Stratigraphy of Pre-Keweenawan Rocks in Parts of Northern Michigan

GEOLOGICAL SURVEY PROFESSIONAL PAPER 314-C

Prepared in cooperation with the Geological Survey Division, Michigan Department of Conservation

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By HAROLD L. JAMES

SHORTER CONTRIBUTIONS TO GENERAL GEOLOGY

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By HAROLD L. JAMES

ABSTRACT

The Precambrian rocks of northern Michigan are placed in three major categories—Lower Precambrian, Middle Precambrian, and Upper Precambrian. This report summarizes stratigraphic nomenclature used by the U. S. Geological Survey for the Lower and Middle Precambrian rocks that occur in Iron and Dickinson Counties.

A sequence of Lower Precambrian rocks—Archean of older reports—is established on the basis of detailed mapping in central Dickinson County; it consists of metamorphosed sedimentary and volcanic rocks, herein named the Dickinson group. These strata rest unconformably on an older granite gneiss, and in turn have been invaded by granitic rocks of batholithic dimensions. The pre-Dickinson granitic gneiss contains inclusions of quartzite and schist, relics of a still older sedimentary sequence. The Dickinson group is divided into three formations—East Branch arkose (oldest), Solberg schist with the interbedded iron-rich Skunk Creek member, and the Six-Mile Lake amphibolite. Separated by a covered interval from strata of the Dickinson group are rocks herein designated the Hardwood gneiss, which may be in part or wholly equivalent to the Dickinson group. The absolute age of the post-Dickinson granitic rocks is not known.

Middle Precambrian rocks consist chiefly of the Animikie series (Huronian of older reports) and post-Animikie, pre-Keweenawan igneous rocks. The term Huronian, used in the region for nearly 60 years, is not used because of the uncertainty of correlation with the type Huronian of Canada. The strata previously correlated with the Huronian are now referred to the Animikie, here expanded from group to series rank, on the basis of accepted correlations with the strata of the Mesabi district of Minnesota, which have been traced into the type Animikie of the Thunder Bay area of Canada.

The Animikie series rests with profound unconformity on the eroded surface of Lower Precambrian (post-Dickinson) granitic rocks in many places in northern Michigan. The Animikie is divided into four groups that are defined in this report. In order of age (oldest to youngest) these are (a) the Chocolay group, comprising the Fern Creek formation, Sturgeon quartzite, and Randville dolomite, and their stratigraphic equivalents; (b) the Menominee group, which in the type area consists of the Felch formation (Felch schist and equivalent rocks of older reports) and the Vulcan iron-formation, with the Traders, Brier, Curry, and Loretto members; (c) the Baraga group, comprising the Goodrich quartzite, Hemlock formation, Fence River formation and its probable equivalent the Amasa formation, Michigamme slate, and Badwater greenstone; and (d) the Paint River group, which comprises the Dunn Creek slate, Riverton iron-formation, Hiawatha graywacke, Stambaugh formation, and Fortune Lakes slate. The strata of the Paint River group, which occur chiefly in the Iron River-Crystal Falls district, previously have been considered part of the Michigamme slate.

The Animikie strata were deformed, metamorphosed, and intruded by dikes, stocks, and sills of gabbroic to granitic composition in a pre-Keweenawan orogenic interval. Recent determinations of A^{40}/K^{40} and Rb^{87}/Sr^{87} indicate a probable age of at least 1,400 million years for the granitic rocks, which commonly have been referred to as "Killarney", on the basis of assumed equivalence in age with the Killarney granite of the north shore of Lake Huron. Recently reported ages of rocks from near the type area of the Killarney granite indicate that the assumed equivalence is not valid.

INTRODUCTION

Since 1943, the U. S. Geological Survey, in cooperation with the Geological Survey Division of the Michigan Department of Conservation, has been engaged in restudy of the iron-bearing districts of northern Michigan (fig. 2). In cooperation with the State of Wisconsin, this study has recently been extended into adjoining areas of Wisconsin. A number of reports on various aspects of the work have been published (Dutton, Park, and Balsley, 1945; Pettijohn, 1947; James, Clark, and Smith, 1947; James, 1948; Pettijohn, 1948; James and Wier, 1948; Dutton, 1949; Good and Pettijohn, 1949; Balsley, James, and Wier, 1949; Dutton, 1950; Wier, 1950; James, 1951; James and Dutton, 1951; Pettijohn, 1952; Wier, Balsley, and Pratt, 1953; James, 1954; James, 1955; Gair and Wier, 1956) and several more have ben placed on open file (Lamey, 1946; Lamey, 1947; Lamey, 1949; Wier and Kennedy, 1951; Pettijohn, 1951; Clark, 1953; Bayley, 1956). Reports on the Lake Mary quadrangle (R. W. Bayley), Central Dickinson County (James, Lamey, Clark, and others), the Iron River–Crystal Falls district (James, Pettijohn, and Dutton), and Southern Dickinson County (Bayley, Lamey, and Dutton) are in various stages of preparation for publication. Most of the early reports

