether this indicates that there never had been as abundant magnetite or that it had been oxidized, for oxidation is fairly intense throughout this part of the range, cannot be stated definitely.

On the other hand, it was found that the higher horizons are more magnetic by 8 to 10 degrees, and a maximum is reached amounting to as much as 12 degrees on the average along a line which represents probably the top of the Ironwood or the base of the Tyler. This represents an horizon of magnetite concentration. Exceptions to the above statement are to be seen on the quarter line of 32, where at the center of the section the attraction reaches the unusual maximum of 65 degrees, and on traverses west where the attraction in these upper horizons grows gradually greater. The interpretation applied to this is that the magnetite is a product of the recrystallization of the carbonate of the formation, that the Keweenawan intrusives to the north are responsible for this, and that for the same reason that the recrystallization intensifies westward, so it would extend farther eastward in the upper horizons than in the lower. The local magnetic anomalies in 32 and north of the Plumer exploration would be explained under this hypothesis as due to the local closer approach of the gabbro intrusive as noted above. Another instance of this same thing is to be discussed in the report for the township immediately west.

Several faults have been shown as probable on the large scale map of the Ironwood. Near Montreal River are possibilities of two or three. The basis for these is magnetic observation and dislocation of the base of the Keweenawan. These faults are evidently responsible for the gap through which the Montreal River crosses the ranges. They are indicated on mine maps and it is quite likely that they played an important role in the making of ores in the nearby properties. It is to be noted also that these zones of faulting apparently determined the northwestward course of the rivers.

In the northeast of section 26 another fault has been drawn on the basis of magnetic work. As noted above, a strong magnetic horizon in the upper horizons was followed in detail across these townships. In the event of a dislocation of the magnetic line a cross fault is the sole interpretation. This particular fault is also found magnetically in the dislocation of the magnetic line correlating with the foot of the Keweenawan. It is shown on the maps of the Windsor Mine. It may well be that the fault is not a single sharp plane but instead a zone of more or less closely spaced shears.

The fault of the West Branch of the Montreal River is already fully enough discussed above in connection with the description of the ore bodies. It is beautifully shown in the dislocation of the Keweenawan and its control of the course of the West Branch parallel to that of the Montreal is clearly a response to the effect of this cross shearing.

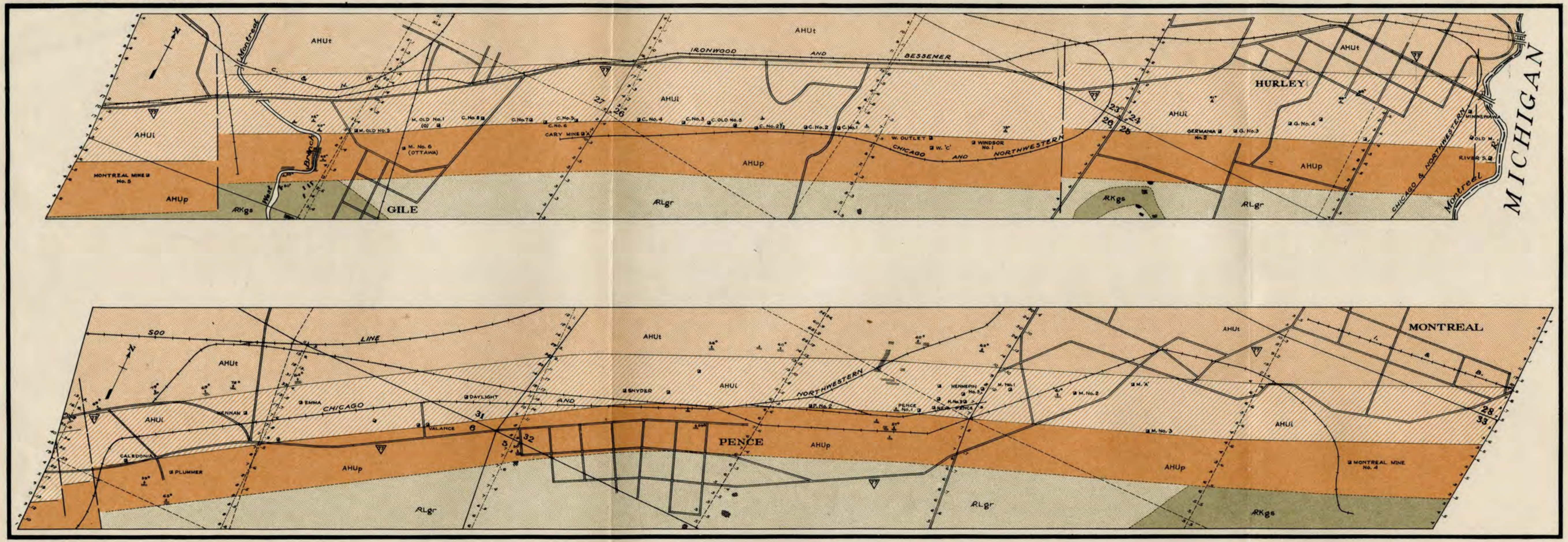
In the west of section 6, within the ground explored at Plumer

Mine, are several cross faults. These also dislocate the Keweenawan and they appear to have been in control of the lower reaches of the Montreal River in the last few miles above its mouth on Lake Superior. They also appear to have occurred subsequent to the intrusion of the laccolite in the Keweenawan.

In summary, the Ironwood across these townships is regular in strike and dip. Structurally it is simple and the only anomalies are the cross faults. The formation is throughout fairly well oxidized but poorly leached, excepting in the known ore bodies. Recrystallization is important only west of the West Branch of the Montreal River, where it is apparently due to the local close proximity of gabbro intrusives. Correlating with the recrystallization is the fact that the outer horizons alone are magnetic. The formation has been well explored to depths of at least 1000 feet and the operating mines are facing encouraging conditions with increasing depth.

*The Tyler.* The Tyler is the thickest formation of the area but less is known about it in detail because there are very few exposures excepting in the west. Here, as noted above, there is a small intrusive of gabbro in section 30, and probably others in section 31. In consequence of the fact that the slates are here affected by contact action, they are much more indurated than at a distance from igneous rocks. In general the formation consists of coarse, somewhat quartzitic graywackes, and finer and softer gray-green slates.

The Tyler has been described in the literature as unconformable with the Keweenawan. There is no angular discordance between Hurley and Mellen. West of Mellen the Huronian has been bevelled across. In Chapter VI this is discussed and is shown to be due to either erosion or thrusting or both. The real evidence on the range is found some distance east in Michigan where the Keweenawan is found lying on an eroded Ironwood, the Tyler being completely missing. So far as the Wisconsin end is concerned the unconformable relations must rest upon the presence of a conglomerate and later arkoses which comprise the section 100 feet thick immediately below the Keweenawan flows. These sediments are the lower Keweenawan. In the mind of the writer these can be looked upon as having been derived from the uplift over the rising magma from which the trap flows were issued. In such a view the unconformity is relatively less important as a time break and in Wisconsin there appears to have been no lapse of deposition.




## LEGEND

- AHUt — Tyler
- AHUp — Palms
- AHUi — Ironwood
- ARLgr — Laurentian Granite
- ARKgs — Keewatin Green Schist
- Cross Fault

Figures left of lines are dip needle readings.
Figures right of lines are dial compass readings.
Dot to left=W. declination.
Dot to right=E. declination.

▪ Shaft

# T46N~R2E

WISCONSIN

GEOLOGICAL AND NATURAL HISTORY SURVEY

E. F. BEAN, DIRECTOR

# 46

# TOWNSHIP 45 N., R. 2 E.

Survey made in October, 1915

Under the direction of

W. O. HOTCHKISS, State Geologist

AND

E. F. BEAN, in charge of Field Parties

M. C. LAKE, Chief of Party
H. D. WAKEFIELD, Asst. Geologist
WM. FOSTER, Asst. Geologist

## SYMBOLS AND ABBREVIATIONS.

The symbols and abbreviations used on this map are explained in Chapter II.

## TOWN AND RANGE LINES.

In constructing this map the south line of the township was laid off as a true east west line. The other boundary lines were then laid off with the lengths shown on the Land Survey plat. Some of the maps are therefore incorrect in shape but this is necessary because definite facts are lacking. The acreage of part of the lots in the north and west tier of sections is shown to give a check on the distances in these sections.

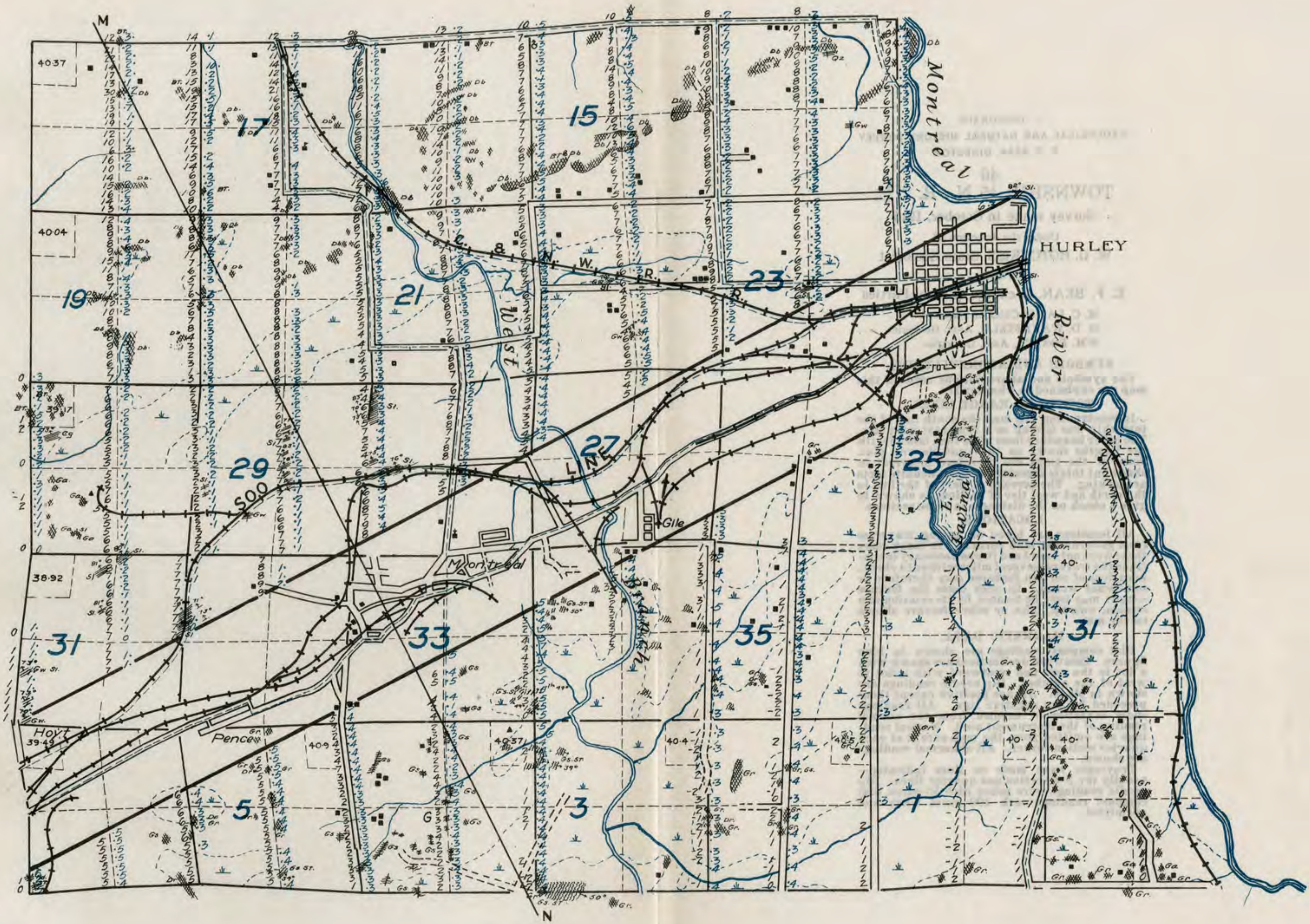
## LOCATIONS.

All locations are based on pacing traverses from government land corners. In many cases these were not found and it was necessary to continue the traverse several miles without a check. Locations of certain features may therefore be somewhat wrong. In such cases the feature sought may best be located by its relation to a stream, swamp, lake, or other feature shown on the map.

## MAGNETIC DATA.

Dial compass readings are shown in blue figures. Eastward declinations are shown with a dot to the east and westward with a dot to west of the number. Dip needle readings are shown in black. All are positive except those preceded by the negative sign. All readings show deviation of needles from the normal reading of the instrument used. Normal readings are omitted from the map except at each quarter section corner. All abnormal readings are shown.

Traverses were made on lines indicated—usually the N-S section and quarter lines. Dip needle readings were taken each 50 paces, dial compass readings each 100 paces when sun permitted.



M
N
HURLEY
Montreal River
West
Gile
Montreal
Hoyt
Pence
SOO LINE
C. & N. W. R. R.
L. Lavina
17
15
19
21
23
25
27
29
31
33
35
31
5
3
1
40.37
40.04
38.92
39.49
40.94
40.37
40.4

### *The Lower Keweenawan*

Above the Tyler or at its top is a series of sediments consisting of a conglomerate succeeded by arkoses and quartzites. The whole series is not over 100 feet thick and its deposition was overcome by the extravasations of the Middle Keweenawan. In another place a more complete record of the section from the top of the Tyler some distance into the Middle Keweenawan is given. The conglomerate and the arkose show a different derivation from the main Tyler and the close sequence of the traps upon these throws the weight of probability upon the idea that they, these sediments, came into being as consequent to the surface deformations caused by the establishment of the vents from which the lavas issued.

### *The Middle Keweenawan*

These formations are basic lava flows in general, although there is from flow to flow more or less variation in composition. Andesitic sheets are not uncommon.

### *The Upper Keweenawan*

There is a major laccolite of gabbro and attendant alkalic differentiates some few thousand feet up from the base of the trap series. This is in general a wedge between the flows but the southern contact and the principal axis of the body cuts at a low angle up and to the east. This finds agreement with the evidence for thrust planes having the same attitude. The interpretation applied is that the formations were subjected to tortion, the low angle thrusts were imposed, and the gabbro intrusions were essentially under their control as they came into place. The rise of the gabbro to the eastward finds some application in the fact that the Ironwood is more magnetic in the upper horizons to the east and this condition gradually settles into the lower members with departure to the west.

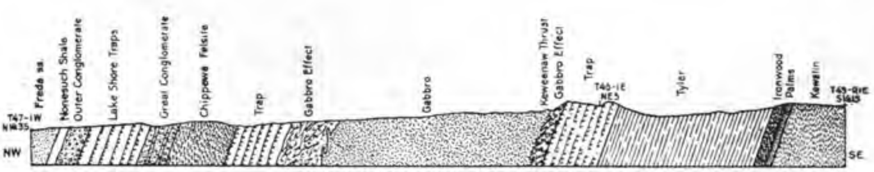
## TOWNSHIPS 45 AND 46 N., RANGE 1E.

The surveyed area in these townships comprises the northern 4 rows of sections in 45—1E., and sections 25, 34, 35, and 36 of 46—1E.

### Surface Features

This area lies entirely within the Lake Superior Highland Physiographic Province. Underlying formations control the surface features. In the north, the topography reflects the presence of the upturned, northwestward dipping Keweenawan lavas and intrusives. The surface is rough with ridges trending northeast and southwest. Bare knobs of basalt and gabbro are abundant. Valleys crossing in a northwest southeast direction indicate the presence of strong joints along some of which there has been considerable movement. Where these cut across the south boundary of the lavas which extends from the west quarter of 7 to the northeast of 25 of 46N., they may be recognized as faults by the offsetting of the exposures. This south boundary is the most striking topographic feature of the area. It is a precipitous escarpment standing 200–400 feet above the valley to the south. The top of the escarpment marks the prevailing level of the Keweenawan upland. Within the gaps of the escarpment there are depressions which are occupied by lakes; Lonesome Lake in section 5 is an example.

South of this escarpment is a broad valley carrying Alder Creek which feeds Potato River in the west of the area. In general this valley two miles in width is nearly flat-bottomed. The cross section Fig. (28) shows, however, that the north wall is far steeper than the south. The underlying formation is the soft Tyler formation comprising slates and graywackes which despite burial to a depth of possibly fifty thousand feet, are apparently not intensely




TRANSVERSE CROSS SECTION T45N-R1E, T47N-R1W

*Scale*

Hor. ... Vert. ...

FIG. 28

indurated. The regional dip of the formations is to the north and west at angles averaging 60 degrees. The underlying iron formation is much more resistant than the Tyler as is also the Keweenawan trap. Accordingly, the south wall is the more gentle but it steepens as it rises to the south. The sole exception to this is a knob of intrusive gabbro in the northeast of section 3 which rises 250 feet out of the middle of the valley. This is similar to the knobs north of the Plumer Mine in the township east and contains an intrusion of gabbro.

The southern ridge, which is the Gogebic Range, is controlled chiefly by the Archean greenstones and the Palms quartzite. It extends from near the southwest of section 19 to the vicinity of the east quarter of section 1. It is in general of the same order of elevation although the local relief is less than that of the Keweenawan or Trap Range. Like the Trap Range, the Gogebic is serrated by prominent gaps most notable of which are the Potato River Gap in section 19, that in the central part of section 16, and that in the east of 10. All three of these contain faults which transect the Gogebic and Trap ranges alike. The result is a number of elliptical ridges separated by these crossings.

South of the Gogebic the formations are largely green schists which have produced a somewhat undulating swampy terrain which drains to the north.

Glacial sculpturing of the area is negligible. The abundant rock exposures testify to the thinness of the drift. To the south of the Gogebic Range there are patches of rough moraine in sections 14, 15, 20, and 21. At Upson, in the valley of the Tyler there are outwash gravels and sands which have been developed for road building and concrete construction.

Drainage of the area is by way of the Potato and its branches. The river flows about N. 30° W., in a course controlled by cross shearing. The tributaries flow parallel to the strike of the formation in the valley of the Tyler slates. The main stream flows over a bowlder strewn bed with a considerable velocity but the branches are sluggish excepting in the time of freshets.

The area has long since been cleared of its timber which was chiefly hardwood and hemlock. Along the north slope of the Gogebic Range the thickets of maple brush and raspberry bushes in the old cuttings make travel extremely difficult and observation at a distance well nigh impossible. In the Tyler Valley and over the crystallines south of the Gogebic Range, considerable areas in the silt loam soil have been cleared. Small farms are springing up and dairying is carried on in a small way with no little success. The region is noted for its heavy stands of clover and hay. The Gogebic is in reality a barrier to the development of the region south, because it may be crossed conveniently only in a few places, principally by way of the several gaps.

Upson and Iron Belt are the only communities of the area. Both reflect their origin in activities now long since ceased, the lumbering industry and mining respectively. These are far from thriving; in fact there is no industry at present save small scale farming and a few shops to supply the settlers with the necessities of life. Iron Belt houses miners who are employed in the mines at Hurley and Montreal in the winter. It has very little promise of great growth. Upson is more fortunately located at a point which when there is extensive development south of the range will be the main route of travel. The Soo Line Railroad maintains stations at each town and State Trunk Highway No. 77 passes through each. From Upson State Trunk Highway No. 122 leads north over the Trap Range to the town of Saxon on U. S. Highway No. 2.

## General Geology

### *Archean*

The Archean in this map area is exclusively Kewatin green chlorite schist. Exposures are confined to the eastern edge of the area and the gap of the Potato River in section 19.

### *Huronian*

For discussion of the relationships between the four Huronian formations of the district, see chapter VII and the remarks on the Huronian in the township report for R. 2E.

*The Bad River Dolomite.* This formation was found by earlier geologists in section 15 as reported in Vol. 3, Geology of Wisconsin, page 108, and in Monograph 19 of the United States Geological Survey. However, despite careful search, during the course of this later survey, no trace of the formation could be found. No exposures of any formations were located here although there are many test pits to disclose the nature of the formations. On the large scale map of the Ironwood and associated formations the dolomite was not shown.

*The Palms.* Only along the bank of Potato River was any natural exposure of the Palms found in the area. Innumerable pits evidently struck the formation as indicated by the material on the dump. In such cases the explorers were satisfied in encountering the quartzite top of the formation so that from these pits no data on the nature of the lower horizons is at hand. On Potato River, the base of the Palms is seen to be a conglomerate about 2 feet thick composed of fragments of Kewatin schist, cemented with a siliceous matrix. Reddish feldspathic slates succeed the conglomerate to the extent of about one-third the thickness of the formation, and are in turn succeeded by more thickly bedded light gray slates. These carry increasing amounts of quartz toward the top and finally give way to the typical vitreous quartzite which forms the top of the formation. The thickness of the Palms, as measured here, is approximately 470 feet, of which the quartzite comprises the upper 50 feet. The contact with the Ironwood is not exposed.

*The Ironwood Formation.* The Ironwood is exposed in only one place in this area, in the east of section 19 on the east bank of the Potato River. A second exposure just across the range line in section 24 of 45—1W., serves both townships in locating the footwall. However, across sections 1 and 11 there has been rather extensive exploration in the course of mining in the Atlantic and Iron Belt Mines. From there west for most part, there has been extensive test pitting and the condition of the formation is revealed in the material on the dumps. The pits are not however, well distributed across section 16 and in consequence little is known about the formation. Beginning with section 10 and from there on west, there has never been an actually thorough, scientific, exhaustive exploration of the formation. For the western townships this is unnecessary perhaps, but in the west of R. 1E., and the east half of 1W., there are very promising areas which might well be explored.

In section 1 there are literally hundreds of pits. Many of these are very old and the early news items in the press of the region refer to these explorations by name. Some of the pits are of later age. The most recent explorations were made with the diamond drill. The Atlantic Mine was operated in the formation across this section. Several shafts were sunk and the formation was explored to a depth of 1500 feet. Some two million tons of ore were shipped, the bulk of which was taken from the zone of the bedding fault or above. Whether the lower member was thoroughly prospected or not is not apparent, but considerable doubt on this question remains.

In section 11 the Iron Belt Mine produced about one and a quarter million tons. This apparently, too, came from the fault zone or above. The information at hand indicates that the formation was not explored to greater depth than about 1500 feet.

From the southeast quarter of section 10, the Shores Mine shipped close to sixty thousand tons of ore. The workings are all caved at present, and no examination by any of the geologists possessed of the greater understanding of the formation accruing through recent years, was ever made. The sketchy maps and sections which alone are available, leave much to be desired concerning the geology of the ore body. As will be discussed at some length in connection with the magnetic data, there appears to be a structural anomaly here and the only interpretation offered is that the formation is sharply faulted south at the west end of the Iron Belt property in the west of section 11. Plate IX

In the southwest of the south east of section 10, and the northwest of 15, the condition of the formation is quite different from that in the Shores property. Oxidation is but nominal. Test pits are numerous and while they indicate the presence of dikes they are fresher appearing than one finds in well oxidized ground, and the formation is dense, green, and highly magnetic. The thin sections from specimens taken off pit dumps show the presence of amphiboles replacing or developing at the expense of siderite. The topography here is also of note. In the east of 10 there is a gap in the range which extends east into the west of 11. From about a quarter of a mile west of the east of 10 the ground rises to considerable prominence, the south quarter of 10 being about 200 feet higher than the east quarter. This condition continues into the northwest of 15 where the ground again slopes westward into another gap. The formation in the central forties of 10 and 15 are, therefore, not promising for exploration.

In a zone from about the east quarter of 16 to about the west quarter of the same section there is a prominent gap in the range. Across the eastern three quarters of the section, there are neither outcrops, pits that seem to have struck ledge, nor known drill holes. The drift is evidently unusually thick. Magnetically there is almost no expression to the formation. Thus, while nothing is known directly concerning the condition of the formation, the topographic depression bespeaks weakness due to cross shears, or to oxidation and leaching consequent upon or independent of the shears and the failure of the magnetic attraction indicates the impoverishment in magnetite which is probably due to the failure of recrystallization. In consequence these forties have many of the ear marks of good explorable ground. A comparison with the productive area indicates that the two are magnetically very similar.

In the west of 16 the surface again rises to the westward forming the west wall of the gap. Test pits are abundant and show a moderate amount of oxidation. In the southeast of 17 and the north and northwest of 20 on top of another of the elliptical hills between gaps, is an old mine known as the Annie. The pits reveal the presence of dikes, oxidation is notable, and some 11 thousand tons of ore are credited to the property. From the meager records available plus the location of the shaft in the formation, it is apparent that the ore was taken from its upper members. There is also minor cross faulting.

Section 19 lies within another of the many gaps. The Potato River takes advantage of this in crossing the Gogebic, and of the northwesterly projection of it in effecting passage through the Trap Range. In this section pits and old exploration shafts are numerous, and there are a number of drill holes. From all the information available from the pit materials, the formation appears to be well oxidized but poorly leached. Dikes have been disclosed. However, thin section evidence shows, in the presence of conspicuous amounts of amphibole developed at the expense of siderite, the fact that the formation has suffered at least incipient recrystallization. While this is not justifiable ground for condemning the region for exploration, it is a heavy discount factor. Incidentally, from section 10 west the footwall is increasingly stronger in its magnetic response which is a confirmatory evidence of recrystallization. So far as is known none of this western two-thirds of the township has ever been thoroughly tested to more than nominal depth. Furthermore, what extensive exploration has been done is confined to the upper horizons, and, as has been indicated, the recrystallization not only increases in intensity to the westward, but involves greater thicknesses of formation in that direction. Accordingly, there would appear to be fairly promising localities for exploration, at least in the footwall horizons west of section 15.

The regular traverses show as a first consideration that the formation is more magnetic than in the township east. Beginning in section 10 and with the exception of section 16, as noted, the footwall is for the first time strikingly magnetic. Apparently the dip of the formation is regular with the possible exception of section 10. The increased magnetic reaction improves the chances of interpreting conditions.

The detailed magnetic work was controlled by tracing the same horizon in the upper members as in the town east. This horizon is probably well identified with the Tyler contact or adjacent horizons. In general, this magnetic horizon could be followed as a clean cut line continuous in some instances for considerable distances. However, as indicated on the detailed map of the formation, this magnetic line is periodically dislocated. In sections 1 and 11 several of these dislocations have been interpreted and drawn as minor cross faults. In several places as in the town east these have been confirmed by the mine maps. Toward the west of section 11, the magnetic horizon gradually diminished in strength until finally it was lost in the more or less uniform variation of the east of section 10. On the east line of section 10 the attraction over the lower horizons is practically wanting. From information available the footwall should cross at about the forty corner north of the southeast corner of section 10. A north to south traverse a quarter of a mile west shows definition of the footwall about 100 paces north of the south line of the section. This is confirmed by test pits. The attraction here builds up to the north so that at 400 paces north of the south line of the section it is 65 degrees. Three hundred and seventy-five paces west of the southeast of the section or only 25 paces east of the last mentioned traverse a south to north traverse showed attraction comparable to that on the east line. Thus between the traverse 500 paces west and the one 375 paces west the attraction changes from a range up to 65 degrees to a range of only 10 degrees. As stated above, on the hill to the west, pit material shows recrystallization with amphibole, and the footwall is highly magnetic. In the northeast of the southeast of the section the Shores Mine produced some 60 thousand tons of ore. The offset in the footwall plus the sharp change in magnetic attraction were interpreted to mean a strong cross fault. The alternative explanation is a fold. However, the flexing of the formation in the quarter of a mile or less would be excessively sharp and probably accompanied by a much heavier generation of amphibole than is apparent. In connection with the situation it is of interest to refer to the presence of the intrusive gabbro forming the knob in the northeast of section 3. This is due north of the Shores Mine and many pits on the property show coarse grained dike rock. It is suggested that the structural and magnetic anomaly in 10 is related to this unusually strong intrusion. It is also possible that the outer horizons have been folded back against the formation causing the widening of the magnetic belt. It is also suggested that the crystallization in the central forties of 10 and 15 is due to this local closer proximity of the intrusive to the iron formation. The fault as drawn finds probable extension across the Trap Range in an offset in the southeast of section 33 of 46—1E. These two locations lie upon a line striking normal to the strike of the formations.

The practically total elimination of the attraction across section 16 has already been referred to in connection with the deduction that it indicates a favorable place for exploration. West of this gap in the range and its magnetic expression the magnetic horizon in the upper member was again detected and followed to the westward. In the vicinity of the Annie Mine another dislocation served as the basis for drawing a probable fault.

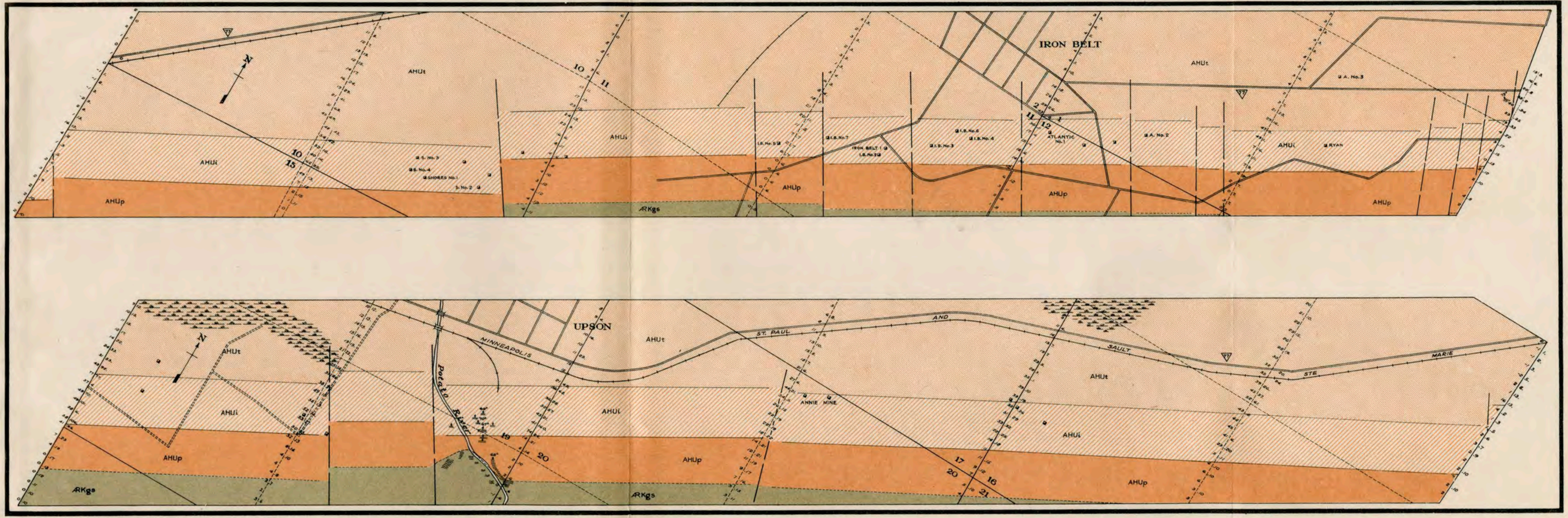
The Potato River fault appears to be a much more complicated dislocation than has been heretofore considered. That there is an offset of the west bank of the stream to the north is clearly evident from the distribution of the exposures of the Kewatin schist. However, the footwall was located on the quarter line of the section practically in line with its projection from the east side of the fault. It is concluded that there is considerable adjustment along the structure. On the map the fault is indicated as a zone of northward offset of the west side. This dislocation corresponds with an observed major offset at the foot of the Trap Range of the same description and lying on a line through the Potato River fault and perpendicular to the strike of the formation. This zone appears to control the course of the Potato across the Gogebic and Trap ranges as far as the position of the great conglomerate in section 15 of 46—1W., where it is deflected westward by the overlying Lake Shore Traps.

In summary, the Ironwood is fairly well oxidized across 1, 11, and the eastern quarter of 10. This is indicated from examination of material thrown from test pits and from the dumps of the Atlantic, Iron Belt, and Shores Mines. Only locally from here west is oxidation apparently advanced to stages promising ores. Section 16 is most promising although this conclusion is based entirely upon indirect evidence. Recrystallization is notable as far east as the central forties of 10 and 15 where the corresponding magnetic attraction also gains strength.

*The Tyler.* The Tyler slates and graywackes measure about ten thousand feet in thickness assuming constant dip and absence of repetition. Quartz and feldspars are the essential minerals with some mica and chlorite. Toward the base the formation is comparatively rich in iron carbonate which on oxidation produces a rock distinguished from slaty iron formation only with difficulty. Exposures are rather scarce and are most numerous along the Potato River.

### *Lower Keweenawan*

Along the base of the Trap Range escarpment at frequent intervals are exposures of the Lower Keweenawan formations. These are sedimentary comprising a coarse conglomerate of quartz, quartzite, iron formation, slate, graywacke, and basalt, in a siliceous cement, a thin arkosic quartzite; and beds showing varying proportions of quartz and feldspar. No complete section is available in this township but the formation is apparently co-extensive with the base of the Trap Range, and from the better exposures in the township west a more complete story can be gotten. It would appear that the sedimentation of the Tyler was succeeded gradually by encroaching agents of increasing capacity for transportation. The consequent sedimentation was coarser for a brief interval. It was followed by finer sediments which continued even until several trap flows had been poured over the region. From what has been seen in the study of the Keweenawan it appears that the flows found their escape from vents to the north and down the dip from which they spread southward. Direction of the streams that brought in the sediments can be read from the ripple marking and cross-bedding which show a derivation from the northeast. The conglomerate can, therefore, be taken as an advance notice of the surface manifestations of the approach of vulcanism. It need not bear the usual connotation of lapsing sedimentation in favor of erosion.




LEGEND

AHUt Tyler

AHUp Palms

AHUi Ironwood

ARKgs Keewatin Green Schist

Cross Fault

Figures left of lines are dip needle readings.
Figures right of lines are dial compass readings.
Dot to left=W. declination.
Dot to right=E. declination.

Shaft

## T45N~RIE

WISCONSIN

GEOLOGICAL AND NATURAL HISTORY SURVEY

E. F. BEAN, DIRECTOR

46

# TOWNSHIP 45 N., R. 1 E.

**Survey made in September, 1915**

Under the direction of

**W. O. HOTCHKISS, State Geologist**

AND

**E. F. BEAN, in charge of Field Parties**

H. N. EIDEMILLER, Chief of Party
H. H. BRADT, Asst. Geologist
E. A. KRONQUIST, Asst. Geologist

## SYMBOLS AND ABBREVIATIONS.

The symbols and abbreviations used on this map are explained in Chapter II.

## TOWN AND RANGE LINES.

In constructing this map the south line of the township was laid off as a true east west line. The other boundary lines were then laid off with the lengths shown on the Land Survey plat. Some of the maps are therefore incorrect in shape but this is necessary because definite facts are lacking. The acreage of part of the lots in the north and west tier of sections is shown to give a check on the distances in these sections.

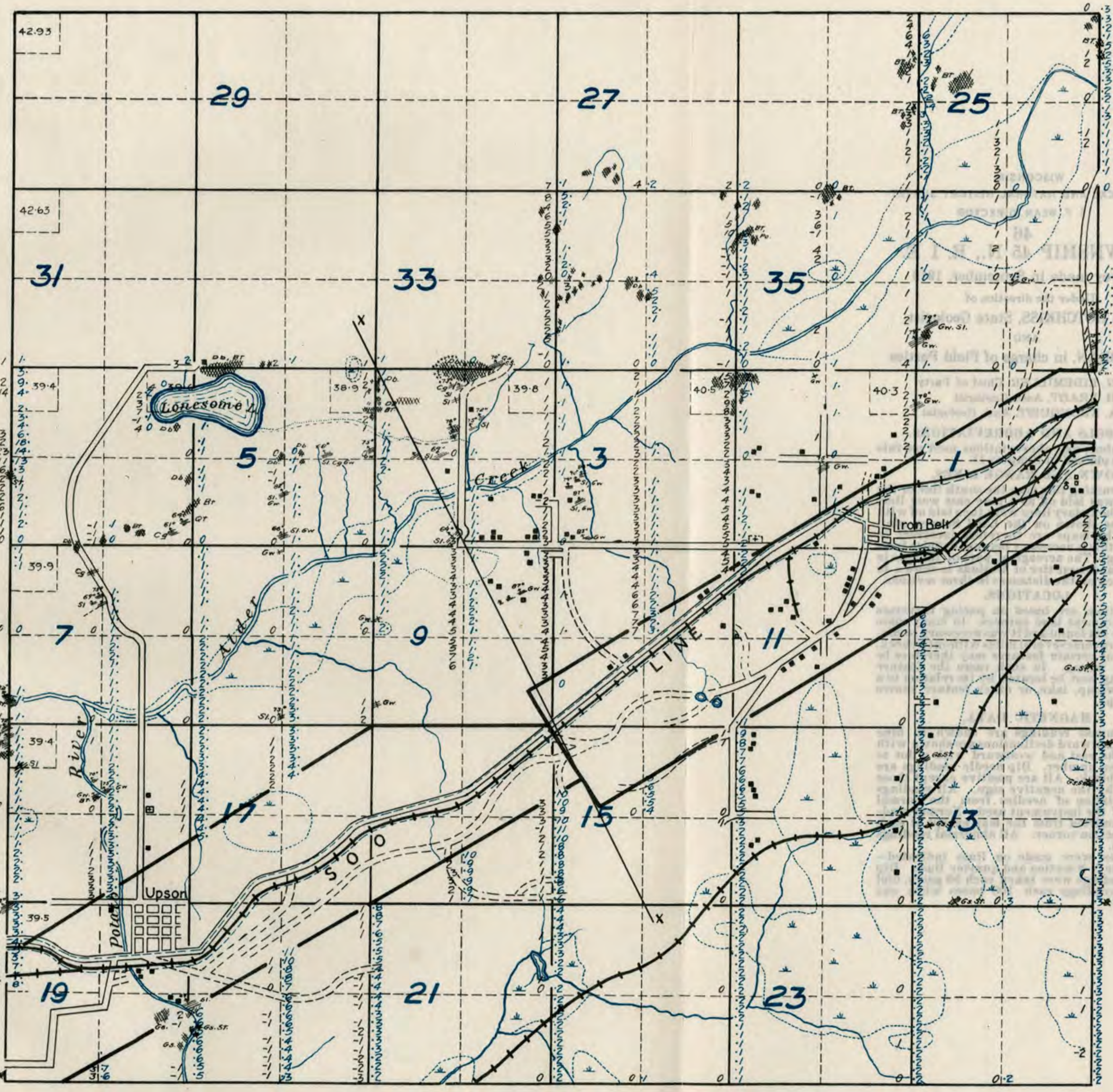
## LOCATIONS.

All locations are based on pacing traverses from government land corners. In many cases these were not found and it was necessary to continue the traverse several miles without a check. Locations of certain features may therefore be somewhat wrong. In such cases the feature sought may best be located by its relation to a stream, swamp, lake, or other feature shown on the map.

## MAGNETIC DATA.

Dial compass readings are shown in blue figures. Eastward declinations are shown with a dot to the east and westward with a dot to west of the number. Dip needle readings are shown in black. All are positive except those preceded by the negative sign. All readings show deviation of needles from the normal reading of the instrument used. Normal readings are omitted from the map except at each quarter section corner. All abnormal readings are shown.

Traverses were made on lines indicated—usually the N-S section and quarter lines. Dip needle readings were taken each 50 paces, dial compass readings each 100 paces when sun permitted.


29
27
25
31
33
35
Lonesome L.
5
3
1
Creek
Alder
Iron Belt
7
9
11
LINE
River
17
15
13
SOO
Upson
19
21
23

### *Middle Keweenawan*

North of the sediments of the Tyler and Keweenawan members are the basalts of the copper-bearing series. These will not be described in any detail since they are not closely related to the problems in hand. They are unquestionably surface extrusions as evidenced by a number of confirmatory characteristics. The igneous formations alternate with sediments, they have vesicular and amygdaloidal tops and they are characteristically ellipsoidal in structure toward the extreme base. Between some of the lowermost flows are to be found thin deposits of carbonate and chert. They are of practically uniform thickness for considerable distance along the strike.

To the north of the base of these flows, and at varying distance, the same being greater in the east of the township and less to the west, is the invading coarse-grained gabbro. This gabbro taken in perspective, wedges itself between the flows, but considered locally along its southern boundary it is an impregnation of the earlier flows with crystals of much the same composition, but larger in size. The presence of the gabbro substance does not cease sharply at a knife edge. Even where its presence is not obvious to the eye it is represented by mineral changes which change the color, the density, and the texture of the flows. It is characteristic for the flows to have tops considerably reddened with iron oxide. In the proximity of the gabbro these tops are green or black and highly magnetic. It is of interest to note that the trend of the southern boundary of the gabbro is more sharply southwesterly than is the strike of either the Ironwood or the flows. In short it approaches the Ironwood toward the west. From what has been observed concerning the intensification of the recrystallization of the Ironwood from the upper to the lower horizons and from east to west this is suggestively related to the noted trend of the base of the gabbro. This base is thought to be the western projection of the Keweenaw thrust.

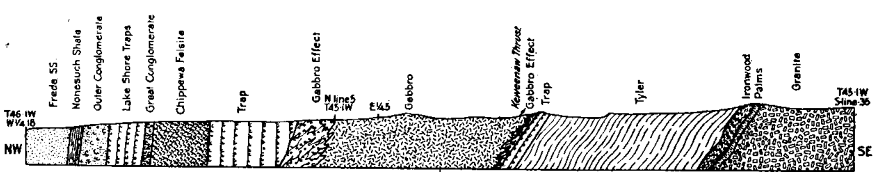
## TOWNSHIPS 44 AND 45 N., RANGE 1W.

The northern of these townships was surveyed in its entirety, the southern only to the extent of the northern row of sections.

### SURFACE FEATURES

This area lies within the Lake Superior Highland Physiographic Province. In it the dominant topographic features are expressions of the composition and structure of the underlying formations.

Two of the principal features of the towns east extend across the area under discussion. See Fig. 29. These are the Trap Range and the Gogebic Range. The third of the features so prominent to the east, the Tyler Valley, is also present as an interrange longitudinal valley but it is a much more complicated feature. In describing this for the towns east it was pictured as a regular but assymetrical cross-sectioned valley, the north wall formed by the Trap Range being precipitous, the south wall having a gentler slope. In the townships under discussion the cross section is markedly different. The north wall continues as a steep cliff as far as the crossing of Tylers Fork, but from there west it is much subdued. From the Potato River fault and to the west, the south wall of the valley is a much gentler slope, or in other words, the elevation of the valley floor holds to higher level for a greater distance north of the Gogebic. Along the very foot of the Trap Range there is a more distinct stream valley along which flow the tributaries of the Tylers Fork. There are numerous broad, blunt, hills in the general mid-valley region which are, therefore, analogous to the two or three small knobs in the townships east. These are not drift hills. In fact there are outcroppings of the Tyler slate upon them. The Tyler is much better exposed in this township in general. In effect,




TRANSVERSE CROSS SECTION—T45 IW—T46 IW

*Scale*

Hor. 0 ½ 1 mi. Vert. 0 1000 2000 ft.

FIG. 29

these hills constitute a third though subordinate and serrated ridge across the area. On the topographic sheet this is a pronounced feature.

The Trap Range is prominent across the east half of the township. It is comparable to that of the townships east, an upland of ridge and trough tendency under control of the north-dipping traps. It is broken here and there and through the two most prominent gaps faults are known to pass. These are followed by the Potato and the Tylers Fork streams. In the base of the Range in section 12, is Lake of the Woods which is comparable to Lonesome Lake not far to the east.

The Gogebic Range on the south is but a low, broad ridge in the east, the reverse of the Trap Range situation. Here the Archean occupies the summit. Following along the Range to the southwest it is found that the Ironwood and Palms gradually gain control through superior resistance to erosion. There are two prominent gaps, the one occupied on its west side by the Tylers Fork, and a second in the west of 33 which does not apparently result from faulted conditions. Elevations in the west rise to 1860 feet giving a relief of the order of 375 feet.

South of the Gogebic in the Kewatin schist area, the surface is rolling and there are numerous swampy depressions. The elevation here is higher than the bottom of the Tyler Valley and the Tylers Fork rises in such swamps.

The glacial episode seems to have played but small part in the fashioning of the surface features. Everywhere the drift is thin as indicated by the abundance and distribution of the exposures of hard rock.

There is very little standing timber left although the region was well forested with hardwoods and hemlock. The sections of better soils are now thickly grown up with hardwood brush and brambles making traverse and observation rather difficult.

Settlement is confined to the southern border of the Tyler Valley and particularly to sections 28, 29, and 33. A few small farms have been cleared here and heavy hay crops enable the farmers to carry a few cows through the long winters. Agriculturally, the area surveyed can never advance far from the present condition. What soil is here supports heavy vegetation, but the rocky ledges and bowlders are too numerous.

There is but one road of consequence and one railroad. The main route through the area is of necessity in the Tyler Valley. This is State Trunk Highway No. 77 connecting Mellen in the west with Hurley and Ironwood, Michigan in the east. The Soo Line maintains a branch from Mellen along the Range to the producing area east. In section 29 it maintains a flag station known as Moore. Moore is the community of farmers mentioned above and has a school, post office, and small store. In the early days of exploration, Moore was to have been a mining town. The Tylers Fork Mine in section 33 was provided with a boarding house and several other buildings which are still standing though in poor condition.

## General Geology

### *Archean*

The Archean in this area is exclusively Kewatin green schist. Exposures are few and somewhat varied. The schistose character varies in intensity and in section 4 of 44—1W., the rock is fairly massive. South of the center of section 33 of 45—1W., are several small exposures of a rock composed of sub-angular to rounded pebbles of dolomite and greenstone. Above it and separated by a conglomerate is the Palms. The matrix of the first mentioned is fine-grained and schistose, so that it bears some suggestion of being Archean. At the time of examination it was suggested that this was a distinct formation and the name of Springdale formation was suggested. However, the exposures are all within a mere 100 paces along the strike, there is little opportunity to study relationships, and it is probably of little significance.

### *Huronian*

The relationships between the various Huronian formations were set out in chapter VII and briefly in the report for 46—2E.

*The Bad River Dolomite.* Reference is made in Monograph 19 and in the third volume of the Geology of Wisconsin to an exposure of cherty limestone in the northeast of section 33. This work was done in the 70's. During the more recent survey, diligent search was instituted to relocate this exposure but without success. No provision is made upon the detailed maps for the formation.

*The Palms.* The Palms is exposed in volume only along the crossing of the Tylers Fork in section 33 and adjacent 34. Small outcroppings were located in the quartzite in section 6 of the southern town and in test pits. From the river west the Palms and basal Ironwood rise to the crest of the Range. The thickness of the Palms is about 400–450 feet.

South of the center of section 33, as referred to above, the base of the Plans is exposed. This is a conglomerate resting upon an irregular erosion surface. The conglomerate contains pebbles of chert, red jasper, quartz, dolomite, and blocks of the underlying formation which was referred to above as a possible remnant of a distinct formation. The matrix is argillaceous and of the same character as the succeeding argillaceous slates. The pebbles are well rounded. The conglomerate is not over 5 feet thick probably.

Overlying the conglomerate is quartz slate with a thickness of about 350 feet. This varies somewhat from a thin-bedded siliceous clay slate showing cross bedding to coarse-grained graywackes, very fine-grained siliceous material suggesting novaculite, and argillaceous quartzite.

At the top of the member is the remarkably pure quartzite. This is approximately 60 feet thick. It consists of fine-grained quartz well cemented by additional silica which has added itself to the original grains in optical orientation with them.

The actual top is marked by a thin bed characterized uniquely by rounded grains of quartz with a matrix of fine chert of the same character as the basal Ironwood. This is the gradational bed between the two formations. It has been called the "sweepings bed" connoting the idea that the grains were swept up by the first of the chert deposits. In Chapter VII, this gradation is given considerable significance as indicating the real relationship between the two formations. There is no structural discordance between the Ironwood and the Palms so far as can be definitely stated. As indicated, the contact is not well exposed, but nowhere is there an irrefutable suggestion of discordance, of lapse of deposition, or of erosion. The usual argument is that the Palms quartzite, originally a coarse, well classified clastic represented a set of sedimentary conditions so unlike those productive of chemical deposits like the Ironwood that there must have been a considerable time break during which the Palms quartzite was silicified and somewhat eroded. If it is considered that the chemical deposits of the Ironwood were of igneous origin which came out upon the surface catastrophically, and that the entire suite of formations are intensely silicified and recrystallized from here on west and some distance east, there is neither demand for a lapse of deposition, intervening erosion or pre-Ironwood silicification of the Palms quartzite. The idea here maintained is that the "sweepings bed" is the evidence of the overwhelming of clastic deposition by catastrophically appearing chemical precipitate.

*The Ironwood.* In this township exposures are slightly more numerous but they are for the most part concentrated in the Tylers Fork valley. The contact with the Palms quartzite was described above. A microscopic examination of a thin section from the sweepings bed provides the following description.

The rock is distinctly banded with rounded quartz grains throughout. One band is dominantly relatively coarse-grained chert enclosing the grains of quartz with a nominal amount of carbonate in aggregates of coarse rhombs more or less oxidized. The other band is dominated by coarse-grained carbonate rhombs enclosing quartz grains. There is also a notable amount of green silicate apparently developed at the expense of the carbonate. This silicate is an amphibole.

The section along the Tylers Fork was specimened, and from the specimens taken at intervals of 3 feet, thin sections were made. The following brief descriptions were made from the microscopic study of the thin sections.

Three feet above the sweepings bed just described, the rock is coarse, recrystallized chert with half inch well-rounded areas stained with red hematite. These too are coarse cherts but would carry the designation of jasper on account of the hematite. They probably represent the so-called footwall conglomerate. Magnetite is abundant as coarse aggregates.

Another 3 feet farther north the material is essentially a chlorite schist. Magnetite is abundant being disseminated throughout but is also concentrated in certain thin bands. The magnetite is not of clastic origin as evidenced by the sharp crystals. There is a notable amount of clastic feldspar and quartz. This is a representative of the footwall slate.

The next specimen is also a thin-banded chlorite magnetite schist containing clastic quartz and feldspar. It is also probably the foot slate.

The next thin section comes from 15 feet above the sweepings bed. It is a recrystallized jaspery conglomerate with areas measuring as much as 1 inch across representing the pebbles which are not, however, set out by any change in grain. Silicate is notable with chlorite dominant. Grunerite is present in aggregates. Magnetite is also present.

At an interval of 6 feet the formation is again very thin-banded and consists largely of fine silicate and chert and magnetite abundant everywhere. This would be classed as slaty formation and possibly represents the foot slate. This is 21 feet above the sweepings bed.

At 24 feet the formation is typical oolitic chert. The oolites are about pinhead in size and are practically the same sort of chert as the ground mass with a sprinkling of red hematite which makes them jasper. There is a nucleus of hematite in the center of some which is ground for the belief that they represent the former presence of siderite. This is from the lower part of the main Plymouth chert.

At 27 feet the formation is much the same, oolitic chert. The oolites are much more readily distinguished in plain light for they are seen to be well supplied with red hematite. The chert texture in oolites and ground mass is the same.

At 30 feet there is no substantial change excepting that amphibole is somewhat more than a minor accessory. Magnetite forms nuclei and rims for many of the oolites.

At 36 feet the rock is still oolitic. Some of the oolites are practically all hematite and magnetite, some are wholly chert, and some are silicate which resembles sericite. The slide contains oxide to the extent of about 40 per cent.

At 39 feet the formation is thinner-banded and more highly ferruginous. Bands of almost pure oxide with some chert and silicate alternate with others which are largely silicate with some chert and oxide. The silicate is probably amphibole. This section is identical with others from the east excepting that in the latter the silicate is represented by siderite.

At 45 feet the rock is still coarse chert with aggregates of hematite and magnetite and also abundant amphibole. The latter appears to play the same role as carbonate on the eastern end of the range.

At 51 feet the same sort of formation. This is oolitic chert with oxides, some carbonate and silicate.

At 57 feet the formation is faintly banded, recrystallized chert and magnetite with abundant silicate. The oolitic structure is nearly obliterated by recrystallization but may be seen by the way the fine dust of oxide traces the outlines across the coarse chert grains. The amphibole is developed as bunches of needles.

At 60 feet the rock is recrystallized chert with much amphibole and magnetite. The latter is concentrated into richer bands at intervals of about one-half inch.

At 63 feet the rocks are still coarse-bedded oolitic structured material but the oolites are practically a felt of amphibole like that seen in the base of the Norrie in section 6 of 45—2E. Chert fills the space between the oolites and the needles of the amphibole extend out into the chert. The oolites resemble tiny burrs with their radiating spines. Phenocrysts of siderite with selvages of limonite stand out in sharp contrast to the felt of amphibole.

At 66 feet the formation is a coarse chert with but bare semblance of oolitic structure. Oxides are abundant in aggregates of crystals and disseminations. Silicate needles and flakes are disseminated throughout.

At 69 feet the formation is oolitic structured again but the oolites are composed of "burrs" of amphibole needles with coarse chert in the interstices. There are several oolites of magnetite and at least one in the section is composed of siderite which is undergoing oxidation to limonite.

At 72 feet the structure is beautifully oolitic but the oolites are again composed almost exclusively of felted amphibole with quartz or coarse chert interstitially. There are a number of phenocrysts of siderite which are obviously secondary and partly altered to limonite. Magnetite is scattered about in individual grains and aggregates.

At 75 feet the rock is well oxidized to hematite and limonite. Coarse chert and amphibole are abundant.

At 78 feet the formation is much the same, magnetite octahedra abundant.

At 81 feet the oolitic structure is again distinct in plain light but the whole is recrystallized coarsely and silicate is abundant.

At 84 feet the conventional oolitic forms are outlined with oxide and in some cases completely composed of oxide. Minor amount of siderite undergoing oxidation to limonite.

At 87 feet coarse ferruginous chert containing disseminated sericite.

At 90 feet much the same sort.

At 93 feet much the same. Oolites are cleanly marked by rings of oxide cutting indiscriminately across the coarse chert grains.

At 99 feet coarse—quartz—sericite—magnetite rock. Mere suggestion of oolitic structure.

At 108 feet the oolitic structure is beautifully developed with oxide abundantly represented in the oolites. Coarse quartz forms the background.

At 111 feet the oolitic structure continues. Abundant flakes and aggregate of sericite.

At 114 feet much the same. Oolites are composed principally of the colorless flaky mineral resembling sericite, a very fine-grained silicate.

At 117 feet much the same.

At 126 feet well developed oolites but same cut indiscriminately across coarse quartz or recrystallized chert. Scattering of the sericite and abundant magnetite. Minor siderite.

At 129 feet about the same as at 126. Magnetite in isolated grains and in chains. Developed either before the recrystallization of the chert or by replacing the same without volume change. Original oolitic mineral entirely gone and outlines of same marked only by a brownish dust probably iron oxide. The original mineral was probably siderite and the dust is probably the slight amount of oxide which almost always is present in the siderite.

At 132 feet much the same. Thinner banded. Oolites are composed largely of the belted sericite and same has rhomb shape frequently.

At 135 feet much the same. Narrow bands of hematite-magnetite mixture. Oolites are poorly represented. Sericite stained with limonite abundant.

At 141 feet thoroughly recrystallized. Much silicate and oxide in coarse aggregates of oxidized rhombs, probably carbonate.

At 144 feet the chert is coarsely recrystallized. On the whole, though, there are areas of finer texture in which are many rhombs of partially oxidized carbonate.

At 147 feet in chert with bare traces of oolitic structures and throughout are individual needles and sheafs of amphiboles.

At 150 feet, formation is narrow banded. Coarse, irregularly recrystallized chert with the roseattes of amphiboles. Narrow band of extremely fine-grained chert disseminated through oxide which is 95 per cent of the band. This band represents one of the series of thin laminae of cherty carbonate which separate the beds of thicker, oolitic chert.

At 153 feet the chert is irregularly recrystallized, sometimes extremely coarse, sometimes fairly fine-grained. In this are coarse rhombs of carbonate almost completely oxidized to limonite.

At 156 feet the rock is much the same as at 153. Irregularly recrystallized chert with abundant rhombs of siderite almost completely oxidized to limonite. Magnetite sprinkled throughout. Numerous bunches of amphibole.

At 159 feet there is practically no chert. Slide is amphibole and magnetite and hematite. Narrow banded.

At 162 feet the formation is beautifully oolitic with the concentric boundaries of the oolites represented by dust cutting across the coarse grains of quartz. Considerable amphibole and some siderite undergoing oxidation.

At 165 feet the formation is oolitic chert as the last noted with recrystallized chert cutting across the oolitic boundaries. Amphibole is notable in quantity. There is some siderite undergoing oxidation.

At 168 feet the formation is narrow-banded. One-eighth inch bands of magnetite and hematite with a sprinkling of *fine-grained* chert alternate with quarter-inch bands of beautifully oolitic coarsely recrystallized chert. Silicate is far more abundant in the thinner bands. This slide is first-class in showing that in the thinner bands of cherty carbonate the chert is always much finer even after recrystallization than in the oolitic chert, and also the amphibole is more abundant in the originally carbonate rich beds.

At 300 feet the formation is practically all a fine felt of sericite (?) which is oolitic, or was prior to recrystallization, and rhombs and chains of rhombs of magnetite carrying some pyrite.

At 303 feet the formation is much like at 168. The thinner bands are, however a felt of silicate. Magnetite in rhombs.

At 306 feet the formation is practically as at 168 and 300. Thin-banded amphibole-magnetite rock. Represents the thin laminae of original carbonate with alternating beds of oolitic carbonate in chert now practically all amphibole and magnetite.

At 309 feet the formation is practically the same thin-banded amphibole-magnetite rock. Originally, laminae of cherty carbonate alternated with oolitic carbonate in chert.

From the base of the section through the sections to 169 feet, the Plymouth member is represented. From the section at 168 feet, which is characteristically Yale slate, through the section to 300 feet the Yale is probably represented. There is a gap of about

120 feet where the formation is not exposed. From 309 feet to 348 feet there is another gap in the section.

At 348 feet the formation is coarsely but irregularly recrystallized chert carrying abundant needles of amphibole and magnetite. The oolitic structure is indistinct.