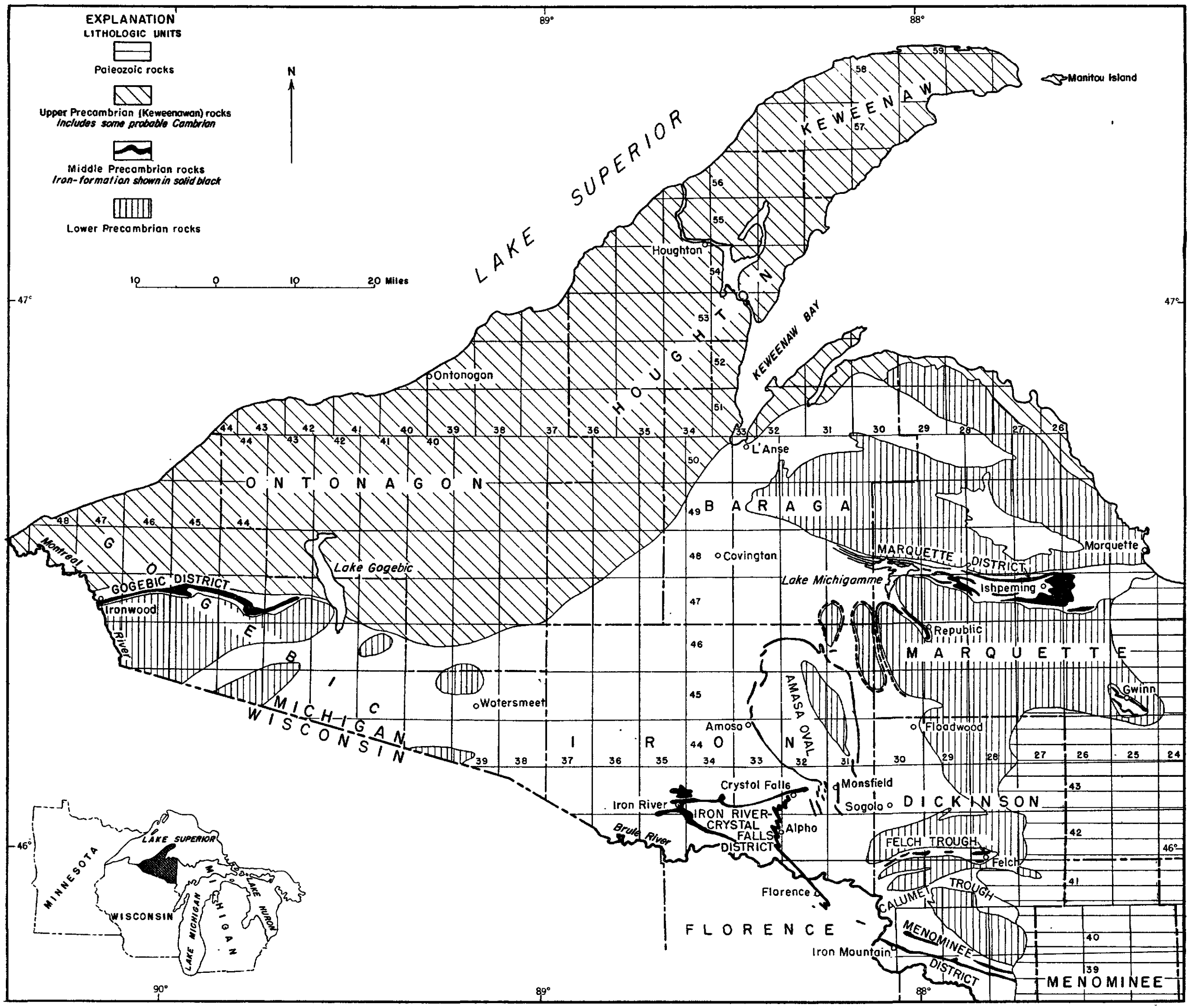

FIGURE 2.—Geologic sketch map of northern Michigan.

and all those placed on open file were preliminary in nature; stratigraphic names were used in conformity with existing terminology or were described only in terms of lithology, without formal designation. The reports now in preparation, however, will contain many new stratigraphic names and revisions of terminology of the pre-Keweenawan rocks. The present paper is written so that the problem can be reviewed in its entirety rather than piecemeal; in part it will summarize that which will be presented in more detail in later reports on individual areas.

The conclusions summarized in this brief report are based on more than 200 man-months of field work. In preparing the report I have drawn heavily on the published and unpublished work of my colleagues: R. W. Bayley, L. D. Clark, C. E. Dutton, Jacob Freedman, J. E. Gair, C. A. Lamey, F. J. Pettijohn, W. C. Prinz, James Trow, and K. L. Wier. Each of these men criticized preliminary drafts of the manuscript and their suggestions have been incorporated. Complete unanimity of view on all points is not to be expected, but we are in agreement on all major aspects of the stratigraphy. The final responsibility for the statements made herein is mine, but the report is a joint effort and I hope it will be so regarded.

SUBDIVISION OF PRECAMBRIAN TIME

Unlike the situation with respect to post-Precambrian time, there exists no widely accepted reference framework of eras and periods to which Precambrian lithologic units and geologic events can be related. The principal reasons, of course, are obvious: lack of diagnostic fossils and the greater degree of deformation and metamorphism. Even within the Canadian shield no satisfactory subdivision has been achieved, although the literature is strewn with the debris of many unsuccessful attempts. Trust in particular lithologic aspects (as in the original definitions of the Archean and Algonkian) and a shield-wide unconformity (the Eparchaean interval) has been shown to have been misplaced; it now seems safe to say that virtually all the familiar time and time-stratigraphic terms—Archean, Algonkian, Laurentian, Keewatin, Algoman, Huronian, and Killarney—have become so beclouded by misuse they are of dubious value except in the type areas (Gill, 1955).

The monograph studies of the Lake Superior region, summarized by Van Hise and Leith (1911), employed a standard twofold classification of Precambrian time into two major units—the Archean and the Algonkian. Emphasis was placed on the complex, crystalline nature of the Archean system, and upon the profound unconformity that separated the Archean from the Algonikian. Subsequent work in the Canadian shield was to show that in many places the Archean contains thick sequences of only weakly metamorphosed sedimentary rocks and that the "Eparchaean" unconformity is not readily defined. The increased uncertainty as to the precise correlation of rocks in separated areas finally led Leith (1934), in his scholarly review of the Precambrian, to propose that the terms Archean and Algonkian be used only in a relative sense—essentially to indicate the nature of the lithology. Leith, Lund, and Leith (1935) adopted the scheme whereby only one term—Precambrian—is used in a strict time sense, and Archean-type and Algonkian-type were used to characterize Precambrian rocks but without definite time significance. This method of designation has not been followed by other workers in the region, chiefly because unless the terms have time sense they are of no value; with less confusion one may refer to a terrane as consisting simply of an older sequence and a younger sequence of rocks. Furthermore, many truly older ("Archean") rocks are not "Archean-type", whereas some younger rocks elsewhere are.

In 1934, a special committee of Section IV of the Royal Society of Canada (Alcock, 1934) recommended that the terms Archean and Proterozoic be used in Canada for Early and Late Precambrian, respectively, which were the terms then in current usage by the Geological Survey of Canada. The base of the Bruce series (lower Huronian) was proposed as the dividing line between the two major divisions. The Geological Survey of Canada follows the recommended terminology, but with recognition of the difficulty of application in some areas and recognition of the uncertainty as to the exact position of the dividing line between the Archean and the Proterozoic (J. M. Harrison, 1957, written communication). Although the two-fold subdivision would seem quite applicable to the rocks in northern Michigan, there remain the same questions of actual time significance that plagued Leith and led him to abandon Archean and Algonkian. The rocks of many, if not most, areas of the Canadian shield can be placed in two main groups separated by a profound unconformity. But is this unconformity of the same age in each area? May it not be that the rocks beneath the unconformity in one area are actually time-equivalent to rocks above a comparable unconformity in another area? What of the interval represented by the unconformity itself? And in some districts profound unconformities separate the rocks into three or more groups. How are the rocks then to be classified in a twofold time sense?

Only one term—Precambrian—is now used in a strict time sense in reports of the U. S. Geological Survey; the terms Archean and Algonkian were abandoned more than 20 years ago. For a region in which at least 2,000 million years of geologic history is recorded in the rocks exposed at the surface and for which the geologic record locally has been worked out in as great detail as in many well-studied younger terranes, the situation obviously is unsatisfactory. Time was an element equally important prior to *Olenellus* as it was later, and the analysis of geologic events demands a greater subdivision than that permitted by the single term Precambrian. Yet it seems equally evident that until gross subdivisions can be placed in an actual time scale by age determinations, they have little general value and in fact may lead to many incorrect conclusions regarding regional problems. Fortunately, many laboratories are perfecting methods of geochronology; the number of absolute age determinations is increasing rapidly, and methods such as potassium-argon permit determination of the age of rocks other than those of intrusive origin. Within a decade, perhaps, it may be possible to define major subdivisions of time in terms of adequately mapped and geologically understood rock sequences in the Canadian shield.

Until an adequate basis for time division is available, informal subdivisions such as Lower Precambrian, Middle Precambrian, and Upper Precambrian are used by the U. S. Geological Survey. Strictly speaking, these are meant to apply only to rock units within a given area, not a subdivision of time (hence Lower and Upper, rather than Early and Late), and the designations apply only to the particular area under discussion. Inevitably, however, because of the overriding need for subdivisions of time, the terms are used informally in a time sense and, regardless of qualifications held by the originators, they will be so interpreted by others (see, for example, Wilson, 1956). Furthermore, unless the implication of time is heeded, workers within the same region—or even in adjoining areas—presumably could, on the basis of local geology, place a recognized correlative unit in different categories. Indeed this has already happened: Grout, Gruner, Schwartz, and Thiel (1951) place the Biwabik and Gunflint formations in the Late Precambrian—an eminently justifiable decision considering the area—whereas in Michigan the agreed correlatives are referred to the Middle Precambrian (James, 1955), which is equally justifiable on the basis of the geology of that area. Until enough absolute age determinations are available properly to define gross subdivisions of time for the region, this obviously unsatisfactory situation seemingly must be endured; all that can be done to minimize the confusion is to define usages as clearly as possible and to apply the same terms to time-equivalent units, so far as this is possible with the means at hand.

TABLE 1.—*Lithologic sequence of Precambrian rocks in Iron and Dickinson Counties, Mich.*

[New stratigraphic names are indicated by asterisks]

Precambrian	Upper Precambrian	Keweenawan series	Diabase dikes and sills (probable age about 1,100 million years)		
		—Intrusive contact—			
	Middle Precambrian	Granitic intrusive rocks (probable age at least 1,400 million years)			
		—Intrusive contact—			
		Metadiabase and metagabbro			
		—Intrusive contact—			
		Animikie series	Paint River group*	Fortune Lakes slate*	
				Stambaugh formation*	
				Hiawatha graywacke*	
				Riverton iron-formation*	
				Dunn Creek slate*, with Wauseca pyritic member*	
			Baraga group*	Badwater greenstone*	
				Michigamme slate	
				Fence River formation	Amasa formation
				Hemlock formation, with Mansfield iron-bearing slate member and Bird iron-bearing slate member*	
				Goodrich quartzite	
			—Unconformity—		
			Menominee group*	Vulcan iron-formation	Loretto slate member
					Curry iron-bearing member
					Brier slate member
					Traders iron-bearing member
				Felch formation	
			—Unconformity—		
			Chocolay group*	Randville dolomite	Saunders formation
				Sturgeon quartzite	
				Fern Creek formation	
		—Unconformity—			
	Lower Precambrian	Gneissic granite and other crystalline rocks		Quinnesec formation (position uncertain)	Margeson Creek gneiss (position uncertain)
		—Intrusive or replacement contact??—			
		Dickinson group*	Six-Mile Lake amphibolite*	Hardwood gneiss* position uncertain	
			Solberg schist*, with Skunk Creek member*		
			East Branch arkose*		
		—Unconformity—??			
		Granite gneiss			
		Quartzite and schist (small bodies included in granite gneiss)			

For the rocks of northern Michigan, the gross subdivisions that will be followed are given in comparison with previously used terminology.

Van Hise and Leith 1911		Leith, Lund and Leith 1935		Grout et al. (Minnesota) 1951	Present Geological Survey usage for northern Michigan	
Proterozoic	Algonkian	Precambrian	Algonkian-type	Late Precambrian	Precambrian	Upper Precambrian
						Middle Precambrian
	Archean		Archean-type	Middle Precambrian		Lower Precambrian
				Early Precambrian		

Most of the recent work of the Geological Survey in Michigan has been confined to Iron and Dickinson Counties (fig. 2), an area which includes the Iron River–Crystal Falls, Menominee, Felch Mountain, and Calumet districts. The stratigraphy of the Precambrian rocks of this area, including terms that will be defined later in the present report, is summarized in table 1.

LOWER PRECAMBRIAN ROCKS

The subdivisions of Lower Precambrian rocks, given in table 1, have been defined on the basis of detailed mapping in central Dickinson County, chiefly by Lorin D. Clark, C. A. Lamey, F. J. Pettijohn, Jacob Freedman, and James Trow. Preliminary descriptions of some parts of this area have been made available (Clark, 1953; Lamey, 1946, 1947, 1949; Pettijohn, 1951) and a general report on the entire area is in preparation (James, H. L., Lamey, C. L., Clark, L. D., and others).

OLDER GRANITE GNEISS AND INCLUDED BODIES OF QUARTZITE AND SCHIST

A strongly deformed granite gneiss is exposed in the northern part of T. 42 N., Rs. 28, 29, and 30 W. and is overlain unconformably by the East Branch arkose (table 1). The rock is described by Clark (1953, p. 10) as follows:

> Although the composition and texture of the gneiss range widely, a coarse brick-red to very light-red rock of porphyritic aspect is most common. The largest phenocrysts are 1½ inches long and are microcline or albite.—A marked cataclastic texture with strong secondary foliation is characteristic of the red porphyritic granite. Many of the large feldspar grains are fractured and rounded. They are separated by laminae of micaceous or chloritic minerals in which are embedded microcline fragments and thin, tabular quartz grains.

Less common varieties of granitic gneiss exposed in T. 42 N., R. 28 W. include fine-grained granite and quartz-rich granite.

The gneiss is especially well exposed in the north part of sec. 7, T. 42 N., R. 28 W. and in adjoining parts of adjacent sections. Foliation trends easterly and is nearly vertical.

Inclusions of schist and of quartzite measurable in tens of feet in width and length are sparsely distributed in the granite gneiss. They are the only known remnants of the terrane in which the granite was emplaced.

DICKINSON GROUP

The rocks here named in the Dickinson group occur in an easterly trending belt about four miles wide in the central part of T. 42 N., Rs. 28, 29 and 30 W. This area is in the central part of Dickinson County, for which the group is named. Magnetic green schist believed correlative with the Dickinson group occurs in the Kiernan and Lake Mary quadrangles to the northwest (Gair and Wier, 1956, p. 27; R. W. Bayley, 1956, p. 13). Detailed mapping by Lorin D. Clark and C. A. Lamey has shown that the group can be divided into three formations in central Dickinson County. These formations—East Branch arkose (oldest), Solberg schist, and Six-Mile Lake amphibolite—are defined below. The rocks are steeply dipping or vertical and the sequence is believed to be conformable.

EAST BRANCH ARKOSE

The strata here named the East Branch arkose are well exposed in broad glacially polished outcrops in secs. 17 and 18, T. 42 N., R. 28 W., along the East Branch of the Sturgeon River (Clark, 1953). Many other excellent exposures occur for about two miles both east and west of this area. The strata comprise arkose, arkosic conglomerate, and interbedded metamorphosed basalt flows and basic tuffs. The sedimentary rocks are characterized by coarseness of grain, poor sorting, and beds of conglomerate. The pebbles of the conglomerate are deformed into elliptical bodies in the plane of foliation. About 75 percent of the fragments more than an inch long are quartzite, but pebbles similar or identical to the underlying granite gneiss are abundant. The arkosic beds have been reconstituted to a gneissic-appearing rock but cross-bedding is well preserved; the beds are steeply dipping or vertical, and the top direction is consistently to the south.

The actual contact with the older granitic gneiss has not been observed, though in some places the two rock units are exposed but a few feet apart. The younger age of the arkose is shown by the presence of granitic gneiss pebbles in the conglomerate and by the absence of any metamorphic effects that can be related to the contact. The strata previously have been referred to the Sturgeon quartzite of the Huronian series by earlier investigators (W. S. Bayley, 1899, p. 471; Van Hise and Leith, 1911, p. 301), who assumed it to underlie Randville dolomite that is exposed a short distance to the north. The pre-Animikie age for the arkose is shown by the following facts:

1. In much of the area, the two formations are separated by a wedge of granite gneiss.
2. The top directions in the arkose are consistently to the south, away from the dolomite that was assumed to overlie it conformably.
3. The arkose shows strong internal deformation, in contrast to the absence of such deformation in the adjacent dolomite. In the SW¼ sec. 3, T.

42 N., R. 28 W., for example, fine-grained dolomite with undeformed algal structures occurs only a few hundred feet north of broad outcrops of arkosic conglomerate in which the arkose is gneissic in appearance and texture and in which the pebbles of the conglomerate are flattened discs.

The East Branch arkose, after making due allowance for structural complications, is believed to be at least 1,000 feet thick in the type area.