At 351 feet the formation is beautifully oolitic but coarse quartz and a sprinkling of magnetite with a few sheafs of amphibole are the only minerals. This is probably Norrie formation.

At 357 feet the formation is much the same as at 351. There is perhaps more silicate. Magnetite is roughly 20 per cent of the section.

At 363 feet the formation contains notable amounts of carbonate aside from which the formation is much the same as above.

At 366 feet the slide shows quite an abundance of carbonate being replaced by magnetite and amphibole. Chert is coarsely recrystallized and was originally oolitic.

At 369 feet the thin section shows beautifully the siderite forming oolites to the extent of 100 per cent and all stages of replacement by silica and oxide. The carbonate oolites are in some cases enclosed completely in structureless siderite more or less stained by incipient oxidation to limonite.

At 372 feet the chert shows oolitic markings and all is coarsely recrystallized. Magnetite forms a quarter-inch band across the section.

There is a gap of 219 feet at this point.

At 486 feet the section shows a very thin laminated quartz-amphibole-magnetite schist. The laminae are of the order of a thirty-second of an inch in thickness.

At 489 feet the rock is still very fine laminated quartz-amphibole-magnetite rock.

At 492 feet the rock is, oolitic chert coarsely recrystallized. There is practically no trace of carbonate remaining in the oolites.

At 495 feet are paper-thin laminae of quartz-amphibole-magnetite schist. The chert is characteristically very fine-grained.

At 498 feet is oolitic chert entirely recrystallized though finely with a scattered carbonate rhomb here and there. A second section shows carbonate being replaced on a large scale by quartz.

At 501 feet very thin laminae of quartz-amphibole-magnetite schist. The magnetite is coarsely chrstallized and the rhombs appear to have developed from massive carbonate. Between the rhombs is the silicate and quartz.

There is a gap to 600 feet in the section.

At 600 feet thin laminated quartz-amphibole-magnetite schist.

At 603 feet the same rock.

At 606 feet oolitic chert with a trace of carbonate and bands of magnetite.

At 609 feet thinly laminated quartz-amphibole-magnetite schist.

At 612 feet oolitic chert recrystallized, magnetite in rhombs, some siderite and minor amount of silicate.

At 615 feet thinly laminated amphibole-magnetite schist.

At 618 feet some with trace of oolitic structure.

In passing from this description of the formation along the section at Tylers Fork it should be mentioned that the thin sections were naturally made from the more transparent portions of the specimens. The formation is an alternation of thick beds of oolitic chert recrystallized and more or less oxidized with thinner beds consisting of many thin laminae of magnetite and hematite with but a nominal amount of fine-grained chert or silicate. From the specimens thin sections were cut to study the chert and not the opaque oxides. This section is perhaps not representative for the entire range of 1 west but the other exposures are scattered, the pits too are scattered and while more or less departure from the conditions represented by the above section were found, this suite of specimens and thin sections is probably close to representative. If it fails in this it is on the side of too little recrystallization rather than the contrary.

In section 25 and the southeast of 24, there are a number of test pits. Those in the southeast of 24 are well up in the upper members of the formation. The pits disclosed the presence of a dike and there is evidence of first-class oxidation but leaching is not noteworthy and it would appear that the work disclosed no ore in quantity. It will be noted on the map that the attraction in the upper horizon is of the order of 70 degrees in this outer horizon, although the footwall is less magnetic; in fact it is not a simple matter to detect the actual location of the footwall along this portion of the Range. On the east line of the section there is an exposure of unoxidized formation which lies not far above the contact and in a series of pits about 200 paces west of the line the quartzite is disclosed.

In the neighborhood of the quarter line of these sections there are several extensive exploration shafts. Two of the shafts are well up in the formation and from the size of the dump it would appear that the total workings were of the order of 400 feet. Whether this represents any drifting or crosscutting could not be learned. There are exposures of Tyler slate just northeast and the dumps show some of the same formation. The southern shaft has an extensive dump and the material shows good oxidation. No dike was found on the dump. This locality offers some indications of promising ground but the magnetic attraction is not inviting.

In the east of section 26, the Range is subdued but rises toward the southwest. No exposures were located in the section and there are but a few test pits. These are in two groups, one in the northwest of the southeast which is located in the mid-section of the formation and showed lean green formation. In the other group oxidation was somewhat more attractive but the location is well up in the formation and no real promise is to be seen. In the physiography and the dislocation of the outer magnetic horizon there is some suggestion of cross faulting. This was not drawn upon the maps but there is a strong likelihood of dislocation in the southwest of section 26 or the southeast of 27.

Section 27 lies upon high ground. This holds for the north of 34 as well. In the southeast of 27 there is an exploration well up in the formation consisting of a shaft which may have amounted to 100–200 feet of workings. A moderate amount of oxidation and leaching is evident from the dump material. Dike material also was seen. It is of interest to note that these explorations described thus far in 1 west were induced by the strong magnetic horizon in the hanging. The foot has not been explored and while the evidence in the explorations is not over-inviting, it still remains that there has been no real exploration in the township.

Close to the west side of the northwest of 34 the range drops off sharply to the west. This is the valley of Tylers Fork. The magnetic record and the physiography indicate a cross fault, the west side being thrown north. In the base of the Keweenawan there is a clean cut offset of the same description. This fault has been drawn upon the map. Plate X

Exposures are abundant along the course of Tylers Fork and a description of the formation as studied under the microscope has been presented.

Section 33 contains the beginning of the real distinctive western phase of the formation. The Tyler Valley is about a half mile wide. There is a sharp rise to the westward, the Ironwood climbs to the crest of the Range, the footwall is distinctly magnetic almost continuously from here west, the width of the belt of attraction increases sharply, drag folding in the hanging is prominent and apparently continuous for some distance and the density of the formation shows a decided increase. If there is a sharp boundary between the eastern phase of carbonate-chert-rock and the western phase of amphibole-magnetite-quartz rock, that boundary can be drawn through the center of section 33 of this township. On the map a cross fault has been indicated here. This is based on the offset in the foot magnetic lines, and the sharp increase in the width of the magnetic belt representing the formation as a whole. There is no topographic expression of the dislocation, however, and there is no corresponding offset in the base of the Keweenawan so far as could be detected. It might be recorded here in passing that the geological work in the Keweenawan referred to at intervals, was not done until 9 years later. Possibly if the attempt had been made to follow the faults of the Ironwood across the Tyler Valley and into the Keweenawan, a greater number of the minor dislocations might have been projected.

In the south of the northeast quarter of 33 there is an old mine known as the Tylers Fork. This property is credited with some ten thousand tons of ore and as far as can be learned from old records the shaft was down 250-300 feet. The collar, as seen on the map, is midway in the formation and the mining was done to the north, which would throw it into the upper members of the formation. There are a series of pits in the vicinity and these show a fair degree of oxidation as well as igneous material, possibly a dike, although dikes from here west are conspicuous by their absence. It is not apparent that the ore came from any dike-controlled body but rather was probably controlled by longitudinal structures, either faults or drag folds. It was a soft hematite with magnetite sufficient to affect a compass needle. It would appear that the lower formation was not explored. From what is available at the present time it cannot be recommended that the property be reopened for exploration, but the fact that there is an obvious enrichment, although due to an unknown factor, would place the property in the classification of possible productive ground.

The west of 33 contains another gap but aside from the physiography no evidence for cross faulting could be found.

On the east line of 32, about a quarter of a mile north of the southeast corner, there are abundant outcrops of the upper slaty horizon. These are closely folded, and in such a way as to demonstrate that the differential movement was up-dip on the part of the upper beds. The formation here is extremely tight, dense, recrystallized and absolutely unfavorable to secondary ore enrichment. The presence of the folds is a strong factor in accounting for the widening of the magnetic belt. Incidentally these folds coming in at the west of a strong cross fault throw weight to the idea that the cross fault blocks were structural units that have been deformed as units.

In the southeast of the southeast of 32 is an exploration about midway in the formation. There are 2 shafts whose dumps show considerable underground excavation. The dumps show abundantly that the formation is well oxidized and leached and there is igneous rock that probably represents a dike despite the fact that dikes are not known in outcrop. It is possible that the igneous rock represents a sill or other intrusion. The magnetic attraction is strong throughout this vicinity which is not good promise of oxidation. The vicinity is not recommended for exploration although thorough examination has never been attempted.

The topographic map shows an offset of the formation to the north at the south quarter of 32. The footwall is expressed magnetically in the east of the section and from a point a quarter of a mile west of the southeast, this footwall carries more to the west and north. In following the formation footwall northeast from the west line of section 5 of the township 44—1W. it is found that the same does not meet that followed to the southwest in the east of 32. There is obviously a discontinuity in strike and possibly in structure. It is shown on the map as a wide swinging fold, although there is a strong fault in the base of the Keweenawan in the west of section 19 such that the west side is thrown northward several hundred feet. This fault lies at a point lying upon a line normal to the strike of the formation through the south quarter of section 32. It is deemed very likely, therefore, that this feature is a distinct cross fault. In its vicinity, however, the magnetic attraction is very weak and the benefit of the doubt was thrown to the fold hypothesis. It is of interest to note also in confirmation of the fault theory that an exploration about 200 paces west of the south quarter of 32 encountered badly brecciated formation. Some excellent fault breccia specimens were taken here. The formation is dense, green, and lean, offering no invitation for exploration.

Across section 6 of 44—1W., the formation is fairly well exposed and the magnetic attraction serves well in defining the foot and hanging of the formation. The attraction is strong throughout and suggests no oxidation. Through the center of the section there is another swing of the formation to the north. The topographic map indicates this as well. No evidence of faulting was found and the feature is shown as another fold. In this connection it is of interest to record that the formation west of Tyler's Fork is obviously deformed by rock flow and recrystallization with a less amount of cross faulting than was encountered in the east. For these reasons dislocations not clearly determined as faults have been shown as folds, although it seems probable that accompanying the folding there must have been a certain amount of breaking.

Summarization of the conclusions drawn from the study of the Ironwood across these townships of 1 west emphasizes the increase in the magnetic attraction, the increase in the amount of amphibole, the decrease in carbonate, the decreasing abundance of dikes, the smaller number of minor cross faults, the presence of drag folds and of broad flexures testifying to the metamorphism of the formation. Exploration has best chance of success in the eastern half of the area although even here chances are deemed to be slight.

*The Tyler.* The Tyler formation is considerably better exposed in these townships and it is to be noted that the formation gets its name from abundance of exposures along Tylers Fork River. Measurements made under the best of conditions afforded indicate a thickness of around ten thousand feet. As stated above, there is no known evidence of any discordance in structure between the Tyler and either the Ironwood or the Keweenawan. It is to be emphasized that the formation changes width abruptly at cross faults, but at the same time the width of the magnetic belt changes indicating a change of the dip or a closer approach to the surface of the Ironwood either through folding or faulting. Evidence has been presented to support the contention that there is drag folding in the outer Ironwood. In the next township west, it will be shown that the surface width of the Ironwood is much greater than elsewhere due to the presence of folding. Therefore, the opinion of the writer is that the evidence of differential movement toward a thickening of the series of slates and graywackes constituting the Tyler formation is far too strong to admit any argument for the great erosion otherwise interposed to account for this change in the computed thickness of the Tyler.

The Tyler rocks are commonly green, gray, or black, and heavily bedded, that is, there are phases in which the bedding planes are several feet apart. Some are fine-grained chlorite schists, some are composed of quartz and feldspar, some are quartzites. On the whole, the formation represents the product of a wasting granitic terrain and in some respects it is the counterpart of the Palms from which it is separated by the extraneous Ironwood which is deemed to represent a geologically brief interval of time and which merely suspended or overwhelmed the clastic deposition excepting for the slaty members which do carry carbonaceous and fine clastic materials.

### *The Lower Keweenawan*

There are several very good sections of the Lower Keweenawan formation in this township. One in section 11 and adjoining section 12 close to Little Lake or Lake of the Woods is perhaps best known but at other points, particularly on the east bank of Tylers Fork in section 16, there are also good exposures.

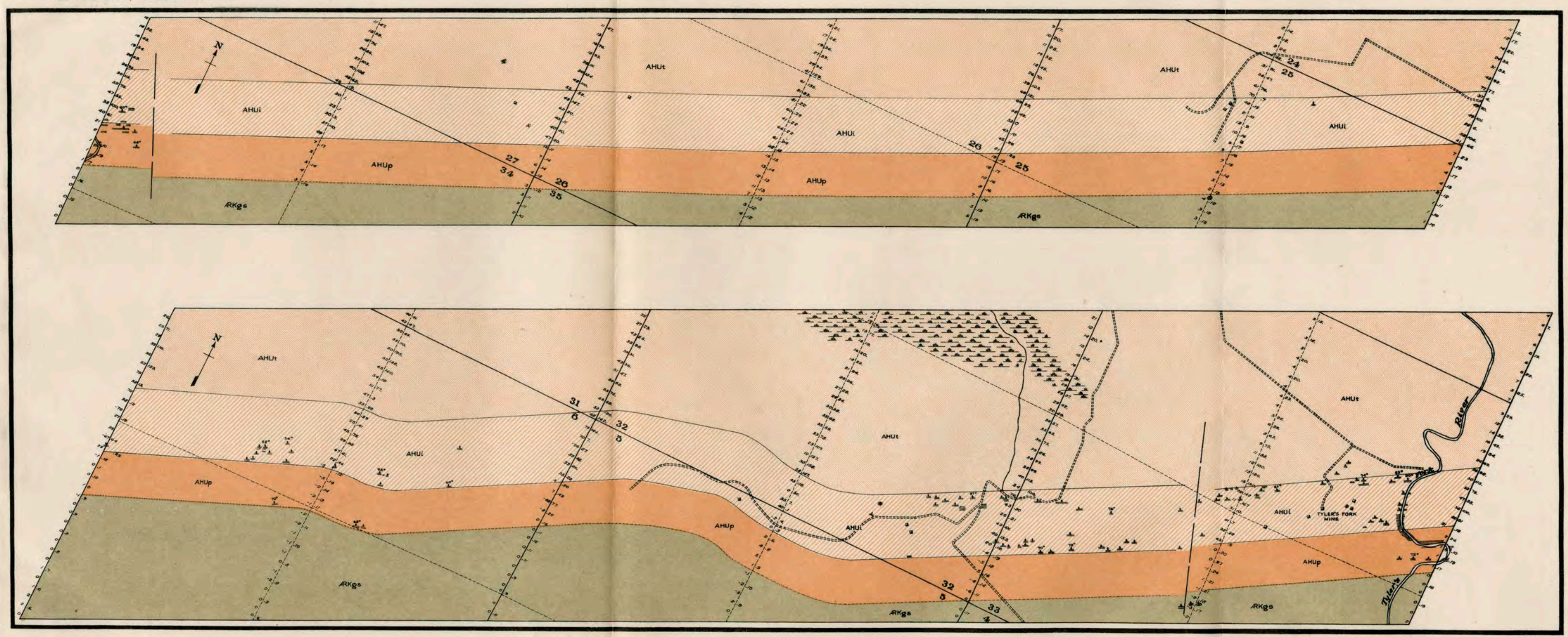
The section near Little Lake is as follows. Near the south quarter of section 12 are exposures of the quartzitic phase of the Tyler. In these rocks are to be seen half-inch, subanglular, vitreous, white quartz pebbles which give a conglomeratic appearance to the rock. Lens-like or pebble-like areas also give a conglomerate appearance. About 150 paces north is an exposure of quartz-iron-formation-conglomerate. The basal member of this is a conglomerate with cobbles up to 6 inches in diameter, well rounded, and composed of 4 varieties of rock, iron formation, crystalline quartz, quartzite, and slate. This is about 8 feet thick. Following this and for another 8 feet with gradational relationships is a quartzite composed of well-rounded quartzite and quartz pebbles. Quartzite succeeds, which is pink on account of an admixture of pink feldspar. The grains are fairly angular. It is about 6 feet thick.

Almost everywhere that these rocks are seen opportunity is provided to see that the first of the lava flows interrupted the deposition of the quartzite. Along the Tylers Fork section the quartzite is interrupted by 6 feet of quartzite-basalt breccia. At the Little Lake section the quartzite is succeeded by an amygdaloid. This is succeeded by a two-foot formation consisting of intercalated layers of micaceous quartzite and a white calcareous chert. The succeeding flow is strikingly ellipsoidal. The chert of this section is duplicated in section 7 of the town east and is, therefore, not a local phenomenon.

The uppermost rocks of the Tyler represent a gradual transition to the rocks of the so-called lower Keweenawan. They show definite mutual affinites. The upper Tyler beds show the conglomerate tendencies so far as the quartz and quartzite pebbles are concerned. The quartzite above the conspicuous conglomerate is in many respects similar to the Tyler quartzites. In short, these relationships and the fact that the flows interrupted the deposition of the sediments are accepted as evidence confirming the absence of any discordance in structure which weighs heavily in favor of the conformability of the series.

### *The Middle Keweenawan*

The Middle Keweenawan series is the series of basic lava flows of the region. Normally this is of the order of 25 thousand feet thick. However it has been invaded by a wedge of gabbro which is more than 3 miles across. The base of this is not exactly parallel to the flows, instead it strikes more to the northeast in consequence of which it is closer to the Tyler contact in the west than in the east. Thus in this township the flows are not over a quarter of a mile across on the east bank of the Tylers Fork, while on the east line of section 1 they are at least a mile across. On the west side of the Tylers Fork fault the thickness of flows is unknown but judged by the magnetic attraction they are not much over the half mile width. Excepting for this narrow and wedge-like series of flows, the rest of the township to the north of the Tyler slates is underlain by gabbros and their differentiates of which the most conspicuous are the red alkalic intrusives which are to be seen from every hand. The fault which Tylers Fork follows was evidently in existence or formed contemporaneously with the invasion of the gabbro, for from the center of section 8 to the center of section 6, there is a more or less continuous ridge of gabbro apparently forming a huge dike along that fault. Also, from the south quarter of 17 at least to the center of 20 and as a narrower feature continuing for at least another mile is a tongue of gabbro about half a mile wide.




LEGEND

AHUt Tyler

AHUp Palms

AHUi Ironwood

ÆRKgs Keewatin Green Schist

Cross Fault

Figures left of lines are dip needle readings.
Figures right of lines are dial compass readings.
Dot to left=W. declination.
Dot to right=E. declination.

▪ Shaft

**T44-45N ~ R1W**

WISCONSIN

GEOLOGICAL AND NATURAL HISTORY SURVEY

E. F. BEAN, DIRECTOR

45

# TOWNSHIP 44 N., R. 1 W.

Survey made in August, 1915

Under the direction of

W. O. HOTCHKISS, State Geologist

AND

E. F. BEAN, in charge of Field Parties

H. N. EIDEMILLER, Chief of Party
E. A. KRONQUIST, Asst. Geologist
C. A. HAMMILL, Asst. Geologist

### SYMBOLS AND ABBREVIATIONS.

The symbols and abbreviations used on this map are explained in Chapter II.

### TOWN AND RANGE LINES.

In constructing this map the south line of the township was laid off as a true east west line. The other boundary lines were then laid off with the lengths shown on the Land Survey plat. Some of the maps are therefore incorrect in shape but this is necessary because definite facts are lacking. The acreage of part of the lots in the north and west tier of sections is shown to give a check on the distances in these sections.

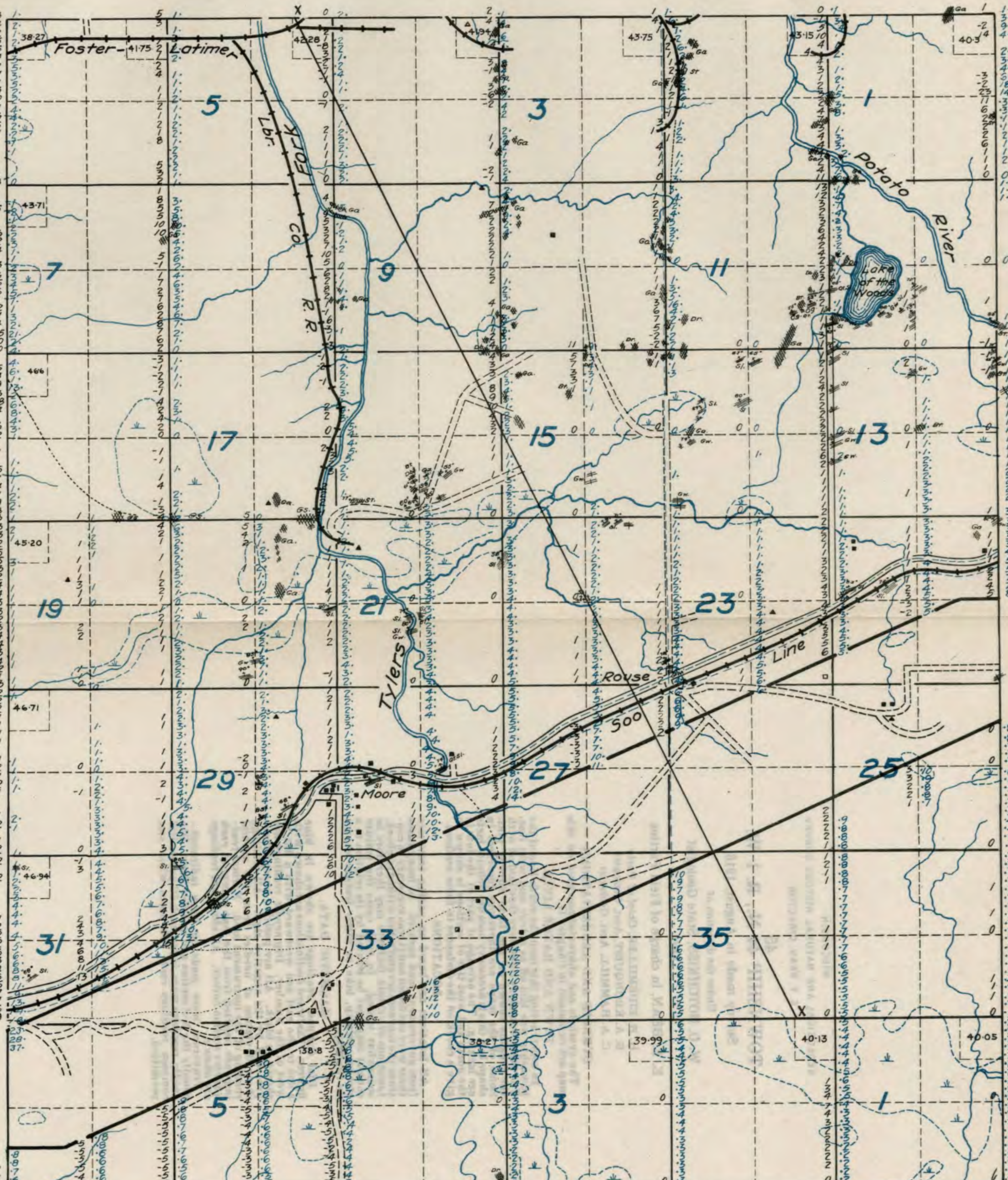
### LOCATIONS.

All locations are based on pacing traverses from government land corners. In many cases these were not found and it was necessary to continue the traverse several miles without a check. Locations of certain features may therefore be somewhat wrong. In such cases the feature sought may best be located by its relation to a stream, swamp, lake, or other feature shown on the map.

### MAGNETIC DATA.

Dial compass readings are shown in blue figures. Eastward declinations are shown with a dot to the east and westward with a dot to west of the number. Dip needle readings are shown in black. All are positive except those preceded by the negative sign. All readings show deviation of needles from the normal reading of the instrument used. Normal readings are omitted from the map except at each quarter section corner. All abnormal readings are shown.

Traverses were made on lines indicated—usually the N-S section and quarter lines. Dip needle readings were taken each 50 paces, dial compass readings each 100 paces when sun permitted.


Foster-Latimer Lbr. Co. R.R.
Fork
Potato River
Lake of the Woods
Tylers
Rouse
Soo Line
Moore
5
3
1
7
9
11
13
17
15
19
21
23
29
27
25
31
33
35
5
3
1
38.27
41.75
42.28
43.75
43.15
43.71
45.20
46.71
46.94
38.8
38.27
39.99
40.13
40.05

In connection with this intrusive and also to point out apparent connection with the metamorphism of the Ironwood it is to be noted that the real marked change in the Ironwood took place at the Tylers Fork cross fault. In the above paragraph it was given that the gabbro makes a closer approach to the Ironwood by, at least, a mile at the crossing of this same fault. Here also in the Ironwood is the first direct evidence of drag folding.

## TOWNSHIPS 44 AND 45 N., RANGE 2W.

The south half of the northern and the whole of the southern townships were surveyed.

### SURFACE FEATURES

This area is a part of the Lake Superior Highland Physiographic Province. It is characteristic of this province that the topographic features are controlled by the composition and structure of the underlying formations.

The area is dominated topographically by three features which are westward continuations of the same features occurring in the towns east. These are the Trap Range in the north of the area, the Gogebic Range in the south of the area, and the intervening Tyler Valley. See Figs. 15, 16.

The Trap Range is an upland of rugged rounded knobs of intrusive gabbros and granites, and ridges of lava flows which the former have invaded. The southern boundary of this group of rocks is a low but precipitous escarpment, here and there broken by cross faults. This northern wall of the Tyler Valley trends about 60 degrees east across the area. It does not exceed 1500 feet in elevation, which provides not over 100 feet of relief above the Tyler Valley. It is to be noted here that the Trap Range is dropping into significance to the southwest. In 46—1E. the Trap Range was the more prominent of the two and relief was of the order of 200 feet.

The Gogebic Range in 44—2W. is by far the more prominent of the two Ranges. The formations south are the same as in towns east, but the Ironwood has been given an increase in the property of resistance so that it has become the most resistant of all in the district. It has consequently gradually climbed to the crest of the Range and in section 9 of 44—2W. it attains one of the highest elevations in the state at 1886 feet above sea. This is Mount Whittlesey. The Range continues as a line of elliptical hills so characteristic in towns east, but the gaps are fewer and deeper. Most prominent of these are the one at Ballou in section 11 and the one followed by Devils Creek in sections 8 and 17. Although the former is probably badly sheared, there is no evidence of any offset. The latter is a prominent zone of shearing and there is a considerable offset in the formation.

The Tyler Valley is rather complex. In this respect it stands in sharp contrast with towns east where it was a more regular feature, although assymetric in cross section, having a steep north wall and a more gentle south wall. Complications in the valley increase with each successive town to the west. In 45—2E. there are one or two isolated knobs about midway in the Valley. In the west of 45—1E. the valley was crossed by the Potato River fault and coincidentally the floor of Tyler Valley west of the fault was elevated about 100 feet. There are more exposures of the Tyler slates in that township than eastward and they occur on a number of elevations in the mid-valley. The drainage is concentrated in a sharp valley at the foot of the Trap Range. In 44—2W. the Tyler Valley is even more complicated with elevations in the mid-region and these are evidently accounted for by structural abnormalities, as will be discussed later.

West of the Loon Lake Fault crossing section 10 the Gogebic swings to the westward, but the Keweenawan Range maintains very nearly its normal strike, although it is offset by faults and complicated by intrusions. The effect of this is that the Tyler Valley narrows to the southwest and in the east of 44—4W. it comes to an end, the two ranges converging at about this point. The simplest offhand explanation of this convergence is that the Tyler experienced erosion following deformation prior to the beginning of Keweenawan vulcanism. Broad field relationships would suggest this. But the detailed field study reveals relationships and facts which put an entirely different explanation in order. This is that the Tyler is wedged off by faulting and intrusion. This will be discussed later.

South of the Gogebic Range are rolling areas and some terminal moraine with swampy tracts and lakes. The formation is Archean schist and the topography is characteristic.

Glacial agencies have had a greater part in the fashioning of the surface of the area than in towns east. Ground moraine of no great thickness covers the area with the following exceptions. In sections 19, 20 and 21 of the northern township and in sections 13, 14, and 15 of the southern township there is a rough knob and sag topography which is probably terminal moraine. The southern area is swampy and there are several lakes. Along Mellen Creek northeast, the Bad River southwest, and Devils Creek straight south of Mellen, there is sand and gravel in terraces which are probably related to higher stages of the pro-glacial Lake Duluth. The suggestion in this connection is that the several streams were bringing this load of sediment to the Bad River whose northern outlet was blocked, impounding a lake. In this the sand was dropped as soon as the velocity of the streams was checked. The ground moraine is composed largely of sandy clay, pebbles, and boulders of trap, Keweenawan sandstone, and felsite from the Keweenawan conglomerates.

There is very little of the original heavy stand of hardwood and hemlock still uncut. Second growth hardwood and brush are rapidly covering the cut-over areas and make observation very difficult.

The main settlement in the area is centered in the town of Mellen in section 6 of 44—2W. Mellen is a most attractive town literally nestled among the hills and in many ways is one of the most beautiful towns in the State. It lies within the southern boundary of the Trap Range at a point where the prevailing precipitous character of this boundary is subdued by having been crossed by two or possibly more cross faults. The Bad River has worn a passage through the Trap Range here. It approaches town from the southwest parallel to the formations after making its way through the Gogebic Range along the Penokee Gap fault.

On all sides of town rise rocky knobs and ridges. Two miles south is Mount Whittlesey, one of the numerous elliptical hills which constitute the Gogebic Range. It rises to an elevation of 1886 feet, which is probably the second highest point in the State. From its crest is gained one of the most magnificent views to be obtained in the region. The outlook to the north commands Lake Superior, the view to the south ranging over the rolling moraine with its sparkling lakes.

Northeast of town about 3 miles the Bad River flows in a rock-walled trench and drops over a steep 30-foot fall which is gaining fame as Copper Falls. Within a quarter of a mile farther down the stream the Bad is joined by its Tylers Fork which comes tumbling down over an even higher fall as though too eager to join company with the main stream. The combined flow passes through a narrow rock gateway and on into the 200-feet deep lower gorge cut from the vermilion glacial clays.

For its variety of geological problems, structural, mineralogical, petrogenic, and metamorphic, there is probably no area comparable to the environs of Mellen. It would be an excellent location for a school of field geology. In the property of the abandoned Berkshire Mine in section 9 is an ideal location for the establishment of such an institution.

Mellen is the junction point of the Soo Line Railroad, which has its terminal at Ashland, and its Iron Range Branch which extends along the Range to Ironwood, Michigan. Paralleling it is State Trunk Highway No. 77, the only direct route between these two cities. Travel in the north and south direction is served by State Trunk No. 13, a main artery traversing the length of the State. There are a few other improved roads in the area, a County Trunk reaching out to Copper Falls, and a second to Lake Gallilee, south of the Gogebic.

There are several manufacturing establishments in Mellen including a sawmill, a veneer mill, a toy factory and creameries. It is the headquarters of the Mellen Lumber Company, which maintains a private railroad into the region to the northeast. In section 29, not over two miles from town, is a working quarry in the anorthositic phase of the gabbro. The rock is a most attractive dark stone and promises to develop a strong demand.

Small farms are being developed along the Tyler Valley and these are probably not capable of great growth on account of the rockiness of the soil. With exhaustion of the timber to the northeast the town will be dependent mainly upon its location with respect to railroads and highways and its scenic attractions, unless reforestation is undertaken or mines developed.

## General Geology

### *Archean*

Exposures of the Archean are very scarce in this area. In section 10, the southeast quarter, are numerous exposures along the crest of the Range. Here the formation is a schistose greenstone with sedimentary resemblances. Quartz, biotite and chlorite are the dominant minerals and the quartz grains are rounded to suggest sedimentary origin. There are drag folds in the schist which pitch to the southwest about 20 degrees. The strike of the schistosity is variable but is generally about 30 degrees northwest with dip to the southwest.

In section 17 the schistosity strikes north 75 degrees west and dips 72 degrees southwest.

### *Huronian*

The relationships of the various Huronian formations to one another are set out in the report for 46—2E. and in Chapter VII.

*The Bad River Dolomite.* Exposures probably representing the Bad River Dolomite occur in sections 10 and 11, apparently continuously, and in the northeast of section 17. Two phases are represented, the dolomitic and the cherty types. In section 11 the latter was not seen, and in 17 the dolomite is not exposed. In section 10 the dolomite is grayish white on fresh fracture surfaces and weathers to a buff or brown. It occurs about 15 feet south of a ledge of brecciated chert containing dolomitic material. Most of the fragments are sharply angular, which fact discounts any idea of its being a conglomerate. In section 17 this chert contains a large proportion of magnetite. The contact with the overlying Palms shows the latter to be a thin-bedded slaty quartzite sometimes carrying pebbles of the underlying chert. The formations are unconformable, as evidenced by the irregularities in the contact and the truncation of the Palms bedding planes by the walls of the irregularities of the older surface. The thickness is about 50 feet.

*The Palms.* The Palms formation can be followed across the entire township, which bears out the statement that this formation and the Ironwood are co-extensive throughout. However, no complete section is afforded by the area. It is best exposed in section 11, where the computed thickness is about 530 feet. At the top is the typical vitreous quartzite, here coarse-grained, massive, and well indurated. It is no less than 20 feet thick. Below is a thin-bedded yellowish gray slaty quartzite succeeded by thin-bedded chocolate colored phases. Toward the base still farther is a dark gray quartzitic slate succeeded by 6-inch to 2-foot beds of clean vitreous quartzite. Straw colored quartzitic slate and a dark green chloritic quartzite containing fragments of chert and magnetite occur at the base.

In section 10 there is a structure which will be discussed more at length in the following paragraphs on the Ironwood. It is a fold pitching westward, possibly complicated by bedding faulting and confined between cross faults. The Palms formation is not exposed in its entire thickness here but complications attending deformation offer so many possibilities that any conclusion that the formation was either originally of less thickness or had been thinned due to folding would be mere speculation. It has been suggested, however, that the high point known as Mount Whittlesey was a shallow in the Palms sea and was not so deeply covered. This is difficult to support.

*The Ironwood.* The Ironwood is well exposed across the township. This follows from the fact that the formation is the most resistant of the series and forms the highest ground of the area. There are a few test pits in section 1, a few in sections 2 and 11, and a greater number in section 10. Nowhere is there decided oxidation or leaching. The formation is very dark, green or black, and very dense. Thin sections show the formation to possess the same sort of original oolitic structure, and there is the same alternation of heavy-bedded cherts with thin-bedded slates. The chert is always well recrystallized with abundant oxide, which is both disseminated amidst the chert grains and concentrated in the oolites. The fact that these oolites occur in these western townships, where the recrystallization has so intensely modified the original composition, proves beyond the slightest doubt that they were not due to the sub-aerial oxidation, such as can be observed in process farther east at the present time. Nor is there any evidence that these western portions of the formation had been exposed to the weather before the recrystallization episode. The oolites are not, therefore, due to concretionary processes attending later stages, but were original or very early formed.

There is little of interest in the formation across sections 1, 2, 11, and 10, or at least the east half of 10. Aside from the above notes in this connection, the magnetic attraction shows that magnetite has been raised in importance. This checks the microscopic examination which shows magnetite and amphibole with a minimum of carbonate.

In the southwest of the southeast of section 10 iron formation is found more than a quarter of a mile south of the footwall, as it was traced southwestward from the town east. Reference to Plate XI will show that this southern exposure of the Ironwood has been traced by exposures and magnetics to join with the regular footwall. This constitutes the most striking departure from the ordinary structure which was encountered anywhere along the Range. At first inspection it appears that the formation has been folded and that the salient extending eastward in the southwest of the southeast of 10 is a westward pitching trough. There are other facts, however, which complicate the situation.

Along the quarter line of section 10, the west line of 10, the quarter line on 9, and the west line of 9, the magnetic observations show a northward decline in intensity from the main belt which is succeeded farther north by a sharper and yet heavy belt of attraction. This outer crest lies usually about 100 paces north of the line of minimum attraction. On the map these outer crests are seen to lie upon a straight line trending not far from parallel to the footwall in the main belt. This is indication of either a local magnetic bed in the Tyler, a dike, or Ironwood formation thrown to the surface either by folding or bedding faulting, and coming in such a place as to parallel the fold already described in the main formation is suggestive of locallized deformation. The identity of the magnetic outer crest line is established by exposures of iron formation on and just west of the west line of 10.

To the east of section 10 and to the west of section 9 this outer crest is not known, nor is there anything like it anywhere along the Range. Obviously, the outer belt of formation comes to an abrupt end in either direction. With this information alone it might well be concluded that the block containing these two longitudinal folds was delimited on either end by cross faults. This is the very evident situation, as will be shown. Plate I

In section 33 of 45—2W. the base of the Keweenawan is dislocated and the west side is thrown south several hundred feet. In the southwest of 32, about 1¼ miles southwest along the strike there is a reverse offset of about the same amount of throw. In effect, a length of about 1¼ miles of the base of the Middle Keweenawan has been faulted south several hundred feet. Within the block delimited by lines normal to the strike through these points of offset, the Tyler Valley floor is elevated in a fashion similar to that at the crossing of the Potato River Fault. The Tyler formation is seen to be more extensively exposed within this same block and intrusives are common. If the two fault lines be projected southeastward, they are found to delimit the outer belt of magnetic attraction dwelt upon above, and also to demark the limits of folding in the base of the Ironwood. Topographically these fault planes are clearly expressed. The eastern or Loon Lake Fault cuts approximately through the southeast of section 10. Off to the south of the Gogebic the topographic map shows probable expression of the same feature. There is apparently only slight offset of the footwall of the Ironwood as it is traced southwest from the east line of 10, but this is not too clear and is not vital to the solution of the problem. Faulting is well confirmed by the several independent observations already presented. It is of relevance to record, however, that from the center of section 10 to the south quarter of 9; in other words, approximately along the normal projection of the footwall, there is a belt of very low or even sub-normal attraction. This parallels the belt of outermost attraction and is a very strong suggestion of a longitudinal fault. Summing up this situation, it is concluded that within the block delimited by the cross faults, there was a strong component of movement up the dip. The whole block was elevated, accounting for the abundance of Tyler exposures, as well as the abnormally high point in the Ironwood designated as Mount Whittlesey. The main footwall of the Ironwood was set south several hundred feet, but differential movement between the beds produced dip folding or up-dip dragging, and possibly bedding faulting. The outer belt of attraction and the formation which is responsible is a drag in the upper Ironwood. On the property of the Berkshire Mine, in section 9, the drag folding can be seen. Here the formation has been stripped of its overburden in preparation for quarrying, and in the railroad cut a large fold of upper members can be seen recumbent to the south.

Confirmatory evidence of the block faulting can be seen in the detailed work over the Keweenawan formations. The two cross faults mark the boundaries of a rhomboid area of anorthositic gabbro, which is quarried here as a black ornamental stone. The western fault is the contact between this and the more common variety of gabbro. Just south of the center of section 30 the gabbro is cut off along its north edge by pink granite, which is full of inclusions of gabbro and trap. The Bad River flows across this contact and no more exposures are to be seen to the north. However, the stream continues on in the northwesterly direction for close to a mile in loose surface materials and then near the center of 19 it swings northeastward. In the northwest of 20 it emerges from the loose materials and enters a gorge formed by the erosion of amygdaloid which here stands practically on edge. These are traps lying below the Chippewa felsite flow. The details of structure beyond this point are not relevant to this problem and will be treated in the report on the Keweenawan formations. It is clear, however, that the eastern of the two cross faults is well supported in the evidence, although the actual faulting has nowhere been seen. That the block has been elevated with respect to the two flanks is evidenced on this Keweenawan end by the presence and relation to adjacent formations of the anorthositic gabbro, which in the vicinity is practically restricted to this rhomboidal area. As has been set out in the chapter on the structure of the Ironwood, the up-the-dip differential movement is but the local expression of the same movement which has affected the entire region and which is deemed to be explained by differential foundering of the Lake Superior Basin and consequent torsional stresses. Attention is called to Plate I of the region of the Keweenawan showing the thrusting of the outer conglomerate of the Upper Keweenawan to truncate the Lake Shore Traps, the Chippewa felsite, and the underlying traps. In this connection, as has been set forth in the chapter on structure, there are innumerable massive blocks of the conglomerate measuring 10 to 15 feet in diameter which are concentrated on the property of the Berkshire Mine. Nowhere else on the Range is there such an accumulation of these boulders. They have been in the past considered as glacial transports and ice-rafted boulders, which explanations are wholly without support and ignore the structural phenomena of the larger area.

A cross section through the Berkshire property is shown in Figure 16. In passing it may be stated that this property has long been the reef on which attempts to beneficiate the Ironwood have been wrecked. There is a large mill upon the property equipped with crushers of various sizes, and jigs and magnetic concentrators which were to have concentrated the iron oxides. Unfortunately the rock must be crushed to about 200 mesh to break down the mixture of the quartz and oxides, and the oxides are both hematite and magnetite in about equal proportions. The formation here is apparently no better adapted to concentration than elsewhere along this part of the Range.

West of the western cross fault the width of the magnetic belt returns to normal width for the region. On the detailed map there is an abrupt change at the fault. Near the quarter mile corner east of the south quarter of section 8 the footwall of the Ironwood is again offset. The main road from Mellen to Lake Gallilee runs up this valley which is controlled by the fault. It passes through the center of the town of Mellen and appears to offset the contact between the granite and the gabbro. The footwall of the Keweenawan is also offset at this point. There is drag folding in the base of the Ironwood here, which west of the Mellen fault produces a slightly greater surface width. However, one-half mile west a fourth in this series of cross faults reduces the Ironwood to normal width. From here across section 18 the formation is well exposed both naturally and in pits. Throughout it is hard and lean, well crystallized and uninviting. The magnetic attraction averages fairly high and about 200 paces north of the probable Tyler contact there is a slight rise in the readings suggesting similarity to the outer line of crests in the Mount Whittlesey fault block. It is considered unlikely that this arises from a magnetic horizon in the Tyler, because in the Tyler the only highly ferruginous beds are close to the very base which is interpreted as a continuation of the chemical deposition after the clastics had resumed deposition. The explanation of this outer line of crests is that it is due to a drag or longitudinal fault. A similar or analogous feature is found west of Penokee Gap fault and will be discussed in the report for 44—3W.

*The Tyler.* The Tyler formation has not been given a detailed petrographic study on account of the difficulties met in working on a fine-grained rock, on account of the lack of complete sections, and on account of no economic value. A detailed study tracing the metamorphism from the eastern exposures to these in the region of intense induration would make an extremely interesting volume. In Monograph 19 Van Hise gives a very comprehensive overview of the formation. He points out that the sediments closely reflect the character of the Archean basement. Where the basement is granitic, the Tyler is more of an arkosic quartzite and feldspathic slate, but where the basement is greenstone, the Tyler partakes of a graywacke character. To the east the formation is much softer with little or no recrystallization and no schistosity, while in the west the recrystallization has converted these rocks to highly schistose mica schists.

The township affords a much greater number of exposures of the formation probably as a consequence of the metamorphism and the greater number of local intrusives. The Loon Lake-Mount Whittlesey fault and the Reservoir fault have formed a block which is apparently upthrust so that within it there are numerous exposures. The cross section, Figure 16, shows the probable structural situation.

The upper members are micaceous quartzitic and graywacke slates. The central portions are graywacke, quartzitic slates, generally thick-bedded and rarely schistose. The lower horizons tend to darker color, thinner beds, higher proportions of mica, and close to the very base contain much iron carbonate and magnetite. The latter observation reflects the fact that the chemical sediment was not through deposition when the clastics resumed domination of the basin. It will be found in Chapter VII that the writer considers the Ironwood to have been a rapidly deposited formation which suspended the domination of the clastic deposition in the basin, although fine sediments continued to come in as reflected in the thinner bedded slaty members, and that when iron formation contributions became less voluminous, the clastics regained the upper hand and became coarser as the down-warping of the basin exposed fresher rocks in the vicinity of derivation.

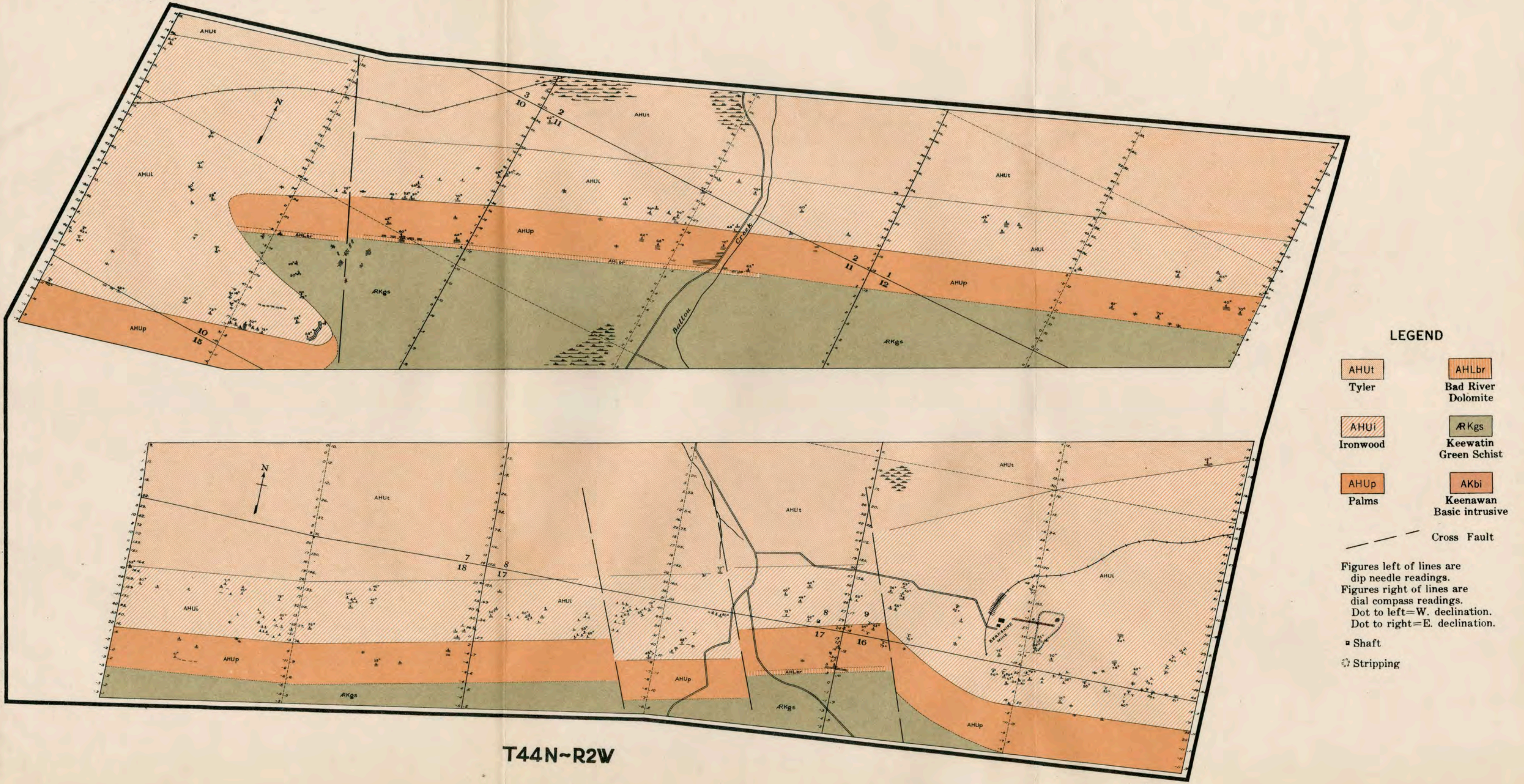
The Tyler is narrower on the west line of the township than on the east. This may be accounted for partly on the basis of change in attitude but largely on the basis of the fact that the lower horizons have swung to the west, while the upper have more consistently maintained their southwestward strike. At the Loon Lake fault the first pronounced deformation is found. From here west the Keweenawan-Tyler contact is badly disturbed by intrusives and apparent bedding thrusts. The interpretation applied is that the entire group of formations have been subjected to torsion consequent upon the differential downwarping of the syncline and the Keweenawan has been upthrust over the Huronian, the Tyler being the incompetent member which has facilitated the deformation.

### *The Lower Keweenawan*

The Lower Keweenawan is the series of conglomerates and arkosic quartzites which occur between the basal lavas of the Keweenawan and the Tyler. These were found in the north of section 26, in the extreme southeast of 28, in the southeast of 31, and in the north of section 6 of 44—2W. The quartz conglomerate is the distinctive thing and in most cases the exposures have been badly confused by the basic intrusions. The principal fact derived from them is that the series is continuous at the base of the lavas.

### *The Middle Keweenawan*

This series consists of basic flows but they have been thoroughly invaded and permeated by gabbro intrusives. The effects of the intrusions are mineralogical and textural. The amygdaloids are thoroughly baked, the flow tops are darkened and rendered magnetic. The age of the intrusives cannot be determined with high degree of precision because of the possibility that they were continued through a considerable range. In this township the


LEGEND
AHUt
Tyler
AHLbr
Bad River Dolomite
AHUi
Ironwood
ÆRKgs
Keewatin Green Schist
AHUp
Palms
AKbi
Keenawan Basic intrusive
Cross Fault
Figures left of lines are dip needle readings.
Figures right of lines are dial compass readings.
Dot to left=W. declination.
Dot to right=E. declination.
Shaft
Stripping
Bellou Creek
T44N~R2W

WISCONSIN

GEOLOGICAL AND NATURAL HISTORY SURVEY

E. F. BEAN, DIRECTOR

# TOWNSHIP 45 N., R. 2 W.

Survey made in August, 1915

Under the direction of

W. O. HOTCHKISS, State Geologist

AND

E. F. BEAN, in charge of Field Partie.

M. C. LAKE, Chief of Party
C. S. CORBETT, Asst. Geologist
WM. FOSTER, Asst. Geologist
H. D. WAKEFIELD, Asst. Geologist

## SYMBOLS AND ABBREVIATIONS.

The symbols and abbreviations used on this map are explained in Chapter II.

## TOWN AND RANGE LINES.

In constructing this map the south line of the township was laid off as a true east west line. The other boundary lines were then laid off with the lengths shown on the Land Survey plat. Some of the maps are therefore incorrect in shape but this is necessary because definite facts are lacking. The acreage of part of the lots in the north and west tier of sections is shown to give a check on the distances in these sections.

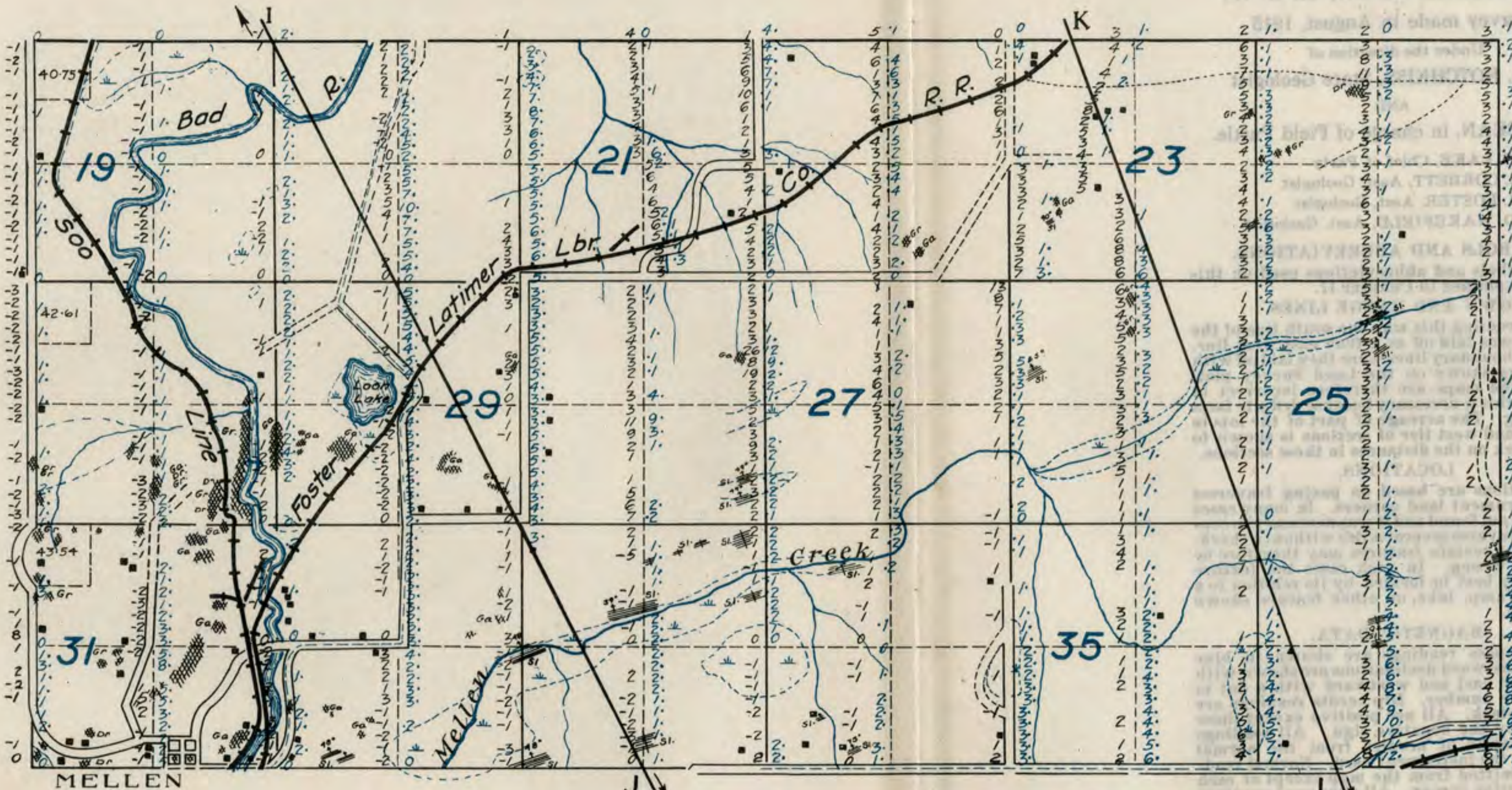
## LOCATIONS.

All locations are based on pacing traverses from government land corners. In many cases these were not found and it was necessary to continue the traverse several miles without a check. Locations of certain features may therefore be somewhat wrong. In such cases the feature sought may best be located by its relation to a stream, swamp, lake, or other feature shown on the map.

## MAGNETIC DATA.

Dial compass readings are shown in blue figures. Eastward declinations are shown with a dot to the east and westward with a dot to west of the number. Dip needle readings are shown in black. All are positive except those preceded by the negative sign. All readings show deviation of needles from the normal reading of the instrument used. Normal readings are omitted from the map except at each quarter section corner. All abnormal readings are shown.

Traverses were made on lines indicated—usually the N-S section and quarter lines. Dip needle readings were taken each 50 paces, dial compass readings each 100 paces when sun permitted.


I
J
K
L
19
21
23
25
27
29
31
35
Bad R.
Soo Line
Latimer Lbr. Co. R.R.
Foster
Loon Lake
Mellen Creek
MELLEN

WISCONSIN

GEOLOGICAL AND NATURAL HISTORY SURVEY

E. F. BEAN, DIRECTOR

# TOWNSHIP 44 N., R. 2 W.

Survey made in August, 1915

Under the direction of

W. O. HOTCHKISS, State Geologist

AND

E. F. BEAN, in charge of Field Parties

M. C. LAKE, Chief of Party
C. S. CORBETT, Asst. Geologist
WM. FOSTER, Asst. Geologist
H. D. WAKEFIELD, Asst. Geologist

## SYMBOLS AND ABBREVIATIONS.

The symbols and abbreviations used on this map are explained in Chapter II.

## TOWN AND RANGE LINES.

In constructing this map the south line of the township was laid off as a true east west line. The other boundary lines were then laid off with the lengths shown on the Land Survey plat. Some of the maps are therefore incorrect in shape but this is necessary because definite facts are lacking. The acreage of part of the lots in the north and west tier of sections is shown to give a check on the distances in these sections.

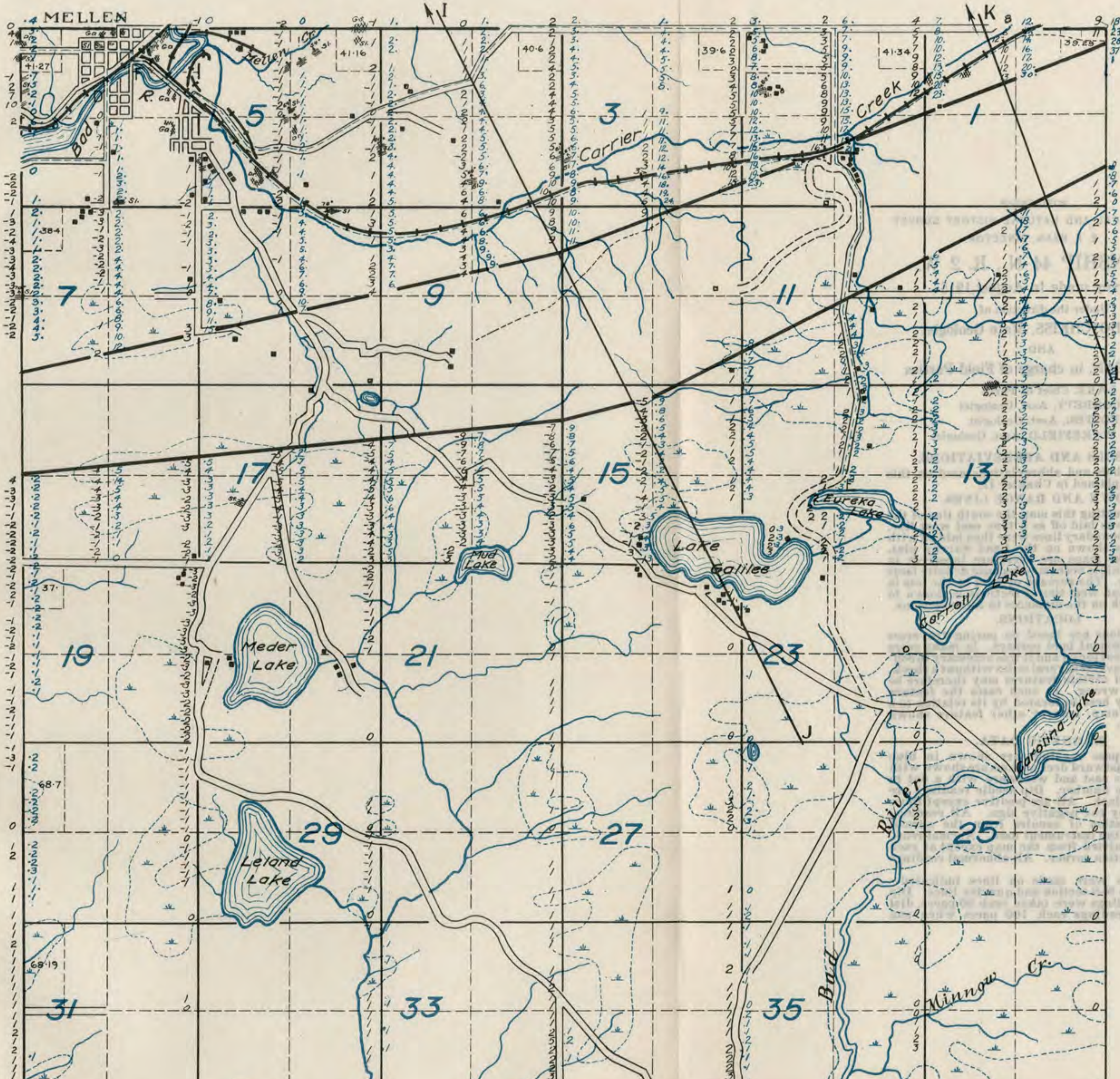
## LOCATIONS.