SOLBERG SCHIST

The unit here defined as the Solberg schist is named for Solberg Lake, in secs. 17 and 20, T. 42 N., R. 29 W., east of which the rock is exposed in scattered outcrops for about 10 miles in a belt 1 to 2½ miles wide. The more northerly (stratigraphically lower) parts of the unit are dark fine-grained hornblende and biotite schists. Some exposures show a banding, parallel or nearly parallel to the steeply dipping foliation that may represent original layering. The more southerly exposures are of massive gray quartz-mica schist and micaceous quartzite.

Interlayered with the Solberg schist is a bed of iron-formation, here named the Skunk Creek member. It is named for Skunk Creek, a tributary of the East Branch of the Sturgeon River, which crosses the iron-rich member near the SE cor. sec. 17, T. 42 N., R. 28 W. The rock is exposed only in a small outcrop in the NE¼ sec. 23, T. 42 N., R. 29 W., but the magnetic anomaly caused by the rock has been traced for more than 20 miles and the bed has been drilled in several places by the M. A. Hanna Company. The drill core shows the rock to consist principally of three interlayered rock types: (a) biotite-hornblende schist with magnetite layers; (b) a distinctive thin-bedded rock consisting of alternating layers of metachert and magnetite; and (c) various mixtures of hornblende, biotite, grunerite, garnet, and epidote. The Skunk Creek member is about 100 feet thick.

The aggregate thickness of the Solberg schist is difficult to determine accurately, but it is about 3,000 feet. Some interbedding with the East Branch arkose is indicated in exposures near the south edge of sec. 18, T. 42 N., R. 28 W. The Skunk Creek member is about 1,000 feet below the top of the formation.

SIX-MILE LAKE AMPHIBOLITE

The Six-Mile Lake amphibolite is named for Six-Mile Lake, in sec. 22, T. 42 N., R. 29 W. The rock is well exposed in low knobs and ridges immediately south of the lake and for several miles to the east and west. It is a massive dark fine- to medium-grained aggregate of hornblende and plagioclase, with strong preferred planar and linear orientation of the minerals. The amphibolite is basaltic in composition and represents a metamorphosed sequence of flows and possible tuffs. The amphibolite grades to the south (across the strike) into a mile-wide zone of banded gray gneiss that is the product of reaction between the amphibolite and post-Dickinson gneissic granite, a granite that forms the basement to the Animikie series in parts of the area.

The thickness of amphibolite is about 3,000 feet, but a considerably greater original amount can be inferred from the widespread occurrence of amphibolite as relict bodies in the gneiss the granite adjoining to the south.

HARDWOOD GNEISS

The rock here named the Hardwood gneiss is exposed principally in sections 5 and 8, T. 41 N., R. 27 W., Dickinson County, a short distance west of the community of Hardwood for which the unit is named. Excellent exposures occur along and adjacent to highway M69, within an area mapped in detail by Jacob Freedman, 1951 (written communication).

The gneiss contains some highly distinctive rocks, many of which are quite unlike any others in northern Michigan known to me. Much of the rock is strongly layered in units a fraction of an inch to a few feet in thickness. The principal rock is dark, medium-grained gneiss composed of hornblende, plagioclase, and pyroxene, which is interlayered with dark fine-grained gneiss, beds of light-colored gneiss with light and dark laminae, garnet-quartz-mica schist, and light-colored rock that resembles quartzite but which probably is volcanic in origin. The layering in general dips easterly at angles less than 40° but many exposures show complex crumpling.

The gneiss, which represents original volcanic and tuffaceous rocks of basic to intermediate composition together with some interbedded rock of sedimentary origin and intrusive metagabbro sills, may well be equivalent to or part of the Dickinson group, but exposures are inadequate to establish relationships. The known thickness, including metagabbro sills, is not great—possibly no more than several hundred feet.

QUINNESEC FORMATION

The term Quinnesec formation applies to greenstone, amphibolite, and schist that form a belt in the southernmost part of Dickinson County and adjacent parts of Wisconsin. These rocks, under the name Quinnesec schists, were referred to the Archean by Van Hise and Bayley (1900), but later (Van Hise and Leith, 1911) were assigned a late Huronian age. Leith, Lund, and Leith (1935) changed the designation to

Quinnesec greenstone and doubtfully assigned the unit to the middle Huronian.

The type area of the Quinnesec formation has been mapped in detail recently by W. C. Prinz (1957, written communication), who finds that rocks placed in the Quinnesec formation by previous workers comprise metavolcanic rocks and younger metagabbro sills. The term Quinnesec formation is retained for the metavolcanic rocks, which are clearly older than the granitic rocks that form a mass of batholithic dimensions to the south. Relationships of the Quinnesec formation and of the granitic rocks to known Animikie strata are not clear; the metavolcanic and granitic rocks are believed to be pre-Animikie, and are so shown in table 1, but until absolute age measurements are made this conclusion is only tentative. The younger metagabbro sills are intrusive into the Quinnesec formation and are younger than the granitic rocks to the south. They are tentatively correlated with the post-Animikie metadiabase and metagabbro.

POST-DICKINSON GNEISSIC GRANITE

Large areas of northern Michigan are underlain by masses of pre-Animikie gneissic granite and related rocks which are surrounded by or contain infolded Animikie strata. In central Dickinson County it has been established that the large mass of crystalline rocks between the Felch and Calumet troughs of Animikie strata is of post-Dickinson age. The basement rocks to the Animikie series in many other parts of the region probably are equivalent to this post-Dickinson granite, rather than to the pre-Dickinson granite, but proof is not available. The pre-Animikie Margeson Creek gneiss of northeastern Iron County (Gair and Wier, 1956, p. 18–26) is in this category; it could be either post-Dickinson or pre-Dickinson in age.

The term "Algoman," commonly used in the Lake Superior region in reference to upper pre-Animikie granitic rocks, may be applicable to the post-Dickinson granite gneiss, but in the absence of actual determinations of age this assignment should be considered tentative or doubtful.

MIDDLE PRECAMBRIAN ROCKS

Middle Precambrian rocks are represented by a thick sequence of metasedimentary and metavolcanic rocks and by scattered bodies of metagabbro and of granitic rocks. The metasedimentary and metavolcanic sequence has been referred to the Huronian series for over 60 years. This designation is now changed in favor of Animikie series.

The term Huronian was applied by Logan and Hunt (1855) to a sequence of sedimentary rocks that lies beneath the recognized Silurian strata on the north shore of Lake Huron. The beds, which consist of conglomerate, quartzite, limestone, and tillite, have an aggregate thickness on the order of 20,000 feet, and were described in some detail by Logan (1863). Restudy of the area by Collins (1925) showed that the strata were divided by an unconformity into two units, the lower of which is now referred to as the Bruce series and the upper as the Cobalt series.

Correlation between the Marquette district of Michigan and the type area of the Huronian was early proposed by Van Hise (1891). The Lower Marquette series of the Marquette range—consisting principally of the rocks now called the Mesnard quartzite, the Kona dolomite, the Ajibik quartzite, the Siamo slate, and the Negaunee iron-formation—was correlated with the Lower Huronian (Bruce series of the type area); and the Upper Marquette series of the Marquette range—consisting chiefly of the rocks now called the Goodrich quartzite and Michigamme slate—was correlated with the Upper Huronian (Cobalt series of the type area). Subsequently, A. E. Seaman (see plate 19 *in* Van Hise and Leith, 1911) discovered an unconformity within Van Hise's Lower Marquette series, at the base of the Ajibik quartzite, and as a result the strata in the Marquette range were divided into three unconformable units rather than two. An international committee reviewed the problem and accepted a proposal for a threefold division of the Huronian (Van Hise, Adams, Bell, and Leith, 1905), in which the Huronian was divided into three units, only two of which—the lower and the middle—are represented in the type area. The Animikie group of the Thunder Bay area of Ontario was to form the third unit (upper), which was correlated with the Goodrich and Michigamme sequence of the Marquette range on the basis of lithologic similarity. The latter sequence, therefore, while retaining the designation of upper Huronian, actually received an entirely different correlation from that originally proposed; instead of being correlative with the Cobalt series of the type Huronian, it was made post-Cobalt in age. This scheme was followed in Monograph 52, the final report of the U. S. Geological Survey series of monographs on the region (Van Hise and Leith, 1911). Although many geologists raised objections—see, for example, articles by Collins, Lawson, Coleman, and others in the proceedings of the 12th International Geological Congress (1914)—the revised classification received and still receives fairly wide acceptance. A later report by the (Canadian) National Committee on Stratigraphic Nomenclature, however, reinstated Upper Huronian as a designation for the Cobalt series of Canada (Alcock, 1934, p. 118).

Marsden (1955) has suggested that the Mesnard-Kona sequence of the Marquette district is "Middle Huronian", but otherwise few major objections have been raised to the fundamental matter of correlation of the Huronian of the type area with the strata of the Marquette district about 200 miles to the west. Yet no iron-formation such as the Negaunee is present in the Huronian of the type area, nor, except by indirect correlation, can relationship be established between the Upper Huronian of the Marquette district, the Animikie group of the north shore of Lake Superior, and the Huronian of the type area. The correlation is based almost entirely upon supposed lithologic similarity between the Bruce series (lower Huronian of the type area) and the Mesnard quartzite and Kona dolomite sequence of the Marquette range, and upon similarities in structural and igneous history.

Actually, the lithologic similarity between the Bruce series of Canada and the Mesnard-Kona sequence of Michigan is not close. If trust is to be placed in lithologic similarities—a questionable procedure at best—other correlations can be made that are of at least equal validity. One of the most distinctive rocks in the Huronian sequence of the type area is the Gowganda tillite, which forms the base of the Cobalt series of Canada. The tillite is overlain by the thick massive vitreous white Lorrain quartzite. In Dickinson County, Michigan, tillite of virtually identical appearance forms part of the Fern Creek formation (Pettijohn, 1943), and the Fern Creek formation is overlain by the Sturgeon quartzite, which is a thick vitreous quartzite comparable in thickness and lithology to the Lorrain quartzite that overlies the Gowganda tillite. If this correlation were to be accepted, it would imply that the entire "Huronian" sequence of Michigan is post-Bruce in age, but other equally plausible correlations could be made.

A second view is that the Michigan strata are pre-Huronian in age. The argument in favor of this view is as follows:

1. In the type Huronian area, the two principal quartzite formations—the Lorrain and the Mississagi—contain abundant pebbles and fragments of chert and jasper, material which is relatively scarce in the surrounding pre-Huronian terrane. Crossbedding in these two units indicates northerly and westerly sources for the clastic material (Pettijohn, 1957, p. 471). The abundance of jasper and chert suggests that major chert-bearing units were undergoing erosion during Huronian time; the iron-formation strata of Michigan are possible sources.
2. The probable age of the granitic rocks that cut the Middle Precambrian sequence of Michigan is more than 1,400 million year. (See p. 39–40.) On the north side of Lake Huron, the Wavy Lake granite (Lake Huron sheet, Map 155-A, Canadian Geological Survey) appears to be essentially a part of the Killarney granite of post-Huronian age. Its age has been determined as 1,025 million years by the potassium-argon method and 1,075 million years by the rubidium-strontium method (Wetherill, Davis, and Aldrich, 1957, pp. 39–40). East of this area the Cutler batholith is known to cut the Sudbury series of probable pre-Huronian age, but though the granite is adjacent to the basal Mississagi quartzite of the Huronian series, no direct evidence of crosscutting has been found. Age determinations on rocks from the batholith are given by Wetherill, Davis, and Aldrich (1957, p. 40) as 1,325, 1,760, and 1,750 million years by the rubidium-strontium method, and 1,380, 1,420, and 1,350 million years by the potassium-argon method. The Cutler batholith, therefore, which may well be overlain unconformably by the basal formation of the Huronian, appears to be of comparable age to the granitic rocks that cut the supposed Huronian series in Michigan.

The arguments for retention of the term Huronian for the Michigan strata are essentially negative—namely that the correlation has not actually been disproved and that the term is deeply entrenched in the literature. Because there are equally plausible alternatives to the correlation, it is our view that continued designation of the Michigan strata as Huronian is not justified.

Application of the term Animikie to the Michigan strata is open to far fewer major objections. The term was used originally in the Thunder Bay area on the northwest side of Lake Superior (Hunt, 1873) to strata that underlie the Keweenawan series. On the basis of physical continuity and bed-by-bed correlation, it has been accepted as a group name by Grout, Gruner, Schwartz, and Thiel (1951), for strata in Minnesota that previously had been referred to the Huronian. These authors use Animikie rather than Huronian because (p. 1042) "* * * the Minnesota outcrops are well correlated with the original Animikie locality and not well correlated with the type locality of the Huronian."

The strata assigned to the Animikie group by Grout and his associates can be correlated with the Michigan strata with reasonable assurance, chiefly because of the presence of major units of iron-formation. The Gunflint of the type Animikie area and of adjacent parts of Minnesota, the Biwabik of the Mesabi district, the Ironwood of the Gogebic district (Wisconsin and Michigan), the Negaunee of the Marquette district (Michigan), and the Vulcan of the Menominee district (Michigan) are accepted as at least approximately equivalent in age (Leith, Lund, and Leith, 1935). In general, therefore, the extension of the term Animikie to the Michigan strata rests on far firmer grounds than the extension of the term Huronian.

The Animikie is given series rank in application to the Michigan strata because it probably includes some rocks that are older and some that are younger than those in the type area, and because it is divided into four groups. Using the generalized sequence represented in Iron and Dickinson County for comparison, the relationship between the Animikie group of Minnesota and the Animikie series of Michigan is given in table 2.

TABLE 2.—*Comparison of the stratigraphic position of the Animikie group of Minnesota with the Animikie series as defined for part of Michigan.*

Minnesota (Mesabi district)		Michigan (Iron and Dickinson Counties)		
		Animikie series	Paint River group	Fortune Lakes slate Stambaugh formation Hiawatha graywacke Riverton iron-formation Dunn Creek slate
Animikie group	—?—?— Virginia slate		Baraga group	Badwater greenstone Michigamme slate Fence River and Amasa formations Hemlock formation Goodrich quartzite
	Biwabik iron-formation Pokegama quartzite —?—?—		Menominee group	Vulcan iron-formation Felch formation
			Chocolay group	Randville dolomite } Saunders formation Sturgeon quartzite } Fern Creek formation

CHOCOLAY GROUP

The Chocolay group, as here defined, is equivalent to the Lower Huronian of earlier reports. It is named for Mount Chocolay and for Chocolay Junction on the Duluth, South Shore, and Atlantic Railroad, about 3 miles southeast of Marquette, Michigan. At Mount Chocolay and the adjacent area to the west (Van Hise and Bayley, 1897, Atlas Sheet 39) the Mesnard quartzite and Kona dolomite are widely exposed. These two formations are accepted as direct correlatives of the Sturgeon quartzite and Randville dolomite of Iron and Dickinson Counties. Lithologically the sequences are almost identical and the correlation has been a basic tenet of Lake Superior geology for 60 years.

In Dickinson County the basal beds of the Chocolay group comprise conglomerate and arkose, with beds of tillite (Pettijohn, 1943). Pettijohn has designated these strata the Fern Creek formation, which is described in more detail by Trow (1948).