All locations are based on pacing traverses from government land corners. In many cases these were not found and it was necessary to continue the traverse several miles without a check. Locations of certain features may therefore be somewhat wrong. In such cases the feature sought may best be located by its relation to a stream, swamp, lake, or other feature shown on the map.

## MAGNETIC DATA.

Dial compass readings are shown in blue figures. Eastward declinations are shown with a dot to the east and westward with a dot to west of the number. Dip needle readings are shown in black. All are positive except those preceded by the negative sign. All readings show deviation of needles from the normal reading of the instrument used. Normal readings are omitted from the map except at each quarter section corner. All abnormal readings are shown.

Traverses were made on lines indicated—usually the N-S section and quarter lines. Dip needle readings were taken each 50 paces, dial compass readings each 100 paces when sun permitted.


MELLEN
Bad R.
Helen Cr.
Carrier Creek
Mud Lake
Meder Lake
Leland Lake
Lake Galilee
Eureka Lake
Carroll Lake
Carolina Lake
Bad River
Minnow Cr.
I
J
K
L
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35

Middle Keweenawan is cut by the intrusives well up into the series. In 44—6W. the Great Conglomerate is cut. It would, therefore, appear that the intrusive activity continued at least until the approximate close of the Middle Keweenawan extravasations, if not well into the Upper Keweenawan, because it seems unlikely that magmas would have been confined as intrusives and not poured over the surface unless there had been a heavy cover to the Upper Keweenawan sediments. From the appearance of segregational banding in the intrusive, it appears that it was formed while the flows were approximately horizontal.

The gabbro masses can be divided into three portions. From the west quarter of 28, where the Loon Lake fault passes and where the width of the gabbro is a little more than a mile, a northeastward trending wedge decreases to zero about 4 miles east. South of this are flows in a narrow selvage. North of the wedge are flows also. Accordingly this gabbro is interpreted as the eastern end of a laccolitic mass. West of the Loon Lake fault are huge knobs of a phase of the gabbro characterized by dominance of anorthite feldspar in large plates. This is the dominant rock south of Loon Lake and as far west as the second cross fault. Its southern boundary is of the more common type of gabbro. The Bad River flowing along the western boundary of the anorthosite is bounded on the west by the more ordinary type of gabbro. The northern boundary of the anorthosite is unknown on account of the absence of exposures and there is no magnetic variation which suggests it. Therefore, the conglomerate which outcrops on the Bad River just below the confluence in the southeast quarter of 17 is projected with the same strike as far as the contact with the granite and gabbro near the center of 30. The anorthosite is, therefore, limited to the fault block and is bounded on the north by the overthrust conglomerate.

The contact between the gabbro and the granite in 30 and 31 is evidently a fault, as indicated by the profusion of fragments of gabbro and trap in the granite. This fault has the appearance of an extension of the thrust at the base of the conglomerate just referred to, and of the diagonal fault with which it seems to connect which cuts the Ironwood in the north of section 13 of 44—3W.

Within this area there are no Upper Keweenawan rocks. On the Bad River below the confluence with Tylers Fork there are numerous exposures of the conglomerates and the sandstones of that series.

## TOWNSHIP 44 N., RANGE 3W.

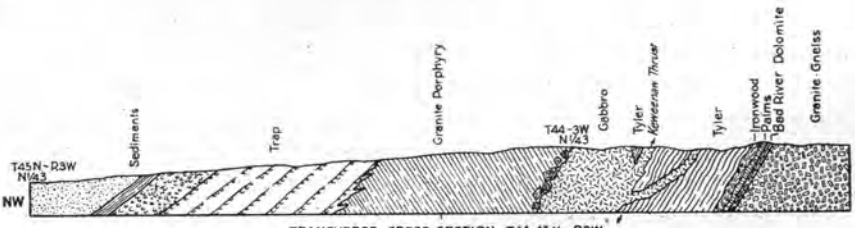
The entire township was mapped.

### SURFACE FEATURES

This area lies within the Lake Superior Highland Physiographic Province. The dominant factors in control of topography are the composition and structure of the underlying formations.

There are three outstanding topographic features, the Gogebic Range, the Keweenawan Highland, and the intervening Tyler Valley. See Fig. 30. The first is the most prominent feature. It averages between 1600 and 1700 feet in elevation. Across sections 13 and the east half of 14 the strike of the ridge is not far from east and west. West of the quarter line of 14 it swings more to the north of west for as much as a mile. In the west of 15 it is practically east and west and in the northeast of 16 it again swings into the southwest. Width varies also from little more than half a mile in the eastern third which extends to a half mile west of Penokee Gap to as much as a mile in the west of the township. This variation is occasioned by dip changes and to some extent by complications of structure. In the eastern portion, the north slope into the Tyler Valley is comparatively steep but in the west it is more gentle and gradational into a marshy tract about a mile wide and limited by the 1400 foot contour which circumscribes English Lake.

The Range is not a continuous feature across this township any more than it was in the eastern areas. Gaps of greater or less depth and width break it into a series of elliptical hills. Most prominent of the gaps is the famous Penokee Gap in section 14




TRANSVERSE CROSS SECTION, T44,45N-R3W
Scale
Hor. 0 1/2 1 m. Vert. 0 1000 2000 ft.
FIG. 30

through which the Bad River makes its crossing of the Range. This is about 200 feet deep and about half a mile across. It is the locus of a series of transverse shears along which there has been movement or faulting which in the horizontal view amounts to close to a quarter of a mile. Second in importance is the sag in the north of 13 through which Highway 13 crosses the Range. This is not over 150 feet deep and it is less than half a mile wide. It too is the locus of a cross fault and so far as can be determined the fault trends to the northeast thereby accounting for the diagonal slope of the Tyler Valley. In the northeast of 16 and the northwest of 15 is a third sag of relatively minor importance. This is about a quarter of a mile wide and 100 feet deep. The English Lake, Brunschweiler Mountain Fault, passes through this gap. It marks the division between the narrow portion of the Range to the east and the broader portion to the west.

In the western portion where the monoclinal dip to the north is relatively gentle, there are a series of gentle folds whose axes trend about N. 20° E. thus crosswise of the regional strike, and which appear to have been occasioned by differential movements from the northwest. It is also probable that these cross folds have passed into faults for they are marked on the east by steep escarpments.

The northern topographic feature, the Keweenawan Highland, is not so clearly differentiated by formations as in townships east. In the first place, the southern boundary is not coincident with the contact of the Keweenawan and the Tyler. The escarpment marking the north wall of the Tyler Valley is in the Tyler slates for a considerable part of the stretch. The contact lies about a half mile north and it is an intrusive contact. The Middle Keweenawan lavas are absent or at best represented merely by remnants in the latter intrusive. From the east of section 1 to the west of section 2 the Tyler is intruded on the north by Keweenawan granites and the terrain is a relatively flat-topped highland. From Penokee Fault west to the crossing of the English Lake, Brunsweiler Mountain Fault in the northwestof 9, the escarpment is also in the Tyler with gabbro intrusive into the slates about half a mile north. West of section 9 and the strong fault across the east end of English Lake the escarpment lies somewhat farther north and is formed by the Keweenawan gabbros. This escarpment crosses the west range line at about the west quarter post of section 7. The topography over the gabbro is extremely rough and knobby, and there are no linear trends.

The Tyler Valley has been referred to casually in the above descriptions of the Gogebic and Keweenawan Highland but is of interest physiographically. On the east range line it is two miles wide but on the west it is only one mile wide. Its north and south boundaries are neither parallel nor regular, as indicated in the description of the Keweenawan Highland.

The south wall of the Tyler Valley is also irregular. On the east range line the Gogebic is about a quarter of a mile south of the northeast of section 13 and as stated above trends roughly east and west to the quarter line of section 14, 1½ miles west. However, on the range line the north slope of the Gogebic or the south wall of the Tyler Valley is a long gentle slope while on the line a mile west it is short and steep. In other words, there is here a slope striking northeast and facing northwest. This is apparently controlled by the northeastward striking cross fault through the north quarter of 13. It is to be noted also that the long gentle northward slope on the range line extends eastward as far as the cross fault, cutting the Gogebic about a quarter of a mile east of the northwest of 17 in 44—2W.

West of Penokee Fault the main valley lies at an elevation of 1400 feet or higher in the case of a series of knobs in the mid region, while east of the Penokee Fault the valley is in general from 100–200 feet lower. Immediately west of the Gap the south wall of the Valley is steep and reaches the 1400 foot contour not more than an eighth of a mile to the north of the Gogebic. With flattening of the structural dip of the Ironwood in the west the slope of the south valley wall becomes more gentle and consequently wider. The change is relatively abrupt in the northeast of 16 at the crossing of the English Lake, Brunschweiler Mountain fault. As noted above, this western portion of the south wall is corrugated by a series of folds in the Ironwood which strike about N. 20° E.

Of particular interest are the several prominent knobs in the middle of the valley between the Penokee Gap and the English Lake, Brunschweiler Mountain Faults. These form a low range trending from the point about a quarter of a mile south of the northeast of 10 to the vicinity of the center of 9. The principal member of the cluster is known as Voight Knob, about a quarter of a mile south of the northeast of 10. This rises 125 feet above its base, is several hundred feet long and strikes approximately east and west. This strike coincides with that of the Tyler slates outcropping on its south side. The knob is a diorite intrusion and judging from its relationship to the bedding of the slates it is probably a sill. The other members of the series are capped by slate or they lack exposures of any sort. The inference from the trend of the series and the occurrence of the intrusion on the most prominent member is that the series represents a more or less continuous sill across the stretch of 1½ miles. What is more, it is deemed highly probable that this sill, some 400 feet thick at least, was guided into place by a bedding fault in the slates.

South of the Gogebic the area is rugged in part due to the glacial deposits but largely as a result of rock control. The prevailing elevation is around 1500 feet or 100 feet above the Tyler Valley. The formations are largely gneisses which are probably the result of injection of Laurentian granite into Kewatin schists. This suggestion comes largely from examination of the exposures along the Soo Line south of Penokee Gap.

Glacial agencies have not played any leading part in the fashioning of the topography of this area. As noted above, the Tyler Valley and the Valley of the Bad River are characterized by broad sand flats which are apparently constructional rather than destructional. It is suggested that these were formed from the sediment carried by the Bad River and dropped on entry into a temporary lake formed at the time of the higher pro-glacial stages of Lake Superior. The main cover of the area is ground moraine which contains abundant iron formation, Keweenawan igneous rocks, and better than 50 per cent of Keweenawan sandstones.

The bulk of the desirable timber has long since been cut off. On the whole the region is not attractive for agriculture and reforestation would seem to be its most logical assignment.

There are two small settlements, Foster, in the south of section 2, and Cayuga in section 36. The former is a mere cluster of cottages and shops at the junction of the Mellen Lumber Company's road with the Soo Line. Cayuga is also a relic of the high tide of the lumbering industry. Along the main highways there are attempts to farm and rarely some degree of success has been met.

## General Geology

### *Archean*

Exposures of the Archean are numerous in this township. They are particularly well concentrated in the valley of Bad River south of Penokee Gap. These exposures are in reality gneisses showing well developed alternation of quartz-and-pink-feldspar-aggregates with hornblende schists. The bands vary in thickness from a fraction of an inch to several feet. They strike generally into the northwest and dip southwest. This alternation of the two types of rock suggests that the granite is Laurentian intrusive into the Kewatin green schists.

### *Huronian*

The relationships of the four Huronian formations were set out in the report for 46—2E. and in Chapter VII.

*Bad River Dolomite.* This formation is exposed in the valley of Bad River just south of Penokee Gap, and a showing is found in the southeast of 17. The latter is discredited as a real outcrop of the formation on account of the distance from the normal location and the absence of any known abnormal structure which would account for the discrepancy in location. The formation is shown on the detail map solely as a residual in the Gap. Plate XII

Both the dolomitic and the cherty phases of the formation are exposed in the Gap. The former is a grayish white, finely crystalline, thin-bedded formation striking south 85° east, and dipping 59° to the north. The beds average from 1–2 inches in thickness. It is more or less tremolitized and shows a structure analogous to that of the Kona Dolomite of the Marquette Range in Michigan. At the latter location the structure has been diagnosed as remains of algal growth.

Above the dolomite which is of the order of 50 feet thick, is a chert bed which is over 25 feet thick. It is grey to white, granular, recrystallized, hard, and in some places well brecciated. The fragments have been recemented with a darker colored chert which in places carries dolomite.

There is no question of the relationships of the Bad River to the overlying Palms, or the Archean below. The exposure is a remnant of an apparently one time extensive formation which was well eroded before the Palms deposition began.

*Palms.* The Palms is well exposed across the township, particularly the vitreous quartzite at the top of the formation. This is especially well exposed in Penokee Gap.

The base of the formation consists of a conglomerate varying in thickness from a few inches to several feet. It consists of fragments of chert and pebbles of iron formation and quartz in a matrix of chlorite and quartz. Above the conglomerate is an alternation of poorly classified clay minerals and quartz. This is succeeded by thin-bedded quartzite of a gray to red color and which is cross-bedded and ripple marked. Above this sequence is a mottled quartzite consisting of dark green chlorite segregated in a massive quartzite. At the top is the vitreous quartzite which is well classified and which is co-extensive with the Ironwood throughout the length of the Range. The main portion of the column consists of the dirty thin-bedded quartzite. In this connection it is well to note that the section in these western townships contains an excess of quartzite as compared with the eastern areas.. This is very likely explained on the basis of the fact that the western section of all the formations has been recrystallized, and what appear as feldspathic clay slates in the east are described as dirty quartzites in the west.

*Ironwood.* Considered as a formation, the Ironwood is well exposed in this township, although there is but one section approaching completeness. Fortunately, there is a diamond drill hole section which can be referred to for certain details and this will be described in its salient points.

The formation occupies the height of land across the township. The crest of the ridge is generally the basal member, or Plymouth, and usually the quartzite of the Palms has supported the Ironwood in its resistance to erosion.

In section 13 there are numerous exposures scattered about a quarter of a mile either side of the quarter line. The bulk of them are well up in the Anvil member and there are Tyler slates exposed in the same region. Rather puny attempts at exploration occur here and from appearances these were inspired by the presence of the exposures as well as by the rather heavy attraction in this outer horizon. On the detail map it will be noted that the attraction extends farther north on this quarter line traverse than on either of the adjacent section line traverses. This is explained in part, perhaps, by the fact that there is a gap in the range some 200 feet deep and also there is an apparent cross fault along which there is a possibility of distortion or drag.

In section 14 there are exposures fairly well distributed along the formation and across the section. In the eastern half the exposures are confined to the lower Plymouth. On the east wall of the Gap there are a number of extensive exposures from the base of the Plymouth to the upper horizons of the Norrie including some excellent showings of the Yale slate member. There is an old exploration here consisting of a shaft, the dump of which represents about 50 feet of workings. It is just off the foot and the material is uninviting. All exposures in the vicinity are hard, dense, dark, unoxidized, and unleached.

The cross faulting through Penokee Gap is spread over a zone at least 200 paces wide. From detailed magnetic observations it is concluded that the main movement took place along two shear planes as indicated on the detail map. Plate (XII). The total displacement appears to have been in the neighborhood of a quarter of a mile.

The best section across the formation in this township and the last good section on this end of the range occurs about on the forty line in the northwest quarter of section 14. This section as well as the one on the east side of the gap were measured with a tape by W. O. Hotchkiss. The sections contain a number of breaks where it was necessary to estimate thickness. Furthermore, close to the fault there is visible more or less folding in the foot portions and there are grounds to expect considerable disruption related to the faulting. The measurements have been represented on the diagram in Mr. Hotchkiss' publication.[1] This measurement gave a horizontal width of close to 700 feet for the Plymouth, Yale, and Norrie, the so-called Lower Ironwood. Mr. Hotchkiss appends a note to the effect that the real thickness can be obtained by applying the proper factor depending upon structural dip which he says averages 60°. The figure for the thickness of the formation arrived at in this way is misleading in that it gives an excessive thickness to the formation. Fortunately, we are in possession of drill core and records for a hole in section 17. From this it has been determined that the total thickness of formation carrying iron formation affinities, that is carbonate and chert, is 714 feet. The upper 125 feet of the section contains an alternation of clean chemical deposit, clastic Tyler, and beds of mixed sediment. Of this it is estimated that fully 50 per cent is clastic. Making the proper deduction for this, the total thickness of the Ironwood is not greatly in excess of 650 feet. For comparison with the formation in the east, the true thickness of the formation measured from drill core in 45—2E. is 600 feet. If full allowance is made for the

[1] Engineering and Mining Journal, September 13, 20, 27, October 4, 1919.

fact that in 44—3W. the structure is complicated by folding, it will be concluded that there is little more than a tendency for the formation to thicken to the westward.

Section 14 was the site of the early explorations of the La Pointe Iron Company. In preparation for the anticipated activities a townsite known as Penokee was platted out but never materialized. The formation is highly magnetic, a fact which probably inspired the hope of producing commercial ores, since at the time the exploratory work was done the furnaces of the country were using magnetite ore. There is little oxidation, practically no leaching, and silicates are the dominant minerals.

Section 15 is well supplied with exposures, particularly so in the eastern half. There is a cluster of pits and trenches in the extreme northeast, but again, these are in the extreme upper horizons and were probably led to by the magnetic attraction. A quarter of a mile west of the northeast there are more pits and a test shaft. These pits are distributed across the formation from the Tyler to the foot slates of the Ironwood. The most southerly is a test shaft some 40 feet deep. No dike appears to have been encountered, there is no leaching or oxidation and the picture on the whole is uninviting. Just over the line in the southwest of the southeast of 10 are a number of pits associated with an exposure of the Norrie member. These show no oxidation but some leaching and honeycombing. The latter is a feature not uncommonly seen in this western end of the range. It is apparently due to the dissolution of some mineral or aggregate of minerals, possibly carbonate. Across the west half of sections 10 and 15 (the formation straddles the line between the two sections) exposures are more meager but there are two shafts. Both are in the Tyler slates.

Section 16 lies at the northeast end of a stretch of formation characterized by considerable folding as indicated on the map. The dip is flatter, averaging 30°, and in the northeast of the section and the northwest of 15 there is a sag in the range which very likely marks the passage of the English Lake—Brunschweiler Mountain Fault. There are a series of exposures near the northeast of the section. As a matter of fact the corner stake and the bearing tree lie upon a line of exposures extending from Palms quartzite at the south to the Anvil on the north. None of these show any oxidation and the only leaching is of the sort referred to before as honeycombing. The dip here is around 45 degrees. There is a sharp northward slope at the north probably marking the Anvil-

Tyler contact. It is of interest also to note in connection with the reflection of formation is topography, that the Yale usually lies in a narrow depression. Several instances of this were made note of in the course of the field work.

Just west of the one-eighth corner west of the northeast of 16 is a gash in the formation trending northwest approximately normal to the strike of the formation. On the east wall of the same is a continuous exposure of the Anvil and Pence. There is no evidence that this gash is related to any considerable dislocation in the formation but it is a decided break. The formation is not oxidized or leached. The magnetic attraction along here is comparatively weak but from all that can be seen this is not probably due to deficiency in magnetite as compared to the formation east or west, but instead to the flattening of the dip. Throughout this part of the range the identification of the foot of the formation is a simple matter since the dip needle shows a sharp rise in attraction at the boundary.

At the quarter line, the strike of the formation swings more sharply to the south. This is the first of a series of flexures to be found from here west. In the center of the northwest of 16 are several pits and a test shaft. The latter is an inclined opening undercutting the Plymouth. It is not over 15–20 feet deep and shows a peculiar type of rock. It is igneous and probably represents an intrusion. The materials thrown from the pits are not altered and show no suggestions of ore possibilities. At about this same point the formation has swung back into the northwest to which strike it adheres as far as the west line of the section.

Across section 17 the formation is fairly regular in strike and dip, the former at about N. 60°E. and latter around 25–30 degrees northwest. As a result of the latter condition, the width of the formation increases considerably. Exposures are almost continuous along the contact between the Ironwood and the Palms quartzite across the section, but elsewhere in the formation they are scarce. It is of some note, possibly, that just north of the formation the dip needle shows a decided drop in reaction. Although this would result from a steep dip of the Ironwood, it may correlate with the presence of carbonate in the outer member which, judging from evidence found in drill core, is here a mixture of the chemically deposited iron formation and the clastic Tyler. The information on the specific disclosures of the drilling is confidential, but that in point in this connection can be entered. Reference to this hole has already been made in connection with the section at Penokee Gap. The hole shows that the formation is approximately 714 feet thick, including from the Palms quartzite to the last of the chemical deposition. However, the upper 125 feet shows alternation and mixtures of iron formation and slate which, as discussed in the chapter on the History of the Ironwood, indicates conformity between these two formations. In this thickness probably 50 per cent is clastic and the iron formation contains, strangely enough, abundant carbonate.

It is this unoxidized, unmetamorphosed, carbonate which possibly is reflected in the low attraction along the north margin of the Ironwood. The drill core has been examined petrographically and shows that the silicates constitute the dominant part of the rock. Magnetite and hematite are ever present and the recrystallized chert is generally present. Excepting in the rather unusual gradational member referred to above, the carbonate is rare, the only two occurrences noted being in the black slate of the Yale, and in the extreme foot chert. The latter is most likely secondary although the entire rock is recrystallized and original carbonates are coarsely crystalline. All the 5 members which have been found to hold for the eastern region can be readily differentiated here in the drill core. This is, if course, based upon the sedimentary textures and structures.

In section 18 there is considerable distortion as stated above. There are drag folds which pitch northeastward. Across the southeast quarter of the section on the west side of a creek is a ridge of outcrops trending about N. 20° E. These are probably Anvil cherts with Pence slates below. On the east side of the creek the Norrie, the Yale, and the Plymouth were mapped. The dip of the Anvil and Pence is about 15 degrees to the west. In the southwest of the southeast of 18 only the Plymouth is exposed and with an east-west strike, dips along the south are northward while those along the north are southward. There is evidently a narrow, close fold here in the Plymouth since dips to north and to the south are between 70 and 80 degrees. From the south quarter of the section on southwest, the dip of the Plymouth is to the north and the strike is about N. 60°E. In the northwest of 19 and the southwest of 18 there is a ridge of exposures similar in attitude to the one first mentioned in the southwest of 18. It trends about N. 20°E. and at the north the strike swings more to the east again. Dips are of the order of 25° to the west. Topographically, these are "highs" and the western slopes are dip slopes while to the east the slope is steep. Another similar situation is found in the township west and not over half a mile from the last mentioned.

The evidence for folding is abundant, and there is strong suggestion of faulting along the east side of the three ridges. As minor structures they are at an angle to the monoclinal Gogebic structure. They are not completely delineated by exposures so that conclusive proof of their nature cannot be obtained. However, they are concluded to be drag folds in the upper members of the Ironwood representing the formation of the synclinal structure to the west which is discussed at some length in Chapter VI.

In the southeast of the southwest of the southwest of 18 are test shafts which are known locally as the former Guest Exploration. The shafts are probably not over 50 feet deep and the life of the enterprise was evidently not long. In the materials on the dumps there is an unusual quantity of rich, specular hematite. This is practically micaceous and it shows evidence of considerable shearing. At the time that the site was first examined by the Survey, considerable stir was created by the find. It was the thought of the group that the specularite reflected the enrichment of the formation locally prior to the metamorphism of the whole. This idea cannot be eliminated but there is little corroborative evidence that the formation was exposed to oxidation prior to the Keweenawan. Nor is the specularite widespread. The alternative idea is that the specularite represents a conversion of a richer carbonate bed to specularite during the rock flowage which has been found so widespread in the vicinity. It is noteworthy in this connection that even as far as the Berkshire property in the township east the iron is about equally distributed between magnetite and hematite. Hard hematite in bands between beds of chert is the normal thing in the formation throughout. Whatever the final word on this may be, and in spite of the fact that rather extensive drilling in 17 failed to show anything like merchantable ore, and furthermore, although there is nothing in the exposures to indicate the activity of ore making processes related to the present erosion surfaces, it still remains that the locality is open to the rather meager chance that there are hard ore enrichments of the type represented by the material here at the Guest.

*Tyler.* The Tyler is the formation overlying the Ironwood. Elsewhere have been set out the factors bearing upon the question of whether the two formations are conformable. In the case of the drill hole referred to in the above paragraphs, the evidence is strongly in support of the gradational relationships of the two and there is no other evidence, one way or the other, in this township,

The following description of the Tyler is quoted from the report of Mr. M. C. Lake who was in charge of the party surveying the township in 1915.

"Outcrops of the formation do not form a continuous section across the formation though enough exposures are present at Penokee Gap section to furnish data covering most of the formation. The formation may be roughly divided into three divisions: (1) the lower black thin-bedded micaceous slate carrying iron carbonate and some magnetite; (2) the middle horizon composed of graywacke and quartzitic slates, generally thick-bedded, massive, and lacking cleavage; and (3) an upper phase of biotitic, micaceous quartzitic to graywacke slates, schistose and extremely foliated. Exact boundaries are not given for the various phases, but a rough estimation would be as follows: Lower slate five twelfths, middle slate four-twelfths, and upper slate three-twelfths.

The lower slate is always thin-bedded, one-fourth to one inch thick, black, dense looking, aphanitic in texture, and usually carrying a slaty cleavage. The rock usually carries a little iron carbonate, magnetite, and occasionally pyrite. It usually has a simple northward dip, though it sometimes exhibits drag folds and small fault planes in Penokee Gap.

The middle slate member consists of gray, greenish gray, dark grayish brown, quartzitic slate, graywacke and graywacke slate, usually massive in beds 6 inches to 4 feet in thickness, sometimes alternating with black slate carrying an unknown metamorphic mineral in important amounts. The massive quartzitic slate or graywacke is composed of well cemented quartz and feldspar grains, cemented by silica and iron carbonate. The latter is noted by its rusty weathering. The massive nature of these beds, their lack of schistosity, and uniform character of strike and dip argue for but slight metamorphism other than extreme induration.

The upper slate member consists of quartz, mica schists, interbedded with impure quartzite or graywacke bands. The mica consists of both biotite and muscovite, possibly sericite. The rock is much folded and contorted. Drag folds of delicate character are abundant. A peculiar phase of this formation is the presence of a boulder-like form of slate within the schist. Many of the "boulders" are of the same composition as the enclosing schist, but not quite so schistose. They range from 2–15 inches in diameter, and have no particular order or arrangement. Schistosity usually bends about them. Some show bedding planes which lie at an angle, and others are structureless. The queer crumpling of the beds, the presence of these round-like fragments, and the presence of tiny vein-like forms visible on the weathered surface, twisting here and there, suggest a change in depositional conditions The fragments representing consolidated mud balls which, perhaps, were rolled about before consolidation, explain the complex nature of the banding, which is difficult to explain under conditions of structural stress for the lack of uniformity and persistency.

This upper slate is found in contact with granite, diorite, and gabbro intrusives, generally intruded by many dikes. In some cases the metamorphism has been so severe at the contacts that the rocks are not easily identified. The important minerals developed at the contacts are biotite, muscovite, and magnetite. The rock is recrystallized and highly sheared."