In parts of Iron and Dickinson Counties the only unit of the Chocolay group is the Randville dolomite (in southern Iron County, its partial correlative the Saunders formation). Whether the Sturgeon is absent because of nondeposition or whether the dolomite in these areas is time-equivalent to both Sturgeon and Randville is uncertain.

MENOMINEE GROUP

The Menominee group is named for the Menominee district of southern Dickinson County, Michigan. It is to be noted that the term Menominee series was used in Monograph 46 (Bayley, 1904) and discarded seven years later in Monograph 52 in favor of Huronian (Van Hise and Leith, 1911). The present definition covers only the middle part of the Menominee series as originally defined.

In the type locality this group consists of two formations—the basal Felch formation, and the Vulcan iron-formation. The latter formation is made up of four members which are, in ascending order, the Traders iron-bearing member, the Brier slate member, the Curry iron-bearing member, and the Loretto slate member. The Loretto was defined originally by Allen (1919) as a post-Curry unit preserved only locally; in most places it was removed by erosion prior to disposition of the overlying Goodrich quartzite or equivalent rocks. The existence of the Loretto is confirmed by more recent studies (R. W. Bayley, 1957 written communication).

The type locality of the Felch schist, here changed to the Felch formation, is in the Felch Mountain district of central Dickinson County, where the designated strata occur between the Randville dolomite and the Vulcan iron-formation. In the Menominee district the term Felch formation is applied to the distinctive sericitic slate-quartzite sequence which similarly lies above the Randville dolomite and below the Vulcan iron-formation, and which has been previously referred to as "Traders quartzite" (Bayley, W. S., 1904), and "Footwall slate" (Dutton, C. E., and Lamey, C. A., 1939). The Felch formation, according to Leith, Lund, and Leith (1935), is probably equivalent to the Palms quartzite of the Gogebic district, and to the Ajibik quartzite and Siamo slate of the Marquette district.

BARAGA GROUP

The Baraga group, here named for Baraga County in which the rocks of this group are widely exposed, comprises most of the strata referred to as Upper Huronian of previous reports, namely, (a) Goodrich quartzite (basal formation), and (b) Michigamme slate, the lower part of which in the Marquette district includes the Bijiki iron-formation member, the Clarksburg volcanics member, and the Greenwood iron-formation. In Iron and Dickinson Counties six formations are represented—Goodrich quartzite (lowermost unit), Hemlock formation, Fence River formation, and its probable correlative, the Amasa formation Michigamme slate, and Badwater greenstone (uppermost unit).

GOODRICH QUARTZITE

Within the area of this report, the Goodrich has been recognized only in the Kiernan quadrangle of northeastern Iron County (Gair and Wier, 1956, p. 34–39), but local beds of conglomerate overlying the Vulcan iron-formation in the Menominee district (Allen, 1920) might well be assigned to this unit, as they occupy a position at the base of the Michigamme slate entirely comparable to that of the Goodrich quartzite of the type area in the Marquette district.

HEMLOCK FORMATION

The Hemlock, named by Clements and Smyth (1899a, pt. 3, 19th Ann. Rept., p. 45–63) for extensive exposures of volcanic rocks along the Hemlock River in northeastern Iron County, has been considered to be Middle Huronian in most previous reports. This assignment was made on the basis of relationships in the Michigamme Mountain area of the Kiernan quadrangle, where it was believed that the volcanic rocks were stratigraphically between the Randville dolomite and a Middle Huronian iron-formation (Clements and Smyth, 1899b, p. 453–456). Gair and Wier (1956, p. 41–57) have since shown, however, that the volcanic rocks that correlate with the Hemlock actually overlie the iron-rich strata (the latter redefined as a highly ferruginous facies of the Goodrich quartzite rather than Negaunee iron-formation) so that the previous assignment is no longer considered valid.

The Hemlock, though several miles thick in its type area on the west flank of the Amasa oval, is not a persistent unit. On the east flank of the oval, the thickness is 3,000 feet or less, and the formation is missing entirely in most of Dickinson County. These variations in thickness are original, not the result of later erosion.

The Hemlock formation consists largely of metamorphosed basaltic rocks, but interbedded sedimentary strata occur in many places. Two of these sedimentary units are sufficiently different and continuous to warrant distinction as members. The Mansfield iron-bearing slate member (Van Hise and Leith, 1911, p. 291–296), named for the Mansfield mine in eastern Iron County, consists in part of chert-siderite iron-formation and in part of slate, with a maximum thickness of about 500 feet (R. W. Bayley, 1956, p. 68). The member occurs within the lower third of the Hemlock formation.

The second member, here designated the Bird iron-bearing member, lies about 1,300 feet below the top of the Hemlock formation in eastern Iron County. The member attains a maximum thickness of 300 feet in sec. 13, T. 43 N., R. 32 W. at the Bird Exploration, for which it is named. At this locality the rock exposed in trenches and test pits consists of oölitic hematite-chert, highly ferruginous quartzite and schist, and a distinctive breccia made up of angular chert and jasper fragments in a matrix of hard blue hematite. The member is overlain and underlain by greenstone.

FENCE RIVER FORMATION

The Fence River formation was named by Gair and Wier (1956, p. 57). In previous reports this unit was assigned to the middle Huronian Negaunee iron-formation (Leith, Lund, and Leith, 1935). It is exposed only in sec. 21, T. 45 N., R. 31 W. but it is magnetic and has been traced for many miles on the east flank of the Amasa oval by magnetic surveys. The Amasa formation, which flanks the west side of the oval, probably is correlative with the Fence River, but the connection has not been completely traced.

The Fence River formation is not known to be present much south of the Amasa oval. Its absence (in part at least) is believed due to post-Fence River, pre-Michigamme erosion.

AMASA FORMATION

The belt of iron-rich strata that overlies the Hemlock formation and flanks the Amasa oval on the west side was referred to the Vulcan iron-bearing member of the Michigamme slate by Van Hise and Leith (1911, p. 298–299), and was believed by them to be areally continuous with the iron-formation at the Dunn and Mastadon mines south of Crystal Falls. Stratigraphically the strata lie between the Hemlock formation and the Michigamme slate, and it is now known that the formation correlates with neither the Vulcan (Negaunee) of the type area nor the strata near Crystal Falls (Gair and Wier, 1956, p. 58; Pettijohn, 1947). It occupies the same stratigraphic position as the Fence River formation, but direct equivalence has not yet been proved.

The iron-rich strata were named the Amasa formation by Royce (1936, p. 86), for the town of Amasa which is about centrally located on the belt. Royce states that the Amasa formation "* * * is separated by a conglomerate from the overlying Upper Huronian slates [Michigamme slate of this report]; intimately associated with contemporaneous volcanics, called the Hemlock volcanics, at its base." Ore has been mined from the formation at the Hemlock, Michigan, Warner, Porter, Hollister, McDonald, Armenia, Lee Peck, Cayia, and Hope mines—all, except the Warner, now abandoned and inaccessible. The formation contains a wide variety of rocks—pyritic slate, ferruginous slate and quartzite, chert, and cherty hematitic iron-formation—that were in part clastic and in part chemical sediments. The aggregate thickness of the ferruginous strata reaches a maximum of about 1,500 feet in secs. 13, 14, 23, 24, and 26, T. 43 N., R. 32 W.

MICHIGAMME SLATE

The Michigamme slate is the most extensive formation of the Animikie series in northern Michigan. It is the only formation that is physically continuous between most of the districts. Reliable estimates of thickness are not easily made, but present evidence indicates a maximum thickness of about 5,000 feet in Iron and Dickinson Counties; locally it may be much less, and in some places the formation is absent. Most of the rock is monotonously interbedded slate and graywacke or their more highly metamorphosed equivalents, but iron-rich beds of apparently local extent occur in the uppermost part of the formation.