This description is included for the lack of a more comprehensive statement and the writer is not familiar with the formation as a whole. However, the area east of the Penokee Gap fault, in the region where the slate is in contact with the Keweenawan has been visited, and in this region, at least, the above description may be modified. In sections 1 and 2, it is not correct to state that the Tyler is in contact with intrusives as if there were no intervening formation. There are here innumerable remnants of the Middle Keweenawan lavas, which have been thoroughly altered by the later Keweenawan granites and pegmatites. A thorough study of the region was not made but it can be stated that much of the area over which slates were mapped in these sections, contains readily recognizable remnants of the old amygdaloids. These remnants have been recrystallized and sheared presenting the appearance of schists and may have been mistaken for altered slates. On the west side of the passage of the Penokee Gap fault through the north wall of the Tyler Valley, there are schists containing abundant somewhat rounded fragments of other schists but these are not widespread apparently and are considered to be related to the thrusting along the base of the granite. It is also apparent that the base of the gabbro which has been noted to cut deeper and deeper into the Middle Keweenawan across townships east was the locus of a longitudinal thrust fault. This thrust apparently completes the bevelling of Middle Keweenawan traps in sections 1 and 2 and is suggestive of the cause of the schistose character of the Tyler in this vicinity. On the map, Plate I, the situation in this corner of the township is shown as a compromise between the view of Lake quoted above and the situation as arrived at from the study of the Keweenawan plus a hurried excursion through the sections named.

The map, Plate I, shows the Tyler slate in contact with gabbro from Penokee Gap to the west range line. This is from the evidence collected by the earlier party. It is possible that shreds of the Lower Keweenawan may occur there but so thoroughly metamorphosed as to be difficult to recognize. It also appears that the Lower and Middle Keweenawan are practically eliminated. And, since to the west of the English Lake-Brunschweiler Mountain fault, the Middle Keweenawan lavas again appear though thrown several miles to the north, their absence, excepting as shreds in the sector from Mellen to the Brunschweiler Mountain fault, must be explained by faulting. As set out in the chapter on the structure of the range, this faulting was probably an up-the-dip movement. And since the Tyler-Gabbro contact is intrusive, the thrust plane must be within the Tyler. This plane of thrusting in the Tyler is held to be the principal cause of the narrowing of the Tyler to the westward. It is seen on the map that the Ironwood has swung to the north of its normal position had it maintained its usual strike, but the north margin of the Tyler has more nearly maintained its normal strike to the southwest.

The subordinate range of hills or knobs in the mid-valley is intruded on the east by the sill of basic intrusive which forms Voight Knob. Although intrusive is not found in the hills farther west, such intrusive would account for the elevations. It is considered quite likely that the sill in this locality was initiated by the presence of a bedding fault.

The Tyler is widest in sections 1 and 12 where it reaches 10,200 feet. From this width it decreases apparently to zero not more than half a mile beyond the west range line. It is this gradual decrease in width and corresponding thickness from Mellen west which constitutes the "broad field relationships" on the basis of which it has long been generally accepted that the Tyler deposition was succeeded by a long period of erosion. The study of the Keweenawan develops information which somewhat discounts this idea, as stated in Chapter VI.

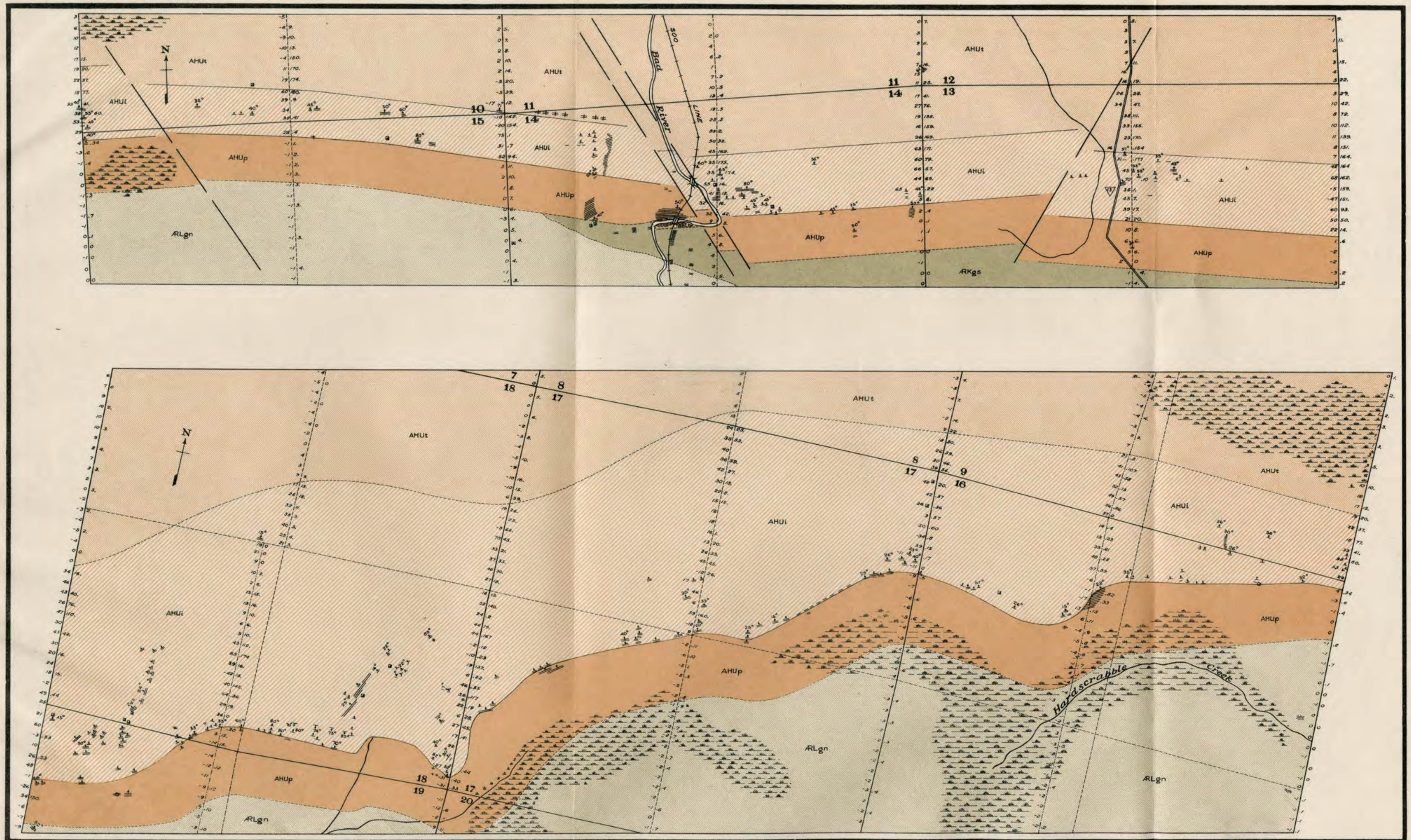
### *Lower Keweenawan*

The Lower Keweenawan is represented by conglomerate in the northeast of section 1. These exposures contain quartz pebbles up to an inch or so across in a finer ground mass and the whole is modified by basic intrusion. On the hills north of Foster on the quarter line of section 2 are exposures of brecciated or conglomeratic quartzite. Just north of these exposures are outcroppings of remnant amygdaloids. To their south are Tyler slates. The location and conglomerate character are, therefore, strong suggestions of Lower Keweenawan affinities. In section 3 are exposures of a somewhat different sort. The exposed rock is fragmental in that it contains 3–4 inch rounded masses of a variety of schistose rock in a fine ground mass. These are suggestively close to the normal position of the Lower Keweenawan and may represent that formation. However, their schistose character is also considered as evidence of the longitudinal thrusting. A more intensive study of these exposures would have provided more reliable data upon the structural relationships of the Tyler to the intrusive Middle Keweenawan. The primary focus and virtually the sole focus of the 1915 survey was upon the Ironwood so that many of these minor but significant problems were neglected.

### *Middle Keweenawan*

According to the conclusions which can be reached from a short visit to the northeast of the township, there are remnants of the Middle Keweenawan lavas in sections 1 and 2. These have been thoroughly injected by later Keweenawan magmas, principally granitic, and are not important as local formations. They do affect the geological history of the region and the structural seqence, however. Whether they exist in the western part of the township is not known but a characteristic of the contact zone along the common ground between the Tyler and gabbro is positive magnetic attraction which is not found elsewhere where the slate and gabbro are in contact. This is suggestive of the possibility that the lavas are present but they have not been reported from the field.

Intrusive gabbro of an age probably late in Middle Keweenawan time is found in contact with Tyler across sections 3, 4, 5, 6, and 7. Usually it has a granitoid texture and the dominant minerals are plagioclase, augite, biotite, and magnetite. A common phase of




T44N~R3W

LEGEND

AHUt Tyler

AHLbr Bad River Dolomite

AHUi Ironwood

ARLgn Laurentian Gneiss

AHUp Palms

ARKgs Keewatin Green Schist

Cross Fault

Figures left of lines are dip needle readings.
Figures right of lines are dial compass readings.
Dot to left=W. declination.
Dot to right=E. declination.

▪ Shaft

WISCONSIN

GEOLOGICAL AND NATURAL HISTORY SURVEY

E. F. BEAN, DIRECTOR

# TOWNSHIP 44 N., R. 3 W.

Survey made in July, 1915

Under the direction of

W. O. HOTCHKISS, State Geologist

AND

E. F. BEAN, in charge of Field Parties

M. C. LAKE, Chief of Party
C. S. CORBETT, Asst. Geologist
D. G. THOMPSON, Asst. Geologist
WM. FOSTER, Asst. Geologist

## SYMBOLS AND ABBREVIATIONS.

The symbols and abbreviations used on this map are explained in Chapter II.

## TOWN AND RANGE LINES.

In constructing this map the south line of the township was laid off as a true east west line. The other boundary lines were then laid off with the lengths shown on the Land Survey plat. Some of the maps are therefore incorrect in shape but this is necessary because definite facts are lacking. The acreage of part of the lots in the north and west tier of sections is shown to give a check on the distances in these sections.

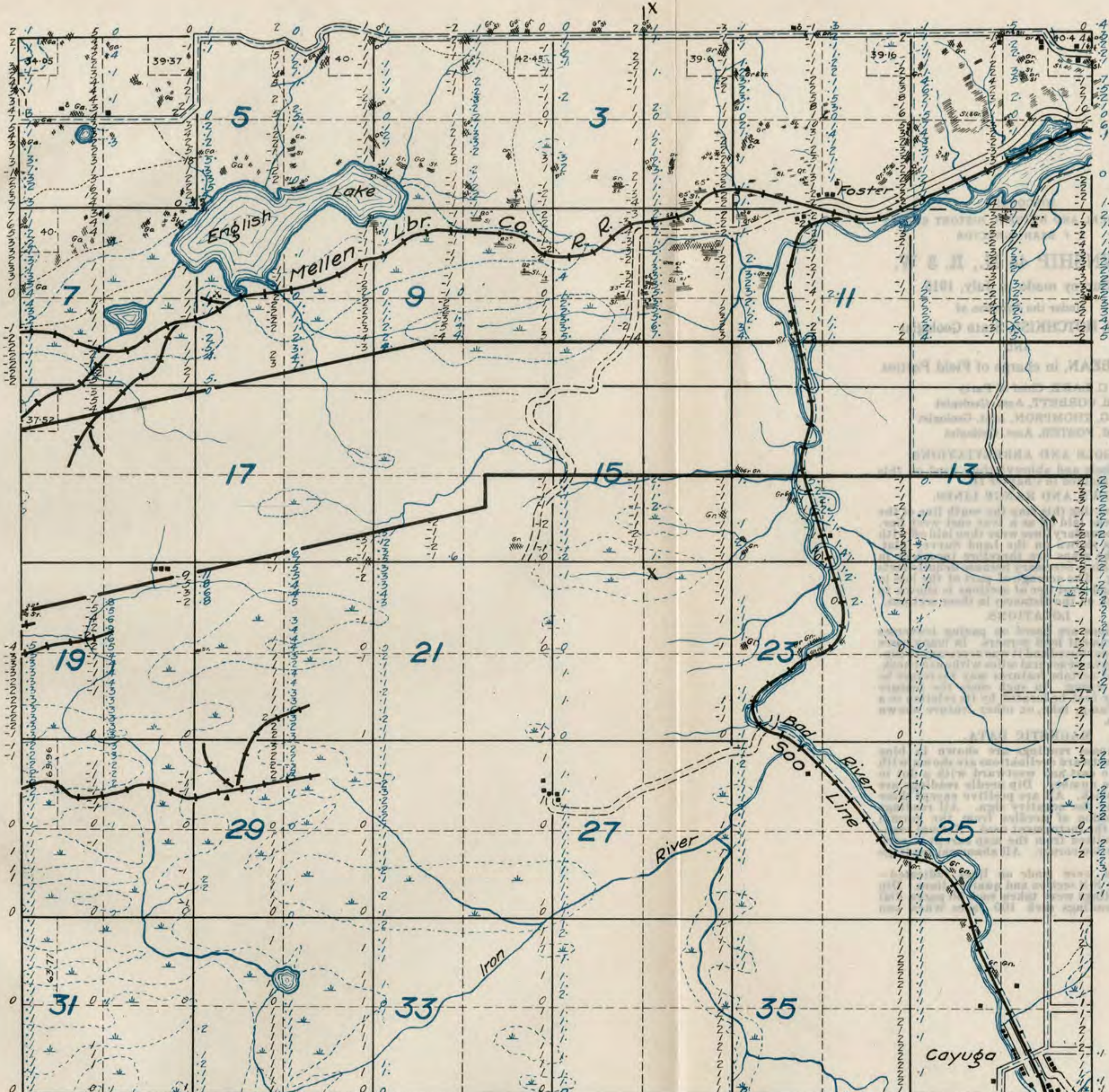
## LOCATIONS.

All locations are based on pacing traverses from government land corners. In many cases these were not found and it was necessary to continue the traverse several miles without a check. Locations of certain features may therefore be somewhat wrong. In such cases the feature sought may best be located by its relation to a stream, swamp, lake, or other feature shown on the map.

## MAGNETIC DATA.

Dial compass readings are shown in blue figures. Eastward declinations are shown with a dot to the east and westward with a dot to west of the number. Dip needle readings are shown in black. All are positive except those preceded by the negative sign. All readings show deviation of needles from the normal reading of the instrument used. Normal readings are omitted from the map except at each quarter section corner. All abnormal readings are shown.

Traverses were made on lines indicated—usually the N-S section and quarter lines. Dip needle readings were taken each 50 paces, dial compass readings each 100 paces when sun permitted.


English Lake
Mellen Lbr. Co. R. R.
Foster
Bad River
Soo Line
Iron River
Cayuga
5
3
7
9
11
17
15
13
19
21
23
29
27
25
31
33
35

the same shows the feldspars as large plates measuring as much as 1½ inches long and one-fourth inch thick. Biotite is not always present. This phase with the coarse plagioclases is apparently closely related to the anorthositic masses which are so abundant west of the English Lake-Brunschweiler Mountain fault. The granite of Keweenawan age intrudes the gabbro just north of the town line.

Intrusive granite of age later than the gabbro is found intruding Lower Keweenawan lavas and the Tyler slate in the northeast of the township, particularly in sections 1 and 2. The gabbro appears to be missing in these sections east of the Penokee Gap fault excepting for masses of anorthositic gabbro in the northeast of section 1. This is discussed in the chapter on the structure of the range as possible evidence of thrust faulting in the Tyler. It is a coarse-grained aggregate of quartz, orthoclase, and biotite. Pegmatites are abundant along the contact which is extremely shattered. The fragments of gabbro, amygdaloids and slate are abundant and many times they are found to be cemented with the pegmatitic feldspars.

Diabase and diorite dikes and sills were reported along the igneous contact with the Tyler, and in the middle of the Tyler Valley as in Voigt Knob.

## TOWNSHIP 44 N., RANGE 4W.

The entire township was mapped.

### SURFACE FEATURES

This area lies within the Lake Superior Highland Physiographic Province. Underlying country rocks and their structures are in control of the topography.

Unlike the townships to the east, this area does not show the three topographic divisions which are so pronounced throughout the 35-mile belt extending from here to the Montreal River. The escarpments marking the base of the Keweenawan and the Gogebic Range have converged in the east of the township and the prominent Tyler Valley is absent.

A perspective view of the township admits of the differentiation of three subareas. In the central east, embracing parts of sections 13, 14, and 24, is the high prominent western terminus of the Gogebic Range. The northeast of 24 is probably the highest point of the township with an elevation of close to 1700 feet. The northern third is a rugged highland characterized by many bald ledges of coarse gabbro having a tendency to northeast-southwest linear trend. The central and southern part of the township is a high but generally monotonous area of vast muskegs and sand flats. Elevations here are probably close to 1500 feet and rock exposures are very scarce. The topographic map covers only sections 13, 14, 23, 24, and part of 11 and 12.

In the northeast quarter, the Brunsweiler river has cut a deep, steep-walled gorge through the gabbro, one of the most conspicuous small-scaled topographic features of the area. Mineral Lake, or Bladder Lake as it is known to some, is but a swollen part of the channel of this stream. Lake Moquah, in section 33 is another.

At the common corner of sections 7, 8, 17 and 18, and in section 18 are two small lakes, the former known as Beaver Lake, the latter by the name of Tea Lake, very appropriate so far as the color of the water is concerned, and consistent with the habit of mind of the sponsor who christened a third body just to the west as Coffee Lake.

The glacial agency is responsible to some extent for the topography of the town. The knobs and ridges of gabbro in the north were evidently scoured and gouged by ice. The southwest and central parts are covered by sandy and gravelly deposits in some localities characterized by a relief of 25 feet associated with small kettles and basins suggestive of terminal moraine, but all is subdued and there is a conspicuous deficiency of clay. The most impressive topographic quality of this part of the township is the monotony of the flats and of the deep muskeg with here and there a clump of tamarac. The writer recalls vividly the monotony of a 3-mile paced traverse westward from the northeast of 27. There is a powerful suggestion of the former presence of a glacial lake of great expanse in this locality embracing many square miles.

The thickness of the drift cannot be measured but an estimate based upon the intermittent showings of gabbro would be expressed in a few tens of feet at the outside. A possible confirmation of this is found in the magnetic attraction which will be brought forward in a later connection but which is of an intensity and continuity greater than any found in the region correlating with any formation other than the Ironwood. It is deemed certain that even a few feet of drift covering the only formation showing in the vicinity, the anorthositic phase of the gabbro, would mask even the barest attraction of which that formation is capable when tested in outcrop.

The township once possessed valuable stands of timber but this has been practically entirely removed. A great many miles of abandoned logging railroad grades wind about through the northern half and at present offer the most convenient routes of travel for hunters and explorers, and trappers. There is no town in the area and very few settlers have shown any inclination to attempt to wrest an existence from the rocky and poorly drained areas. Reforestation alone would offer economic returns on this township. The central part and the south have been burned over repeatedly and these fires of an unknown origin have held back the development of a forest cover.

## General Geology

### *Archean*

From the description of the surface features of this township it may be gathered that the delineation of formation boundaries is met by great difficulties. The exposures in the south are exceedingly rare, small, and badly weathered. As will be brought out presently, a study of the magnetic attraction offers practically the only chance of determining the local formations. From such a study it is deemed likely that the southeast of the township is underlain by the Archean formations. A line from the northeast of 22, southwest to the vicinity of the south quarter of 33 would mark the probable boundary of these oldest rocks in this southeast corner. The formations would extend north as far as the south boundary of the Huronian series in 23 and 24. There is an exposure on the Brunsweiler River in the northeast of 28 of basalt and granite which is, perhaps, of Archean origin. This is inadequate for any extensive study and it is unsafe to draw too broad conclusions from such. It may be an inlier of Archean in the valley of the Brunschweiler where it has cut through the later rocks. The corner assigned to these most ancient rocks of the area is set out in sharp contrast to the rest of the township by the observations of magnetic intensity. The line described as the western boundary of the area is the western boundary of an area of no magnetic variation which is continuous to the eastward with a known Archean area.

In the southwest, namely, in the south, and in the west of 31, there are a few small exposures of granite and gneiss reported. Examination of hand specimens from these leads to their classification as probable Archean representatives. In this southwestern corner again, the magnetic observations have functioned as the sole clue to the underlying formation boundaries.

### *Huronian*

The relationships of the four Huronian formations to one another have been set out in Chapter VII and in the township report for 46—2E.

*Bad River Dolomite.* There is only one exposure of the Bad River dolomite known in the township. This occurs in the northeast of 24. It is represented by a greenish rock carrying abundance of tremolite and cherty phases with veinlets of tremolite. The exposure is about 125 paces long north and south and the strike of the beds is N. 35°–43° E. and the dip is 16°–35° NW. The Ironwood just to the north is badly folded and the variation of the dip and strike in this dolomite probably is accounted for by the same deformation. Plate XIII

*Palms.* The Palms is exposed only in the northeast of 24. Both the slaty phases and the quartzitic phases are present although badly folded and fractured. In section 13 the Ironwood is dipping to the south under the drift and the Palms is not exposed.

*Ironwood.* The Ironwood presents a series of baffling problems in this township. It is present in 13, 24, and 14, exposed to view in great ledges continuous with the range in the township to the east. It has all the characteristics of the formation east including the folding and recrystallization, and the pronounced magnetic attraction. The metamorphism here due to gabbro intrusions can be seen in actual contacts between the two formations. But the exposures disappear from view once and for all so far as this township is concerned near the common quarter post of sections 13 and 14. So far as ordinary methods go, this would settle matters for the formation. However, that property which is so characteristic of and which is so exclusively prominent for this formation among the many occurring in the region, can be carried without a significant gap from these exposures in 13 and 24 completely across the township and to make the closure again with exposures of the same identical formation, so far as one can judge from the general character and associated formations, in the east of the next succeeding township to the west. The question coming first to mind is whether this continuity of so outstanding and diagnostic a property as magnetic intensity should constitute safe ground for the conclusion that the Ironwood is continuous across these 5 or 6 miles of monotonous muskeg. To repeat, the magnetic attraction originates at either extremity on outcroppings of Ironwood and it is of an intensity, regularity, and character demonstrably unlike that correlating with any other formation in the district. This can be stated definitely at this time because the Archean to the south and the entire series of Keweenawan formations to the north and continuously for 30 miles to the east and west have been mapped magnetically. Plates I, XIV (in pocket.)

There are no outcrops within at least half a mile of the magnetic maximum on any of the profiles excepting the easternmost where gabbro is exposed. That the gabbro is not responsible for the attraction is reasonably certain because countless observations have been made over gabbro with no such reaction, and because on the closest exposures, for example, in sections 16, 20, and 21, the magnetic intensity is practically normal. If in outcrop with a minimum of distance between it and the instrument the reaction is normal, it stands the test of logic that the same formation at a distance of a few tens of feet of burial under the drift would not produce attraction of the order of that obtained on the iron formation. Furthermore, the particular variety of gabbro found in these outcrops is the anorthositic phase which abounds in the northern part of this township and the southeast of the town to the north. While it may be that the gabbro is intruded into the Ironwood, and in fact near Mineral Lake, it is so intruded, it is deemed probable that it is the Ironwood that gives rise to the magnetic attraction and not the gabbro or even the contact rocks common to the two formations.

With this review of the information at hand and the aggregate interpretations from the same, the writer is convinced that the Ironwood is not cut out by the gabbro intrusive which is present in force at Mineral Lake, that on the other hand it goes through to reappear near Coffee Lake in 44—5W. The precise nature of the cause of the failure of the formation to expose itself in this interval is unknown, naturally, but there are several suggestive observations pointing to the occurrence of strike or thrust faults at the base of the Keweenawan section. This was discussed at some length in the discussion of the geological structure of the township east. In the report for the township west further points indicative of such thrusting will be related.

In greater detail, the Ironwood is exposed in a well folded complex in section 13 and the north of 24. On the east range line exposures are scattered over a distance of a quarter of a mile and the strike is practically east and west with the dip to the north. Within the succeeding half mile to the west, however, there is one complete transverse drag fold throwing the beds into north-south strikes, and also strike folding in the Plymouth. West of the quarter line the strike is about 45 degrees to the northwest and the dips are exclusively to the southwest. This last piece of formation is interpreted as the exposed upper limb of an overturned drag fold.

In this series of exposures in section 13, the entire succession of five members are represented. Taken together they represent a pair of two northeast plunging drag folds on a flat monoclinal major structure.

Magnetic observations on the east range line continue in strength for 600 paces north of the southeast corner of section 13. This outer magnetic boundary drawn westward across section 13 reflects the folding by broad curves. On the quarter line the boundary is

700 paces north of the south quarter indicating a convergence to the westward of the north and south boundaries.

In the northwest of the southwest of 13 intrusions of gabbro are first seen. Near the west quarter of the section exposures of Ironwood with igneous contributions strike east and west and dip northward. Magnetic lines associated with these exposures, and connecting the same with similar exposures in section 14, and striking east and west were traced nearly a quarter of a mile east of the west quarter of 13. This is exactly at right angles to the strike of the formations just described in the southeast of the southwest of 13, and a magnetic traverse from one situation to the other showed a distinct break. Therefore, the series of east-west exposures near the common quarter post of sections 13 and 14 are open to the interpretation of having been thrust across the ruptured ends of the northwesterly striking members. On the other hand, the entire situation is capable of interpretation as a series of drag folds in the apex of the sharpest of which gabbro intrusions have made their appearance to complicate the situation.

From the east quarter of 14 the magnetic lines were traced west and south for more than a half mile into the region south of Mineral Lake. The magnetic observations on the section and quarter lines farther west indicate the continuity of the horizon as expressed elsewhere.

Along the south shore of Mineral Lake, and into contact with the Ironwood are abundant exposures of the Keweenawan gabbros. There is no evidence of the presence of the upper Ironwood and, of course, no trace of the Tyler. The specific question arising is whether these have been cut out by deep pre-Keweenawan erosion or by faulting, or by a combination of faulting followed by gabbro intrusion.

The belt of magnetic attraction in the southwest, as shown on the maps, varies in width, in strike, and in intensity. In general it follows the trend of a line of maxima located internally and somewhat to the south of the center of the belt. It cuts across the southeast of section 15, and in a southwesterly direction across section 22 to about 250 paces north of the southwest of that section. Here it turns to the west to about 200 paces north of the south quarter of section 20 where it again swerves southwest to the east quarter of 30, and to about 300 paces north of the south quarter of that section. Here it turns to the northwest and leaves the township about 300 paces south of the northwest of the section.

The boundaries of the belt following the line of maxima more or less faithfully are as much as 2 miles apart at the widest place and are very strongly suggestive of the control of sedimentary structure. The north boundary trends westward from the north quarter of 14 swinging gently to the south to pass through the center of 16. From this point the strike becomes more nearly westward for practically a mile. Near the center of 17 it turns southwestward to intercept the east line of 19 about 300 paces south of the east quarter corner, and continues southwestward as far as the quarter line of 30 where, just south of the south quarter-corner it turns west and northwest to cross the range line about a quarter of a mile north of the west quarter of 19. At this point it apparently turns southwestward across section 24 of the township west. The south boundary of the belt has been drawn from 400 paces south of the east quarter of 14 south and west to about 400 paces north of the northeast of 22, then southwest through the south quarter of 22. From this point and on to the southwest through the center of 33 and extending into the township south, a line may be drawn which borders on the east an extensive area of attraction. However, the belt of disturbance of magnitude believed to represent the iron formation is bounded on the south by a line following closely that just described for as much as a half mile but swinging westward near the east quarter of 28. It then extends westward to cross the quarter and west lines of 28 about 250 paces south of the center and west quarter corners. In the southeast quarter of section 29 it turns southwest passing close to the south quarter of 29 and across 32 to a point about 150 paces north of the southwest corner. From here it again turns west and northwest in the southeast of 31, crossing the quarter line of 31 about 200 paces south of the center of the section, and leaving the township about 400 paces north of the southwest of 30 at which point it is again swinging to the west.

In townships east, traverses run from south to north on encountering the footwall of the Ironwood show a sharp and abrupt dip needle reaction excepting in the extreme east where the formation is well oxidized. Furthermore, the maximum reaction occurs well up in the formation, and from the maximum the curve of attraction is generally a smooth curve to the northward reflecting the gradual increase in depth of the north-dipping formation. Here in 44—4W. and particularly in sections 33, 32, 31, 28, and 29, there is a long gentle slope to the curve of attraction up to the line drawn to represent the south boundary of the pronounced reaction. From this line the slope is considerably steeper up to the line of maxima, and then fairly smooth and slightly less gentle off to the north as far as the north boundary of the belt. In other words, the complete profile is more nearly symmetrical with respect to a vertical through the point of maximum attraction. This symmetry is indicative of a flattening of the dip of the formation to the northward. Further testimony of the same sort is offered by an examination of the profiles in the townships to the east. With a structural dip of 60 degrees, the curve of attraction is down to normal about a mile north of the footwall. Here in 44—5W. the attraction is not down to normal until about 1½ miles north of the line of maxima nor until more that 2 miles north of the line drawn as the south boundary of the belt of strong reaction. If the wider area of low attraction extending farther south be taken into consideration this northern boundary is in places several miles north. If it be concluded that this attraction is due to the presence of the Ironwood, it would be necessary to conclude also that the formation was close to flat-lying with perhaps gentle folding. In this same connection, it is notable that in 44—5W. the area of attraction continuous with the one under discussion forms a mere trapezoid in sections 24 and 25, but is then resumed in an elongate area in the south of 14, the north of 23, the south of 13, and extending nearly a half mile into 18 of 44—4W. In other words, the formation as revealed in exposures near Coffee Lake, is thrown north nearly 2 miles from the line of maxima in the south of 30. This brings the formation back approximately to the line of strike at Mineral Lake and compensates for the southward throw as suggested in the belt of attraction under discussion. Such a throw of the formation can be accomplished by faulting or folding. And the flatter the dip the greater the horizontal gain in the displacement of the formation. These considerations plus the curving of the boundaries and of the line of maxima which simulate folding support the belief that the Ironwood is present in a broad gentle northward dipping monoclinal which has been drag-folded in a syncline of comparatively major proportions in a manner similar to the observed conditions east of Mineral Lake. Further suggestion of this idea is seen in considering the distribution of the anorthositic gabbro. As nearly as can be determined with the facts available, the anorthositic gabbro extends as far north as a line from the north quarter of 3 approximately to the southwest of 6. This permits of a surface width of at least 2 miles for this plagioclase intrusive. But in the township west, the formations having been mapped, there is no more than a mere semblance of this thickness and practically none north of the iron formation north of Coffee Lake. Therefore, such a width for the formation could well be accounted for as a very thin but flat-lying sheet or laccolite lying at the base of the Middle Keweenawan series of lava flows, and upon the Huronian sediments forming a flat-lying, gently folded monocline.