BADWATER GREENSTONE

Large areas of southern Iron County, northern Florence County (in Wisconsin, immediately south of Iron County, Mich.), and southwestern Dickinson County are underlain by greenstone. The formation is here named the Badwater greenstone for the extensive exposures in secs. 1, 2, and 11, T. 40 N., R. 31 W., in the vicinity of Badwater Lake, southern Dickinson County. The greenstone in the adjacent area of southeastern Iron County, Dickinson County, and Florence County (Wisconsin) has been referred to as the Mastadon-Spread Eagle-Lake Antoine belt (Leith, Lund, and Leith, 1935, p. 4). The greenstone in the eastern part of this belt was assigned to the Archean by Bayley (1904), but in Monograph 52 (Van Hise and Leith, 1911, p. 345) the statement is made:

> This area of schists at the time the Menominee monograph was written, was supposed to be equivalent in age to the Quinnesec schist of Menominee River, then regarded as Archean. Later work by G. W. Corey and C. F. Brown (unpublished field notes, 1905) has shown that they are really intrusive and extrusive in the upper Huronian or in part contemporaneous flows.

Leith, Lund, and Leith (1935) doubtfully assigned the greenstone to the Middle Huronian.

Detailed mapping in the northern part of the Menominee district by C. A. Lamey, and in the Commonwealth quadrangle of southern Iron County and adjoining areas of Wisconsin south of the Brule River by C. E. Dutton, K. L. Wier, and the writer has demonstrated that the greenstone is stratigraphically above the Michigamme slate. The conclusion as to relationship is based on many top directions established by graded bedding in the Michigamme and ellipsoidal structures in the greenstone. This relationship is of critical importance in that it establishes the position not only of the greenstone but of the sequence of rocks that overlies it in the Florence district of Wisconsin and the Iron River–Crystal Falls district of Michigan.

The maximum thickness attained by the Badwater greenstone is several miles (in the area bounding the Iron River–Crystal Falls district on the north), but such thicknesses are not maintained far along the strike. As the beds now exposed are about vertical, the map patterns are cross-sections of the original volcanic accumulations. They reveal great mound-like piles in which thicknesses of several miles diminish to the vanishing point within as little as 15 miles along the strike. The presence of ellipsoidal structures at many localities indicate that the greenstone is largely submarine in origin.

PAINT RIVER GROUP

The definition of the stratigraphic relationship between the Badwater greenstone and the Michigamme slate permits—or demands—redefinition of the stratigraphic position of the strata in the Iron River–Crystal Falls district. In previous reports these strata, which include productive iron-formation, generally were considered part of the Michigamme slate (Leith, Lund, and Leith, 1935). The Iron River–Crystal Falls district is a deep tightly folded major synclinal structure incompletely bounded by Badwater greenstone. In the area immediately east of Crystal Falls, greenstone is absent and the strata of the district proper rest directly on the Michigamme slate, which doubtless is the reason they were previously considered an extension of that unit. Recognition of the stratigraphic position of the Badwater greenstone forms the basis for definition of a new group, here named the Paint River group for the Paint River, which drains the northern and eastern part of the district. The five formations that comprise the group are the youngest strata of the Animikie series in Iron and Dickinson Counties, and probably are the youngest Animikie strata preserved in northern Michigan. Some of their characteristics have been described in previous papers (James, 1951, 1954).

DUNN CREEK SLATE

The basal formation of the Paint River group is a sequence of siltstones and slates here named the Dunn Creek slate. The name derives from Dunn Creek, in eastern Iron County south of Crystal Falls, in the vicinity of which are abundant exposures of the unit. The rocks in this area have been described by Pettijohn (1947). Much of the Dunn Creek is graywacke and slate that are physically indistinguishable from rocks of the Michigamme slate, but in the type area of eastern Iron County the formation is thicker and more complex; it contains one or more layers of slaty sideritic iron-formation. The probable maximum thickness is about 800 feet; the probable minimum, about 400 feet.

The uppermost part of the Dunn Creek, immediately underlying the productive iron-formation, is a black pyritic graphitic slate, probably 30 feet or less in true thickness but commonly much greater or less because of squeezing and shearing. The rock typically contains 35 to 40 percent pyrite, extremely fine grained, and 5 to 10 percent free carbon (James, 1951). This distinctive rock is exposed at only one place, a road cut south of the town of Alpha (Pettijohn, 1947; 1948), but is known from test pits, mine workings, and drill holes throughout the district. It is here named the Wauseca pyritic member, for the Wauseca mine at Iron River, in which the unit is exposed in thousands of feet of mine workings. The member itself is subdivided into two or three parts in the detailed geologic mapping of the mines. One of these subunits is of particular interest. It is a chaotic breccia that ranges from a foot or so to about 50 feet in thickness and is composed of small (less than 1 inch diameter) fragments of pyritic slate in a matrix of the same composition. The uniform composition of the rock, the complete lack of extraneous material, and its occurrence over distances measurable in miles strongly suggest that the rock is the product of a widespread submarine slump. If so, the unit is precisely time equivalent over the entire district.

RIVERTON IRON-FORMATION

The productive iron-formation of the Iron River–Crystal Falls district—the host rock for the ore bodies—is here named the Riverton iron-formation. The name is taken from the Riverton mine at Iron River, the first site of mining in the district about 75 years ago. The formation is visible in the walls of the caved workings of the old mine and the original discovery of iron in the district about 100 years ago was in one of the few natural exposures of the formation in the Iron River area, within a hundred feet of the old mine. Small exposures are widespread in the eastern part of the district (Pettijohn, 1947; Good and Pettijohn, 1949; Pettijohn, 1952), but much of the knowledge concerning the formation is derived from the hundreds of miles of mine workings and the thousands of diamond-drill holes that have intersected the rock.

The formation consists dominantly of interbedded chert and siderite. Its thickness ranges from less than 100 feet in the western part of the district to about 600 feet in the eastern part. Locally the upper part of the formation is absent because of erosion prior to deposition of the overlying Hiawatha graywacke, but most of the variation in thickness is to be ascribed to the nature of sedimentation.

HIAWATHA GRAYWACKE

Overlying the Riverton iron-formation, locally with minor unconformity, is a unit of clastic rock, here named the Hiawatha graywacke. The name is taken from the Hiawatha mine at Iron River, near which the rocks are exposed in scattered outcrops and in which the formation is crossed by extensive mine workings. As the name implies, graywacke is the dominant rock, but it is interbedded with considerable amounts of slate, particularly in the western part of the district. The lower part of the formation quite commonly is a breccia that consists of scattered angular chert fragments in a graywacke matrix (see photographs in James, 1951, pl. 2). This rock is locally well exposed along the course of the Paint River at the north edge of the town of Crystal Falls (Pettijohn, 1952).

The formation ranges in thickness from 50 feet or less in the eastern part of the district to 400 feet or more in the western part—the reverse of the thickness aspect of the underlying Riverton iron-formation. The formation also becomes more arkosic in composition toward the west.

STAMBAUGH FORMATION

The strata here named the Stambaugh formation are iron-rich rocks that range from chlorite mudstone and slate to a laminated cherty siderite-magnetite rock. The distinctive feature of the formation is that it is magnetic (the only formation that is consistently so over most of the district) and as a result can be traced by magnetic methods. Tedious though the magnetic surveying is, it has been of inestimable value in working out the map patterns in this structurally complex area of poorly exposed rocks. The distribution of the magnetic slate, as it is called locally, is better known than that of any other unit in the district.