The Bad River limestone, the Palms, and the Tyler are not exposed in this covered country. Nor have we any magnetic evidence of their presence. Concerning the Tyler, this may be said. The only formation represented by angular loose material or in outcrop is the anorthositic gabbro. If these loose blocks of surface float represent local material, then the formation must overlie the Ironwood. If the outcrops are mere high points on a formation covering the greater area, then they testify to the same conclusion. But these blocks may be glacially transported material and the outcrops may be merely local small intrusions such as dikes. Of the last, there would seem to be little chance because such igneous rock is generally considered to be a differentiate in a large intrusive. But whether the Tyler is present between the anorthosite and the Ironwood cannot be more than speculation at this time. From a digest of the many angles of the structural and igneous problems of the region, as set out in the chapter on the structure of the ranges, it is believed that thrusting of upper formations up the dip over the lower provided planes of weakness for the injection of the gabbros and red rocks of the region, and also it is believed that such thrusting alone will account for the abnormal thinness of the Middle Keweenawan series of lavas in 44—6W. where one thrust of major proportions has been definitely established. While it may be merely circumstance that the Tyler was a maximum in thickness just east of Mellen, in 2 west, at a point where the destruction of the footwall of the Keweenawan and the top of the Tyler by these great intrusions began, the observed fact that intrusion has been guided in the region by bedding and cross faulting, and that thrust faulting has played a leading part in the development of a most complicated structural situation, leads to the belief that, although the Tyler is not exposed in 44—4W. it has been sheared off by low dipping thrusts and covered by a thin sheet of injected anorthosite.

### *Keweenawan*

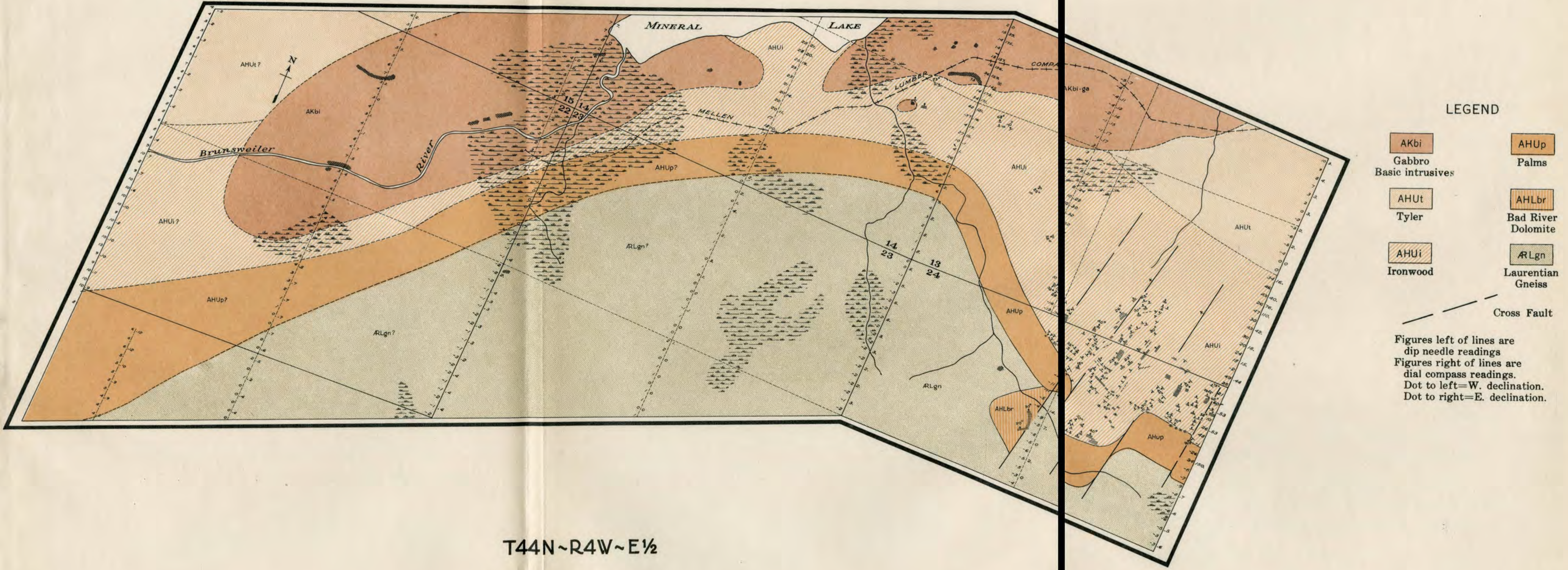
The Keweenawan has been discussed to a considerable degree in the above consideration of the Ironwood. More in detail, these later rocks are without exception igneous intrusives, and dominantly they are basic, although alkalic pegmatites, probably differentiates from the gabbro, have been encountered in the field.

On the basis of general characteristics the gabbros fall into two classifications, one a granitoid textured mixture of plagioclase, augite, and prominent magnetite, the other an almost pure aggregate of plagioclase with a minimum of either augite or magnetite and in which the plagioclase occurs as thin plates commonly an inch in diameter and usually oriented with the flat plates parallel. The rock is close to the group known as anorthosites which are considered to be accumulations of crystals settling out from a large chamber of injected magma.

The first type of gabbro is confined to the southern or southeast border of the total mass, that is, in a belt from one-fourth to a mile wide cutting diagonally across section 12 to the north east end of Mineral Lake, along the north side of the lake as far as the south quarter of section 11. It makes contact with the Tyler slates as an extension of the north limit of these Huronian sediments, and in the northwest of 13 and south of Mineral Lake in 14 it makes contact with the Ironwood. In a number of instances the gabbro was noted to contain inclusions of a dense black rock which were described in the field notes as basalts. It is to be noted that the exposures closest to the Ironwood contain the greatest abundance of magnetite, and also that in such situations the dip needle responds most markedly. In this observation there is the suggestion that the abundance of magnetite is accounted for in the assimilation of iron formation followed by the recrystallization of the iron as magnetite. While this may be the case, it is also to be repeated that even where the gabbro is in contact with the slates of the Tyler it contains sufficient magnetite to produce a belt of magnetic attraction. The combination of the two observations gives rise to the idea that at the actual contact of the gabbro with the country rock, the first rock to crystallize more nearly represents the composition of the undifferentiated magma, thus accounting for the augite as well as magnetite, that here, magnetite, one of the first minerals to crystallize has to a limited extent been enriched by the settling of crystals from the melt, but that when in contact with the Ironwood the proportion of magnetite has been still further augmented by the process of assimilation and reprecipitation.

In following this consideration through on the map, it is at once suggested that the belt of attraction to which so much space has been given in a discussion of the Ironwood is a continuation of the same belt of contact magnetite. The theories of crystal settling would tend to support this suggestion. However, as emphasized in the discussion of the Ironwood, the belt of attraction in the southwest of the township is stronger, more regular, and more constant than any observed in connection with the gabbro, or with any formation excepting the Ironwood. Over the gabbro the attraction may be as high or even higher than any on the Ironwood, but within the space of a very few paces in any direction the attraction may vary from a high positive maximum to as high a negative maximum. It is extremely irregular or in field parlance, "bunchy."

Aside from the segregation of this belt of granitoid gabbro, on account of the scarcity of exposures the rest of the northern part of the township is mapped as probably underlain by the anorthositic phases of gabbro, excepting the extreme northwest where a triangular belt from the north quarter of 3 to the southwest of 7 is believed to be underlain by the more common type of gabbro with granitoid texture and prominent proportions of augite. It is noteworthy, however, that even here the magnetite is not sufficiently abundant to produce any marked attraction. In this connection it is perhaps of interest to record that the gabbros of this Keweenawan province never reveal any notable attraction excepting in contact situations, and in fact only in connection with the intrusion of gabbro into relatively basic rocks, such as iron formation, slate, or basalt. This perhaps has the meaning that the iron of the magnetite is won from the country rock and hence can only be gotten from basic formations. As an observation in the field in connection with all manner of intrusive problems it is set up as a rule that alkalic intrusions or basic intrusions into alkalic rocks do not produce magnetic attraction at the contact.


MINERAL
LAKE
Brunsweiler
River
MELLEN
LUMBER
COMPA
AHUt?
AKbi
AHUi?
AHUp?
ÆRLgn?
AHUi
AKbi-ga
AHUt
AHUp
AHLbr
ÆRLgn
15
14
22
23
14
23
13
24
N
LEGEND
AKbi
Gabbro
Basic intrusives
AHUp
Palms
AHUt
Tyler
AHLbr
Bad River
Dolomite
AHUi
Ironwood
ÆRLgn
Laurentian
Gneiss
Cross Fault
Figures left of lines are
dip needle readings
Figures right of lines are
dial compass readings.
Dot to left=W. declination.
Dot to right=E. declination.

T44N~R4W~E½

WISCONSIN

GEOLOGICAL AND NATURAL HISTORY SURVEY

E. F. BEAN, DIRECTOR

# TOWNSHIP 44 N., R. 4 W.

Survey made in July, 1915

Under the direction of

W. O. HOTCHKISS, State Geologist

AND

E. F. BEAN, in charge of Field Parties

W. L. DOBIE, Chief of Party
C. W. HONESS, Asst. Geologist
C. A. HAMMILL, Asst. Geologist
WM. FOSTER, Asst. Geologist

## SYMBOLS AND ABBREVIATIONS.

The symbols and abbreviations used on this map are explained in Chapter II.

## TOWN AND RANGE LINES.

In constructing this map the south line of the township was laid off as a true east west line. The other boundary lines were then laid off with the lengths shown on the Land Survey plat. Some of the maps are therefore incorrect in shape but this is necessary because definite facts are lacking. The acreage of part of the lots in the north and west tier of sections is shown to give a check on the distances in these sections.

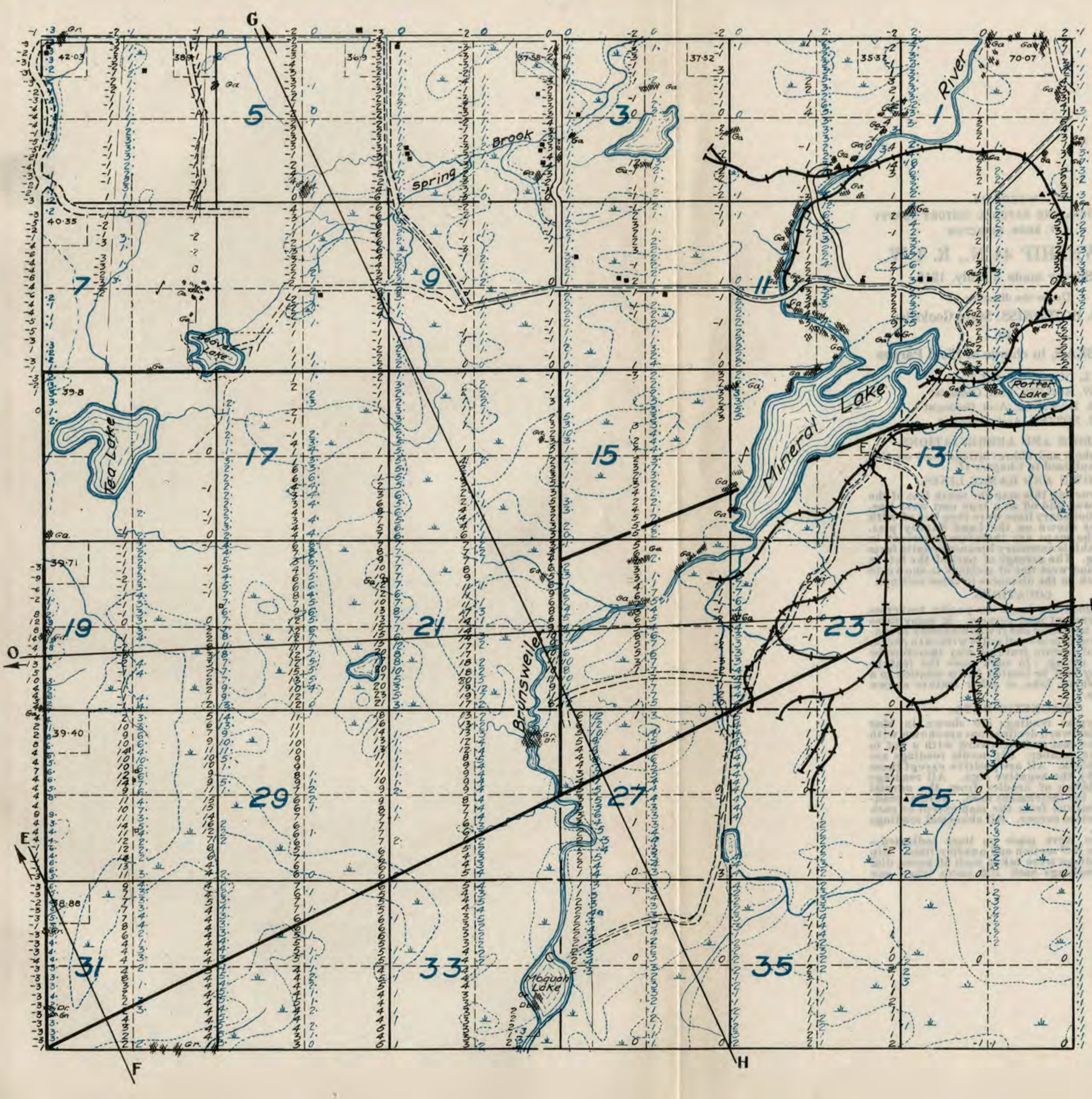
## LOCATIONS.

All locations are based on pacing traverses from government land corners. In many cases these were not found and it was necessary to continue the traverse several miles without a check. Locations of certain features may therefore be somewhat wrong. In such cases the feature sought may best be located by its relation to a stream, swamp, lake, or other feature shown on the map.

## MAGNETIC DATA.

Dial compass readings are shown in blue figures. Eastward declinations are shown with a dot to the east and westward with a dot to west of the number. Dip needle readings are shown in black. All are positive except those preceded by the negative sign. All readings show deviation of needles from the normal reading of the instrument used. Normal readings are omitted from the map except at each quarter section corner. All abnormal readings are shown.

Traverses were made on lines indicated—usually the N-S section and quarter lines. Dip needle readings were taken each 50 paces, dial compass readings each 100 paces when sun permitted.



River
Spring Brook
Beaver Lake
Tea Lake
Mineral Lake
Potter Lake
G
H
E
F
O
P
1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35

## TOWNSHIP 44 N., RANGE 5W.

The entire township was mapped.

### SURFACE FEATURES

This area lies within the Lake Superior Highland Physiographic Province in which characteristically the surface features and topography are under the control of the underlying formations and their structure.

The township can be divided roughly into two equal subprovinces along the east and west center line. The north half is a ruggedly dissected, extremely rocky area underlain by the Keweenawan extrusives and intrusives and along its southern margin by intermittent remnants of the Huronian formations. The south half is largely a rolling, drift covered, upland underlain by the Archean granites and gneisses.

Within the north half the most striking feature is the valley of the Marengo River. This is 200 or more feet deep and in most places the valley walls are bare rock with a variety of color seldom seen in this part of the country. Fortunately, there is a road passable by cars in favorable weather which makes three crossings of the river and affords an opportunity to view the gorge from these several vantage points. The red and blue-gray intrusives alternating with the dark green extrusives are fascinating to view. A second feature is the valley of Twenty Mile Creek, which may have been a former course of the Marengo, and which flows northwestward across the northwest quarter of the township. In the lower reaches of the Marengo and Twenty Mile alike there are extensive flats of fine gravel and sand deposited and distributed in the higher levels of glacial lake Superior at elevations of 1160–1180 feet.

In the south half the principal features are the iron formation ridges along the north margin. One of these trends northeastward from the north end of Atkins Lake through the southeast of 17 and into southwestern 16. A second extends from the center of 20 into the south of 16. The third occurs in the northeast of 23. Farther south the control of topography is largely in the glacial moraines.

Surficial material consists of a thin ground moraine containing sand, boulders, and some silt and clay. Only in the south is there any relief due to terminal where patches with a 50-foot maximum height above the surrounding country are to be found.

Timber is now practically all removed but twenty years ago there was a good stand of mixed hardwoods on the high ground. There are very few attempts to settle the township and roads are of the winding, heavy grade variety and for most part have been built upon the old railroad grades. Ten years ago the logging railroad extending south into this country from Grand View in T. 45—R. 6W. was in operation and afforded a means of transportation through the rough area. Today this has been abandoned and the steel has been removed but in considerable part the grade is available for the construction of roads whenever such are in demand.

## General Geology

The geology of this township presents some of the most intriguing problems imaginable. Exposures are far more abundant than often are met with in northern Wisconsin. Despite this the complexities are such as to require far more time for field study than has been possible to date. Furthermore, the mapping by the Survey is based upon the original land survey and in this township, perhaps, more than in any other township of the 300 which have been surveyed to date, the original survey was evidently extremely poor. Corners have been found in most important instances but the tying of these together is a matter still open to debate. To a greater degree than anywhere else, therefore, it is possible that some distortion of the geological boundaries is represented on the maps. This is not deemed to be serious enough greatly to discount the main conclusions reached as to the geological situation.

### *Archean*

Although many square miles in the south of this township have been mapped as Archean, this is based to no small extent upon the magnetic evidence since the only exposures assignable to the Archean are found in the southeast along the Marengo River drainage. In 36, on the east range line there are two exposures of gneissic rock evidently representing the basement on which the Huronian was deposited. In the northwest of the same section, and along the quarter lines of 35, 26, and 23 there are other exposures of the same type of rock. The magnetic attraction observed over this area is comparable to that in the remainder of the area mapped as Archean. A possibility remains that the north half of 24 may be underlain by these oldest formations, there being exposures of granite much similar to the Archean types, and furthermore, there is the narrow belt of normal or slightly subnormal attraction related to these exposures and separating the heavy attraction of the Coffee Lake Ironwood from the similarly heavy attraction of the south of 24 which presumably is also due to Ironwood.

These granites and gneisses are generally pink and hence when not banded there is difficulty in determining whether they are Archean or Keweenawan. The gneissosity generally strikes about N. 80°W. and dips steeply to the north.

### *Huronian*

The relationships of the four Huronian formations were discussed in the report for T. 46—R. 2E. and in Chapter VII on the History of the Ironwood.

*Bad River Dolomite.* This formation is exposed extensively in the south of 15 and the northwest of 22. The outcrops form a series of broken ridges on a rise of ground some 40 feet above the Marengo River. A small stream flowing northward through the northwest of 22 is confined for some distance to a limestone gorge. Plate XV (in pocket)

The strike varies considerably with the general trend of about 45 degrees to the northeast. The dip also is inconstant but is generally low or around 20 degrees to the northwest. If the limits of the formation be taken in the outcrops, and if the dip be considered as 20 degrees to the northwest, the formation has a thickness of 270 feet. However, there is probably folding and possibly faulting to render this figure inaccurate, and furthermore, there is associated with the exposures a magnetic attraction of as much as 20 degrees, and in some instances as little as 4 degrees. If the area indicated by this abnormal attraction be considered as marking the extent of the formation then there is a much greater area than confined to the exposures and consequently a possibly much greater thickness.

The character of the formation varies from a recrystallized marble to siliceous and tremolitic dolomites. In a single outcrop all these varieties may be found. Some beds are massive, others are thin and laminated. There are basic intrusions occurring in outcrops and the effect of the intense magmatic history of the vicinity is probably represented in the recrystallization. Near the south quarter of 15 is an exposure of rock probably correlating either with this formation or the base of the Palms. It is described as pebbles of limestone in thin-bedded cherty slate.

*Palms.* This formation is seen in outcrop in the region between Marengo Falls and the northeast of 23, also along the south slope of the iron ridge which extends from roughly the center of 20 to the center of 16. An estimate of its thickness from the surface distribution in a direction normal to the probable regional strike, and assuming a dip of 45 degrees to the northwest, although there is obvious folding, gives a figure of 360 feet. This is not reliable as a measure of the true thickness on account of the above abnormalities and also on account of the fact that the differences in elevation of the exposures have not been taken into consideration.

The formation runs true to form as represented in the east, at least to the extent that there is an upper vitreous, pure quartzite and a more slaty structured quartzite below. The quartzitic character of this slate should be regarded as a recrystallized counterpart of the feldspathic slates such as were noted at Upson. This banded phase shows considerable folding. The quartzite is generally pinkish and commonly has veinlets of hematite. It is badly broken in places but practically never is deformed by folding. The granite which intrudes at Marengo Falls has shattered the quartzite badly. There is no known exposure of any contact between the Palms and the Bad River limestone so that the nature of the relations cannot be given. Nevertheless, the strike of the limestone projected brings it south of the Palms in section 16. Along the south slope of the iron ridge there are numerous scallops and apparent offsets, two of which are of some magnitude, and these are loci of intrusions of basalt. The intrusive is generally very fine-grained.

*Ironwood.* The Ironwood occurs in this township in two areas of outcrop. In each case there is distinct evidence of folding, and basic intrusions are profuse. In two other areas there is magnetic attraction deemed to represent the presence of the formation although there are no exposures of it. The one is in the southeast of 23, the south of 24, section 25, and the central north of 36. In this area there are gneissic granites marginal to the attraction and these have been classified as Archean. There are also numerous exposures of gabbro of the variety dominated by labradorite feldspar and referred to as the anorthositic variety of gabbro. This area of attraction is continuous with and similar in magnitude of magnetic reaction to a belt which completely traverses the township to the east. Although there is not a single exposure of the iron formation in the belt, and despite the fact that there are a few exposures in the town east and several in the present township of the variety anorthositic gabbro, it is maintained that the attraction reflects the presence of iron formation. The attraction originated on exposed Ironwood, and excepting for the narrow belt in the north of 24 of the present township, it terminates upon or joins with that of the exposed iron formation northwest of Coffee Lake. In the paragraph on the Archean it was stated that there were exposures of granite in the north of 24 and that these were difficult of determination as between the Archean and the Keweenawan. The structure of the formation thus postulated on the basis of magnetic attraction as deduced likewise from the attraction is part of a well folded complex, more or less dissipated and perhaps covered by anorthositic intrusion. See cross section Fig. (18).

The second area mapped as probable Ironwood is in the northwest of 19 northwest of Atkins Lake. Here, on the west range line there is a belt about 250 paces north and south showing heavier attraction than can be reasonably attributed to any but iron formation. It was not found to project far to the east, but was followed to the west for a quarter of a mile. This is situated as a point of interpolation between the Atkins Lake exposures and the Trappers Lake exposures in the township of 44—6W. Plate XVI.

The first of the areas of exposed Ironwood to be considered is in the north of section 23. The majority of the outcrops are in the northeast quarter of the section and in the north half of the quarter. Dips and strikes here are variable and suggest a synclinal fold plunging to the northeast. However, the north quarter post of 23 is upon an exposure of the formation which dips northwest and strikes northeast indicating that if this is in continuity with the other exposures that there has been a return of the folding.

The formation represented in the exposures is of the cherty as well as the thin-bedded or slaty variety. Consequently it would appear that the group as a whole represents central or upper parts of the formation. To add weight to this, there is no quartzite associated with the exposures in the northeast quarter. There is quartzite about a quarter of a mile west of the north quarter, but this is dipping northwest and would not appear to be in normal relationship with the iron formation at the north quarter.

From the north quarter, north and easterly in the southeast of 14 there is attraction showing beyond reasonable doubt that the formation is present there under cover of the drift at least. This attraction then is traced across the southwest of 13 and across the quarter line for perhaps 250 paces where it is apparently thrown to the north at almost right angles. About 250 paces east of the center of 13 it swings northeasterly through the east quarter and into section 18 of the township east. Here, in the west side of Tea Lake (sometimes known as Eighteenth Lake) the attraction is gradually lost in a region containing outcrops of gabbro. Across section 13 and into 18 the belt is never more than 250–300 paces wide and excepting for the two right-angled turns there appears to be no folding. This area of combined outcrops and associated attraction trending roughly N. 70°E. is separated from the area of attraction south by a belt about one-half mile wide containing exposures of granite (possible Archean) and also anorthositic gabbro. Coffee Lake occurs in the belt. The attraction in this narrow belt is negative or very slightly positive. The boundary of the area of attraction to the south is parallel to that of the area described above. The interpretation placed upon the situation is that the formation striking northeast and southwest was drag-folded up the dip from the northwest, that the drags were then broken by overthrusts, and that the intrusive gabbros came up the thrust planes.

The main body of the Ironwood in the township lies farther west. In general it forms an elliptical area characterized by abundant exposures of the formation, by a topographic relief, and by the typically high magnetic attraction. It extends in a southwest-northeast direction from the north side of Atkins Lake, in the northeast of 19, to the northwest of the southeast of 16. The entire elliptical area, is, however, profusely spotted with exposures of basic intrusive. Furthermore, in more detailed examination it is clear that the area as described, is in reality a pair of northeasterly trending belts, each with its exposures, its topographic relief, and its attraction. Only the southern belt is supplied with the Palms quartzite which would mark it definitely as to stratigraphic position. Between the two belts the attraction is dominantly negative indicating either a flattening of the dip as if this central area were the top of an anticlinal fold of which the two belts were the limbs, or conversely the trough of a synclinal fold, or else a belt of other rock perhaps occasioned by a bedding fault. As to the possibility of a fold, little can be said other than that on the two "limbs" the dips are fairly steep to the northwest. The situation cannot be a simple synclinal fold nor an anticlinal fold. On the other hand, in the southwest quarter of 16 there is a long line of test pits which some persistent explorer has put down in the hope of finding values. The material thrown from these pits plus that seen in outcrop in the vicinity show conclusively that there, at least the rock in this mid belt is basic intrusive. Farther southwest in 17 and 20 this mid belt is a narrow swampy lowland and exposures are missing. Therefore, from the information available, it is considered that these two belts are analogous to the two just described farther east. The Ironwood has been split by a bedding fault and the basic magma took advantage of this inherent weak zone or was, by the development of low pressures attending the thrusting, imbibed into the zone.

The two belts of attraction and exposures are apparently cut by at least two transverse faults. At least there are offsets indicated topographically, magnetically, and lithologically, and marked by intrusive. These are parallel and strike roughly N. 40°W. The one to the northeast is in the southwest quarter of section 16. The other cuts almost through the southwest corner post of the section.

The formation throughout the township is the heavy, dense textured, dark colored, unoxidized, unleached, highly magnetic, recrystallized and amphibolitized siliceous formation so characteristic of the region from Mineral Lake west. There can be no good gambling chance of finding iron ore of the present day definition in the township, or at least in the portion represented by outcrops, and so far as is known the covered area to the south is Archean or at best Keweenwan intrusive. That there may be other patches of the formation in this country is a possibility, but, even the unmetamorphosed and highly oxidized condition as obtains in Range 2 east the formation has a well defined magnetic attraction and there is nothing in this township that even suggests such conditions or such formations. If there were, owing to the thousands of feet of intrusive above, (to the north) such formation would be highly magnetic and hence detectable and also valueless.

The outstanding question coming to the mind on examining the map, is "What accounts for the abrupt northeastern termination of the western iron ridge?" It is noted that this ridge is headed for the vicinity of the center of 16 but is cut off by the valley of the Marengo. This question cannot be answered without considering a similar question involving the Bad River limestone which, it will be noted, also ends abruptly at the Marengo River. Beyond the river, in each instance, are the Keweenawan intrusives and earlier, now much altered, lavas. The river is, of course, an incidental thing but its course appears to mark the contact between these two sets of formations. The problem merges again with the belted character of the Keweenawan rocks.

The most satisfactory explanation arrived at from a consideration of the entire suite of problems embracing Huronian and Keweenawan formations of the entire district from Montreal River to the Eau Claire Lakes, is that the Huronian and Keweenawan lavas and sediments were astraddle the wedge of magma coincident with the present axis of the Superior syncline and from which the lavas and later intrusives were derived. The recovery of stability following the extravasations required both a lateral adjustment, that is pressures from northwest and southeast as well as foundering above the wedge. The formations bridging the wedge were not able to withstand these failures of the foundation. There was, however, differential foundering as well as differential pressure. That is at certain points along the axis of the wedge, foundering was more rapid than at others. On this account the bending members were subjected to torsion. At the same time and on this same account as an accompaniment of the differential foundering, the axis of foundering having an arcuate trend, there appears to have been a tendency toward buckling of the beds and lavas. From the work on the Douglas County Keweenawan this buckle appears to have crossed the axis to emerge there in the vicinity of Poplar and Wentworth. The buckling tendency then appears to have been emphasized or magnified by the progressive foundering over the magmatic wedge. The result of the buckling of the beds was first a reduction of the pressures within the zone affected which initiated the injection of the gabbro and the bed rocks, and second an overthrusting of the upper beds over the lower, the direction of overthrust being to the south and east.

Within this theory, the distribution of the Ironwood and the Bad River limestone is acounted for as follows. The Tyler, Ironwood, Palms, and Bad River were drag-folded to the south and east in broad folds. The accumulating stresses then passed through the stage of folding to that of overthrusting. The Tyler was reduced by the thrusting to nothing within the confines of this township but may possibly be present in the townships both to the east and to the west. The top of the broad fold of the Huronian series was cut across exposing the truncated edges to the incoming of the Keweenawan intrusives. This theory embodies an explanation of the thinness of the Middle Keweenawan of the township as well as the township to the west. This series of formations is only a fraction of the thickness represented by the overthrust portion north of the Davis Hill conglomerate, in T. 44N.—6W. or of the normal thickness known in the townships east. The two problems, that of the Huronian and that of the Middle Keweenawan are inseparable. Only an explanation covering both will be satisfactory to either.

## KEWEENAWAN

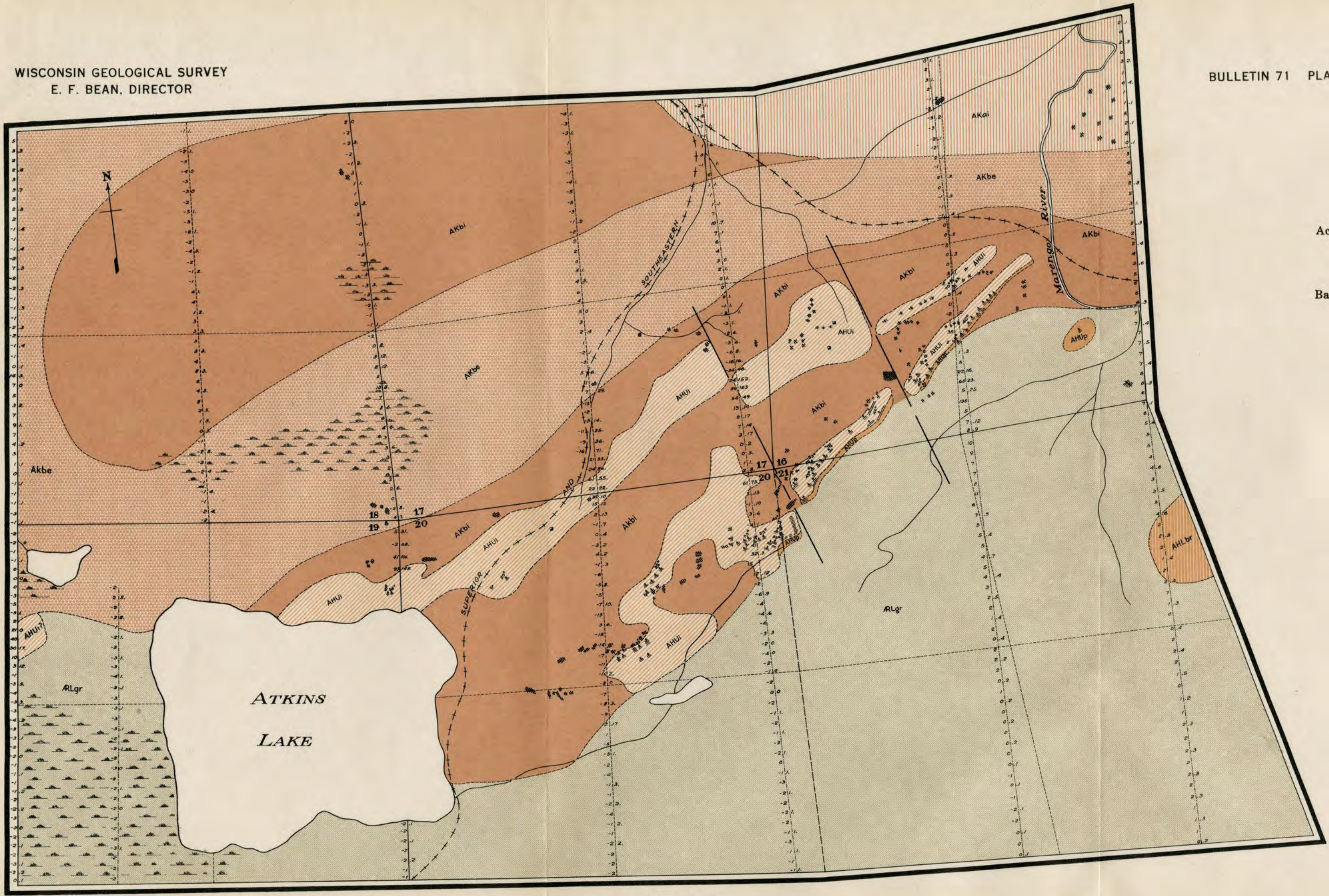
### *Middle Keweenawan*

The middle Keweenawan is represented by the amygdaloids and traps of the northern half of the township. The uppermost are found in the northwest of section 6 where several pits have been sunk in the search for copper.

From the south of 7, through 8, across 9, the north of 10, diagonally across 2 and 1, there is a belt of diabase and amygdaloid apparently a unit of flows and probably continuous. This appears to fork near the center of 9 and a southern belt extends across the south of 9 and 10 and into the west of 11 where it again splits and one part seems to extend northeasterly across the northwest of 12. The other fork trends east across the southeast of 11 and the north of 13 and the south of 12. A third belt is found in the southeast of 18 then cutting across 17, 16, 15, and well across 14.

These belts of trap are separated by or are caused to fork by lenses or belts of gabbro and red rock intrusion. As referred to above, the appearance is that the flows were buckled much as the leaves of a pamphlet are forced to buckle if it is held tightly to prevent slipping of the leaves when the pamphlet is bent. The leaves separate. Here, to apply the example, the pile of sediments and lava flows was flexed. There was no opportunity for the beds to slip over one another along the strike, and as a result they separated and into the zones of weakness the magma was imbibed by the low pressure there existant. When then in compliance with the downwarping of the syncline this cross buckle was forced to make an adjustment, it exerted end thrust and produced the thrusting of the Keweenawan up over the Huronian. It will be noticed on the map, Plate I, that the complex of belted flows and intrusives forms a broad tongue extending several miles south of the base of the middle Keweenawan as drawn in the township west. If the tongue be farther extended to include the anorthositic gabbro in the south of the township east, this southward projection will be a couple of miles greater.

In the Keweenawan extrusives and intrusives there is probably no mineral value. Conceivably there may be monumental rock or building stone values but this is problematical.




LEGEND

AKai Acid intrusives

AHUi Ironwood

AKbi Gabbro Basic intrusives

ÆRLgn Laurentian Gneiss

AKbe Basic Extrusives

Cross Fault

Figures left of lines are dip needle readings.
Figures right of lines are dial compass readings.
Dot to left=W. declination.
Dot to right=E. declination.

▪ Shaft

T44N~R5W~W½

WISCONSIN

GEOLOGICAL AND NATURAL HISTORY SURVEY

E. F. BEAN, DIRECTOR

# TOWNSHIP 44 N., R. 5 W.

Survey made in June, 1915

Under the direction of

W. O. HOTCHKISS, State Geologist

AND

E. F. BEAN, in charge of Field Parties

W. L. DOBIE, Chief of Party
C. W. HONESS, Asst. Geologist
C. A. HAMMILL, Asst. Geologist
WM. FOSTER, Asst. Geologist

## SYMBOLS AND ABBREVIATIONS.

The symbols and abbreviations used on this map are explained in Chapter II.

## TOWN AND RANGE LINES.

In constructing this map the south line of the township was laid off as a true east west line. The other boundary lines were then laid off with the lengths shown on the Land Survey plat. Some of the maps are therefore incorrect in shape but this is necessary because definite facts are lacking. The acreage of part of the lots in the north and west tier of sections is shown to give a check on the distances in these sections.

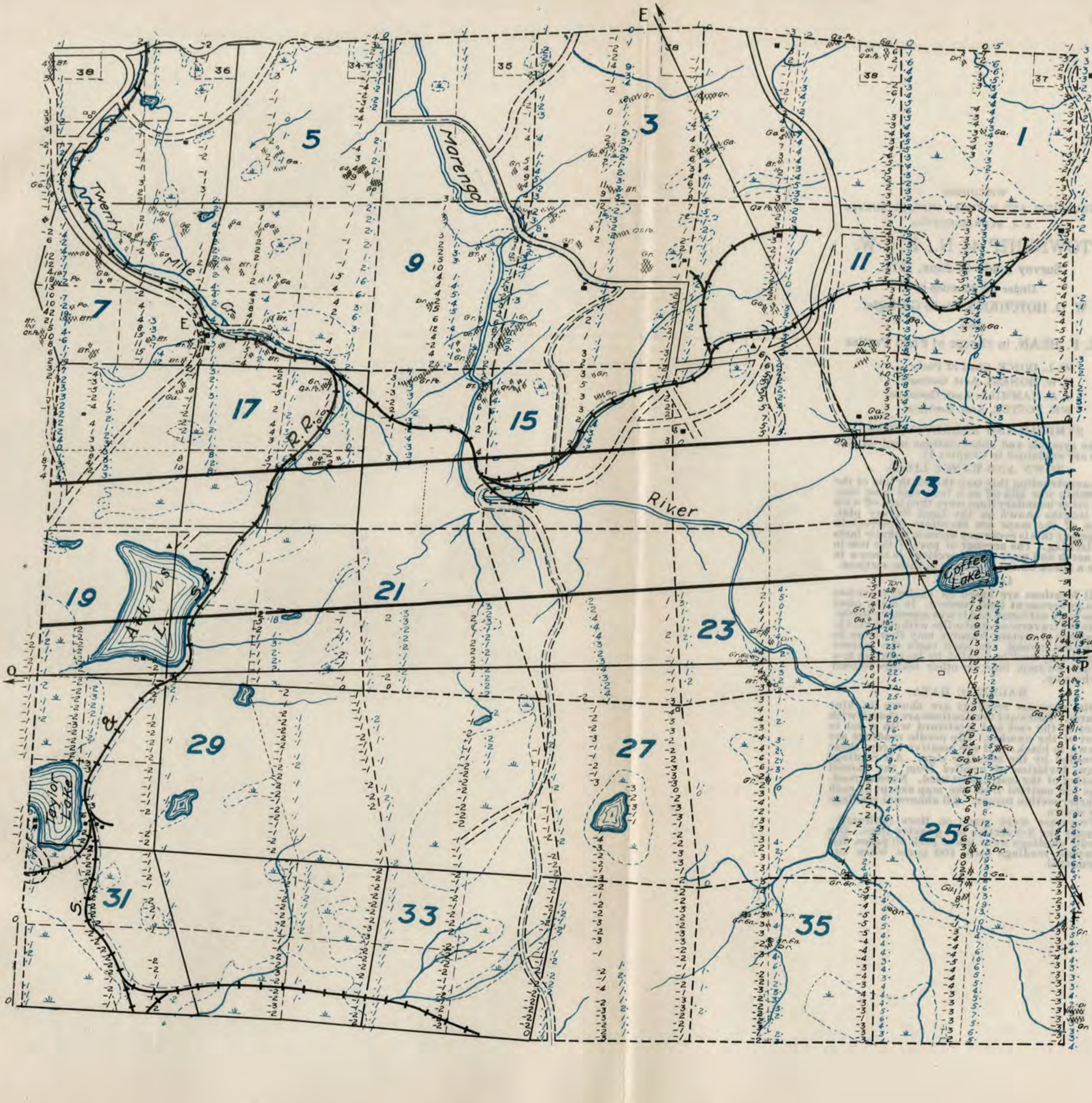
## LOCATIONS.

All locations are based on pacing traverses from government land corners. In many cases these were not found and it was necessary to continue the traverse several miles without a check. Locations of certain features may therefore be somewhat wrong. In such cases the feature sought may best be located by its relation to a stream, swamp, lake, or other feature shown on the map.

## MAGNETIC DATA.

Dial compass readings are shown in blue figures. Eastward declinations are shown with a dot to the east and westward with a dot to west of the number. Dip needle readings are shown in black. All are positive except those preceded by the negative sign. All readings show deviation of needles from the normal reading of the instrument used. Normal readings are omitted from the map except at each quarter section corner. All abnormal readings are shown.

Traverses were made on lines indicated—usually the N-S section and quarter lines. Dip needle readings were taken each 50 paces, dial compass readings each 100 paces when sun permitted.



1
3
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
Marengo
River
Twenty Mile Cr.
R.R.
Atkins L.
Coffee Lake
Taylor Lake

## TOWNSHIP 44, RANGE 6W.

The entire township was mapped.

### Surface Features

This area lies within the Lake Superior Highland Physiographic Province in which the surface features and topography are controlled by underlying formations.

The township can be divided into 4 general provinces. The northern row of sections forms a ridge of Middle Keweenawan flows or traps which strike east and west and dip very steeply to the north. The south slope of this ridge is precipitous along its major extent. There are two prominent transverse gaps, one in section 5 and the second in section 2. These are occupied respectively by Eighteen mile Creek and a branch of Twenty mile Creek which flow northward.

South of this northern ridge is a prominent valley. The south slope of this is less steep than the northern one, at least west of the east line of section 10. East of this line the slope is irregular and generally steep. This valley also varies in width. In the east it is roughly one half mile wide. On the west range line it is approximately 3 miles wide. The valley is underlain by Upper Keweenawan conglomerate striking about N. 60°E. and dipping about 55° NW. In the northwest of 10 and adjacent 9 there are several prominent well-rounded conical hills of this conglomerate. East of the east line of 10 and 3 the conglomerate has been intruded by gabbro which accounts for the steepness of the valley wall in that region. That part of this steep south wall adjacent to the southwest of 2 is known as Davis Hill.

The narrow northern ridge and the prominent valley immediately south are explained by the presence of a very important thrust fault. Along this fault the Middle Keweenawan flows of the north ridge were upthrust over the Upper Keweenawan conglomerates which occupy the valley.

South of a line drawn from approximately the east quarter post of section 1 to the southwest of 19 the topography is in general a series of ridges which, though discontinuous, strike about N. 60°E. These are surface expressions of the trap flows which have the same strike as the ridges and dip about 55° to the NW.

This province is rougher and more abundantly supplied with outcrop in the east than in the southwest where glacial deposits dominate the topography. It is also the divide between Lake Superior drainage and that of the Mississippi River system.

A line drawn from approximately the northeast of section 24 to the south quarter of 31 bounds the high belt of subordinate ridges along its south. South of this boundary is a belt of variable width characterized by much marshy country and many lakes. Sands abound and are probably the deposits of glacial streams. This belt is analogous to the Tyler Valley in townships east and is known to be underlain by the Tyler slates, at least in part. The iron formation as revealed by outcrops and associated magnetic attraction is expressed topographically as a low discontinuous ridge. In the southeast the land is low and marshy.

## General Geology

This township is replete with interesting geological features. Only in small part, however, are these of immediate interest in connection with the Ironwood formation. In describing the surface features and their reflection of underlying formations the great thrust fault in the north was mentioned. This is part of the Lake Owen thrust described in major detail in Chapter VI. The southern boundary of the central belt of high ridges is part of a second thrust which in Chapter VI is referred to as of Crystal Lake-Atkins Lake or Keweenaw thrust.

Immediate interest in connection with the Ironwood study is confined to the belt including sections 24, 25, 26, 27, part of 28, 32, 33, and 34. This belt embraces all known exposures of the Ironwood in the township and the magnetic attraction associated with it.

The extreme southeastern sections are concluded to be underlain by Archean granites. There are no exposures of these in this township, however, and the conclusion is based on the character of the magnetic attraction which is like that in the Archean area of the townships east.

### *The Huronian*

Only two of the Huronian formations have been discovered in this township, the Ironwood and the Tyler slates.

*The Ironwood.* On figure (31) are shown the exposures of the Ironwood and intrusive basic rocks. These are confined to the

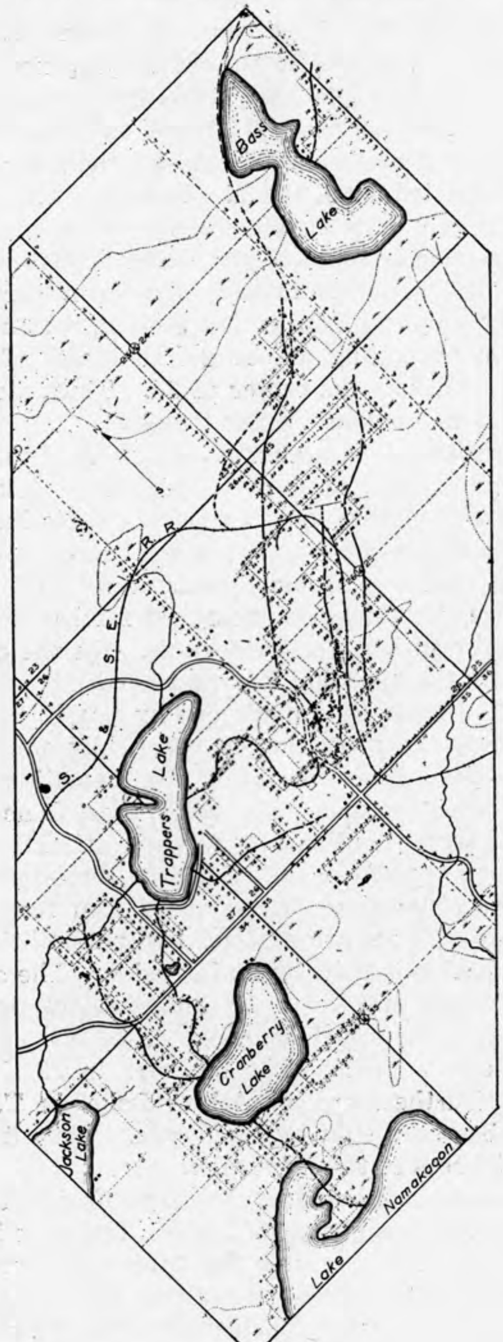

Bass Lake
S. E. R R
Trappers Lake
Cranberry Lake
Jackson Lake
Lake Namakagon

Fig. 31

southeast of section 26. They show a strike averaging about N. 45° E. and a dip to the northwest varying from 35° to 56°. There are no southerly dips and hence the monoclinal structure found northeast still persists. If these outcrops were the sole evidence it would be necessary to consider the formation as present only in an isolated small patch. However, there is associated with the exposures a very distinctive type of magnetic attraction. When this attraction is followed out, there is justification for the conclusion that the formation extends with but minor interruptions from the northeast of 24, across that section, across 26, and with turns indicative of folding across the southeast of 27, and evidently southward across the center of 34. Thus, along the strike the formation is more than 3 miles long.

Across the strike the situation is outstandingly different from what was found in townships east. In this western area there are at least three separate and distinct magnetic lines. The distance across the belt is three-tenths of a mile and with an average dip of 45° the thickness would appear to be 1013 feet thick or practically twice the thickness measured farther east. There is little evidence for such a great thickness. On the other hand, it is clearly seen on the map that the most northerly of the magnetic lines is separated from the middle one by nearly two-tenths of a mile along which the attraction is practically wanting. In the west of T. 44—3W. where the dip of the formation is most comparable to this situation under discussion, there is no such alternation of belts of strong and extremely weak attraction. It is possible to conclude, therefore, that this belt three-tenths of a mile wide is not one continuous succession of iron formation with a simple structure. There are at least two possibilities. The first is that the formation is split by an intrusion. The second is that there is dip folding and the outer line of attraction represents a long drag fold in the upper members. The former of these possibilities has some support. The outcrops in 26 show intrusive igneous rock. Furthermore, at Atkins Lake, in T. 44—R. 5W. the formation has been split by basic rock. Thus it is impossible to state the thickness of the formation.

In all the specimens taken from the exposures and the test pits, recrystallization is strongly in evidence. The rock is a magnetic amphibole schist. Whether this condition represents the effect of the intrusions or of folding and faulting which will be discussed next below, cannot be stated conclusively although the known volume of the igneous rock does not exceed that seen at Atkins Lake and at that point the Ironwood is by no means a schist. In other words, although the origin of the schistose character cannot be definitely ascribed to dynamic metamorphism the writer considers that to be the case. From the standpoint of the possibility of ores this schistose character can be looked upon as decidedly unfavorable.

From the trends of the magnetic lines it is evident that in the southwest of 26, the southwest of 27 and the central part of 34 the formation is folded. This fold appears to be a drag fold in which the northern or upper formations were forced northeastward toward a major anticlinal fold by compression in a synclinal farther west but not yet known. Beyond knowing that the pitch of these folds must be into the northern quadrants little can be said. It is unknown whether the pitch is northeastward or northwestward. At least, however, it can be said that the major anticlinal of which this is part of the western limb lies farther northeastward in T. 44—R. 5W.

*The Tyler Slate.* The formation which normally overlies the Ironwood is the Tyler slate. Only one exposure of this is known in this township. This lies about 400 paces north and 100 paces west of the center of 26, just northeast of Trappers Lake. However, it is again possible to fall back upon the magnetic record. With this available it is seen that between the magnetic attraction of the Ironwood and the southern boundary of the Keweenawan traps about one half a mile north, there is a belt of no magnetic variation. It is low ground and has the general appearance of the Tyler Valley farther east. It is, therefore, believed that although there is but one exposure, that this entire belt is underlain by the Tyler formation. Examination of the outcrop shows it to be comparable to the formation known farther east. Nothing is known as to the detailed structure of this formation. It evidently must be folded with the Ironwood. Its thickness is evidenly in excess of 1000 feet. The relationships between it and the Middle Keweenawan will be discussed in subsequent paragraphs.

### *Middle Keweenawan.*

The Middle Keweenawan is represented in this township by many exposures of the amygdaloidal basic flows. Textures vary greatly from exposure to exposure. As has been stated above, there are two belts of these flows separated by a belt of Upper

Keweenawan conglomerates. The structure of the southern belt is simple. The dip is 55° NW. and the strike N. 60° E. The structure of the conglomerate is conformable with this. However, in the northern belt the strike is East and West and the dip is practically vertical. This discordance, the position of the conglomerate, and the areal distribution and structure of the basaltic flows of the north belt as shown by work in neighboring townships leaves no doubt but what the contact of the northern flows and the conglomerate is a strong thrust fault. The northern flows were first bent into an arch trending across the main syncline toward Douglas County, and then thrust upwards and to the southeast.

WISCONSIN

GEOLOGICAL AND NATURAL HISTORY SURVEY

E. F. BEAN. DIRECTOR

# TOWNSHIP 44 N., R. 6 W.

## Survey made in June, 1915

Under the direction of

**W. O. HOTCHKISS, State Geologist**

AND

**E. F. BEAN, in charge of Field Parties**

M. C. LAKE, Chief of Party

H. N. EIDEMILLER, Asst. Geologist

C. S. CORBETT, Asst. Geologist

D. G. THOMPSON, Asst. Geologist

### SYMBOLS AND ABBREVIATIONS.

The symbols and abbreviations used on this map are explained in Chapter II.

### TOWN AND RANGE LINES.

In constructing this map the south line of the township was laid off as a true east west line. The other boundary lines were then laid off with the lengths shown on the Land Survey plat. Some of the maps are therefore incorrect in shape but this is necessary because definite facts are lacking. The acreage of part of the lots in the north and west tier of sections is shown to give a check on the distances in these sections.

### LOCATIONS.

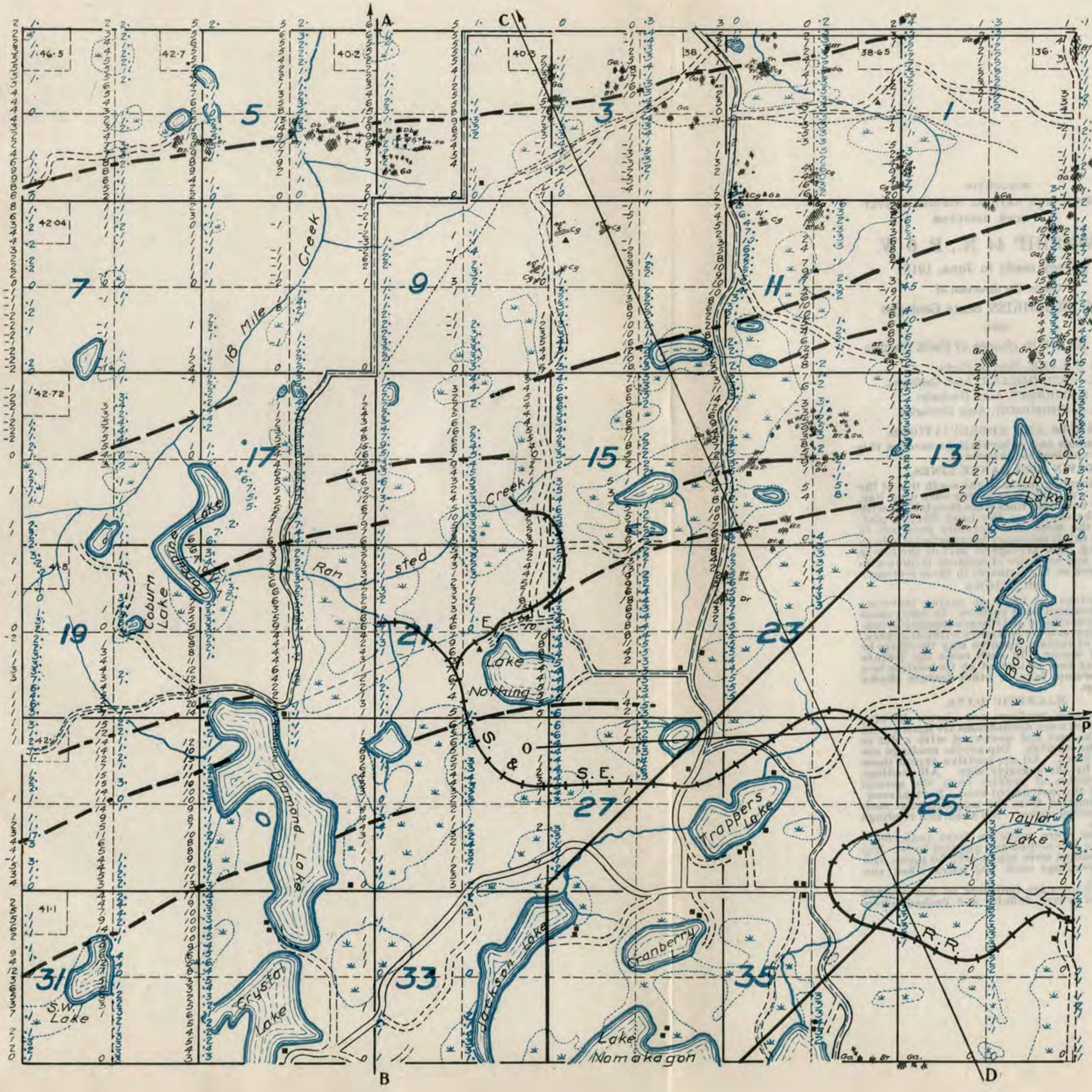
All locations are based on pacing traverses from government land corners. In many cases these were not found and it was necessary to continue the traverse several miles without a check. Locations of certain features may therefore be somewhat wrong. In such cases the feature sought may best be located by its relation to a stream, swamp, lake, or other feature shown on the map.

### MAGNETIC DATA.

Dial compass readings are shown in blue figures. Eastward declinations are shown with a dot to the east and westward with a dot to west of the number. Dip needle readings are shown in black. All are positive except those preceded by the negative sign. All readings show deviation of needles from the normal reading of the instrument used. Normal readings are omitted from the map except at each quarter section corner. All abnormal readings are shown.

Traverses were made on lines indicated—usually the N-S section and quarter lines. Dip needle readings were taken each 50 paces, dial compass readings each 100 paces when sun permitted.

Magnetic lines are indicated by heavy black lines, solid where definite and dashed where doubtful.



A
B
C
D
E
O
P
5
3
1
7
9
11
17
15
13
19
21
23
31
33
35
27
25
18 Mile Creek
Ran sted Creek
Coburn Lake
Porcupine Lake
Lake Nothing
Diamond Lake
Club Lake
Bass Lake
Taylor Lake
Trappers Lake
Cranberry L.
Jackson Lake
Crystal Lake
S.W. Lake
Lake Namakagon
S. & S.E. R.R.

# INDEX