The formation is named for the town of Stambaugh, in the western part of the district. The hill on which the town is built is in large part underlain by the formation (here compressed into a tight complex syncline) and numerous small exposures can be seen on the grounds of the Stambaugh High School. Better exposures are present in the eastern part of the district (Pettijohn, 1947; 1952), but like most units of the Paint River group, a large part of the information has come from mining explorations and developments.

FORTUNE LAKES SLATE

The strata underlying the central part of the Iron River–Crystal Falls synclinal basin are very poorly known, but they underlie a larger area than any other unit of the Paint River group. The main areas of exposure are between Crystal Falls and Fortune Lakes, for which the unit here is named, and in the area between Alpha and the Brule River. The exposed rocks consist mostly of slate and minor graywacke, with characteristic thin beds (10 feet or less) of coarse massive graywacke about 300 feet above the base. Sideritic slate is present in some areas between Crystal Falls and Alpha, and in one exposure near Fortune Lakes oxidized chert-siderite rock (iron-formation) is present. The character of the bulk of the formation is not known, however, because of lack of exposure.

The aggregate thickness of the unit probably is at least 4,000 feet. This estimate is based on structural inferences rather than any measured thickness.

MIDDLE PRECAMBRIAN IGNEOUS ROCKS

The Middle Precambrian igneous rocks of northern Michigan fall into two principal groups—metadiabase and metagabbro of Animikie or post-Animikie age, and granite and allied rocks that are younger than the metadiabase and metagabbro. Other Animikie or post-Animikie igneous rocks appear to be exceedingly scarce.

The metadiabase and metagabbro were metamorphosed during the post-Animikie, pre-Keweenawan interval (James, 1955). Several large bodies of metagabbro have been mapped; one, the West Kiernan sill (Gair and Wier, 1956; R. W. Bayley, 1956) of the Lake Mary and Kiernan quadrangles of eastern Iron County, is a differentiated sheet, now vertical but originally horizontal, that is about a mile thick.

The granitic rocks are believed relatively minor in surface expression but are widely distributed. Narrow dikes of granite and pegmatite are common in the Felch area (where they cut Animikie strata as well as older rocks) and a complex mass, perhaps several miles across, occurs in the southern part of the Lake Mary quadrangle of eastern Iron County (R. W. Bayley, 1956).

The existence of post-Animikie granite in northern Michigan has been known almost since geologic work was begun more than a hundred years ago, but considerable debate has arisen as to its extent. Lamey (1931, 1933, 1934, 1937) contended that some of the large areas of granitic rocks regarded by others as pre-Huronian (pre-Animikie of this report) are in fact post-Huronian, and introduced the term Republic granite for the rock between Republic and the Marquette district (1933). In subsequent papers he extended this term and concept to include the large areas of granitic rock in Dickinson County (Lamey, 1934; 1937). Dickey (1936) took issue with this conclusion and reaffirmed a pre-Huronian age. Later Dickey (1938), on the basis of the intrusive relationships of granite to quartzite in the Ford River area of northern Dickinson County, introduced the possibility of a post-Lower Huronian granite (post-Chocolay of this report) for the Republic granite. At that time, however, Dickey was not aware of the existence of the pre-Animikie sedimentary sequence in the Norway Lake area (Clark, 1953) a few miles south of the area studied by him. The Ford River area has been examined by the writer and his colleagues. The quartzite referred to by Dickey almost certainly is pre-Animikie rather than Sturgeon, and the pre-Animikie age for the granitic rock was established by finding an exposed unconformable contact of Randville dolomite on the granite in the NE¼SE¼, sec. 15, T. 43 N, R. 29 W.

Pettijohn's conclusions (1943) on the age relations of the main bodies of granitic rock in southern and central Dickinson County have been borne out by the detailed mapping of the area by the U. S. Geological Survey, in which Dr. Lamey has participated. These conclusions are in essential agreement with the earlier studies summarized by Van Hise and Leith (1911), but the detailed mapping has also shown that post-Animikie granite is more abundant than previously recognized.

The Republic area has not been mapped in detail during the present study, but a study of the metamorphism of northern Michigan (James, 1955) indicates that in the type area of the Republic granite described by Lamey the main mass of the granite is not post-Huronian (post-Animikie) but rather is pre-Animikie, although some post-Animikie granite is present. With Lamey's concurrence, it is recommended that the term Republic granite be abandoned because of the practical difficulty in distinguishing older from younger granite.

Measurements of absolute age have been made on several samples of the post-Animikie granite of Michigan by the lead-alpha (zircon) method, the potassium-argon method, and the strontium-rubidium method. Determinations by the lead-alpha method on zircon concentrated from a post-Animikie granite body near the town of Crystal Falls by H. W. Jaffe were earlier reported to yield an age of 820 million years (James, 1955, p. 1458). Potassium-argon determinations on post-Animikie granite from the Felch area were reported by Wasserburg, Hayden, and Jensen (1956, p. 158–159), as follows:

Locality	*Material*	*Branching ratio*	*Apparent age (million years)*
Pegmatite quarry in sec. 19, T. 42 N., R. 29 W., Dickinson County.	Muscovite	0.126	1,610
As above	Microcline	.085	1,490
As above	Microcline	.085	1,450
Groveland mine, sec. 31, T. 42 N., R. 29 W., Dickinson County.	Total granite (mica free).	.085	1,410

The value of the branching ratio (0.085) used by Wasserburg and his associates to compute the ages of the microcline and the granite is an empirical value assumed to correct for loss of argon. The value of 0.126 used for the mica determination is a maximum value and the age so computed is a minimum. Unpublished determinations made by L. T. Aldrich, G. W. Wetherill, and G. L. Davis by the strontium-rubidium method on micas from several samples of metamorphosed Animikie strata and from post-Animikie, pre-Keweenawan granitic rock yield values of about 1,400 million years, and feldspar from the same pegmatite reported on by Wasserburg, Hayden, and Jensen yields a value near 1,750 million years (L. T. Aldrich, oral communication, 1957).

Recent determinations by the potassium-argon method on rocks from the Lake Superior region have been reported by Goldich, Nier, and Baadsgaard (oral presentation and program abstract for the annual meeting of the American Geophysical Union, at Washington, D. C., April 29–May 2, 1957). Mica from granite near Crystal Falls, Mich., yielded an age of 1,700 million years, as computed using the branching ratio of 0.118 that now appears most suitable for mica. Baadsgaard, Nier, and Goldich (1957) also report determinations on microcline from Dickinson County, Mich., probably from the same localities from which the samples run by Wasserburg, Hayden, and Jensen (1956) were obtained. The values of A^{40}/K^{40} are closely comparable, but the age calculation using a branching ratio of 0.118 (as compared with 0.085 by Waserburg, Hayden, and Jensen) yields values of 1,210, 1,200, 1,220, and 1,210 million years. These values, considering the probable argon leakage, are likely to be significantly lower than the true ages.

The net results to date of work on absolute ages suggest that the age of the post-Animikie, pre-Keweenawan epoch of diastrophism, metamorphism, and granite intrusion is more than 1,400 million years. For comparison, the age of the Keweenawan or post-Keweenawan intrusive rocks (Duluth gabbro and related rocks) is about 1,100 million years (Goldich, Nier, and Baadsgaard, 1957). The term Killarney commonly has been applied to the post-Animikie, pre-Keweenawan granitic rocks in Michigan, but the validity of this designation is uncertain. Wetherill, Davis, and Aldrich (1957) report that the apparent age of the Wavy Lake granite of Ontario, which is near the type area of Killarney, is between 1,000 and 1,100 million years. If this is actually the age of the Killarney granite proper, the post-Animikie, pre-Keweenawan rocks of Michigan are distinctly older, and the term Killarney is not applicable.

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