Geology of the Kelso Junction Quadrangle Iron County, Michigan

GEOLOGICAL SURVEY BULLETIN 1226

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

Geology of the Kelso Junction Quadrangle Iron County, Michigan

By KENNETH L. WIER

GEOLOGICAL SURVEY BULLETIN 1226

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

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1967

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

Library of Congress catalog-card No. GS 66-320

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

CONTENTS

ILLUSTRATIONS

[Plates in pocket]

TABLES

GEOLOGY OF THE KELSO JUNCTION QUADRANGLE IRON COUNTY, MICHIGAN

By KENNETH L. WIER

ABSTRACT

The Kelso Junction quadrangle covers about 51 square miles in eastern Iron County, which is in the northern peninsula of Michigan. The quadrangle is an area of low relief, most of whose bedrock surface is covered by Pleistocene glacial deposits which are known to be locally as thick as 175 feet.

Rocks of Precambrian age underlie the entire quadrangle and, in general, form subparallel belts that strike northwestward and dip steeply southwestward along the southwestern flank of an anticlinal structure known as the Amasa oval. Lower Precambrian Margeson Creek Gneiss is exposed in the northeast corner of the quadrangle as part of the inner core of the oval and is overlain by middle Precambrian strata of the Animikie Series which, from oldest to youngest southwestward across the quadrangle, are the Randville Dolomite of the Chocolay Group and the Hemlock Formation, Amasa Formation, Michigamme Slate, and Badwater Greenstone of the Baraga Group.

Sills and dikes of mafic rock intrude strata as young as Michigamme Slate, although some dikes in the Margeson Creek Gneiss may be of lower Precambrian age. The West Kiernan sill, an irregularly shaped intrusive body several thousand feet thick within the Hemlock Formation, apparently was differentiated while in a horizontal position, so that it now consists of a normal metadiabasic central part and locally an ultramafic basal zone and a granophyric upper zone. Quartz porphyry, a massive fine-grained rock which contains blue opalescent quartz phenocrysts, appears to intrude the Randville Dolomite.

The Margeson Creek Gneiss is mainly gray banded granitic gneiss and gray to pink nonbanded granitic rock of granodioritic to tonalitic composition. It is separated from the overlying middle Precambrian rocks by a major regional unconformity. Randville Dolomite, poorly exposed, is a relatively pure medium-grained dolomite which contains sparse quartz grains. The dolomite is inferred to cross the quadrangle as a belt 1,500–2,000 feet in width, but it may be thinner or missing locally because of post-Randville and pre-Hemlock erosion. The Hemlock Formation is about 15,000 feet thick, and consists mainly of metabasaltic flows and pyroclastics and minor amounts of rhyolitic and felsic flows and tuffs. Ellipsoidal and amygdaloidal structures are common. The Amasa Formation, which is known within the quadrangle only from drill explorations, is an iron-bearing sedimentary formation about 600 to possibly 1,000 feet thick. In the quadrangle it is mainly ferruginous slate and slaty and cherty iron-formation, although iron ore has been mined from the formation nearby. Locally, the Amasa Formation is apparently interbedded with the underlying volcanics of the Hemlock Formation. The Michigamme Slate is about 5,000 feet thick, and it probably unconformably or disconformably overlies the Amasa Formation. The few

exposures of Michigamme Slate are quartzose slate, but drilling data show the formation to be mainly slate and graywacke, locally ferruginous and possibly interbedded with volcanics. Badwater Greenstone, at least 5,000 feet thick, apparently conformably overlies the Michigamme Slate in the southwest corner of the quadrangle. Exposures are of massive fine-grained ellipsoidal metabasalt.

The gross structure within the quadrangle is simple. In general, steeply dipping strata occupy the position between the anticlinal core of the Amasa oval in the northeast corner of the quadrangle and the synclinal Iron River-Crystal Falls basin just southwest of the quadrangle. In the southwestern part of the area a northeast-trending fault shows a horizontal displacement of about ¼–½ mile, and in the east-central part of the area a small isolated anticline apparently brings Randville Dolomite to the erosion surface within a surrounding area of the Hemlock Formation. No other faults or folds have been recognized, but such structures may be the cause of the seemingly abnormal local thicknesses of some of the geologic units.

At least two periods of metamorphism are reflected in the rocks: (1) a lower Precambrian granitization-migmatization which formed the Margeson Creek Gneiss, and (2) a pervasive and widespread post-Animikie metamorphism, isotopically dated at about 1.8–2.0 billion years ago, which affected all the rocks. The regional metamorphism increases from chlorite grade in the southwestern part of the quadrangle to biotite grade in the northeastern part.

An aeromagnetic survey over the entire quadrangle and a ground magnetometer survey along the belt of the Amasa Formation show that magnetic anomalies are caused chiefly by metavolcanic flows and by pyroclastics of the Hemlock Formation. The Amasa Formation is virtually nonmagnetic.

Iron ore has been mined from the Amasa Formation both to the northwest and to the south of the quadrangle. Undiscovered iron deposits may be present within the quadrangle, but they likely would be small and of low grade, similar to those mined elsewhere from the formation. Under present mining conditions, such deposits probably would not be of economic value. The low metamorphic grade, the probable thorough oxidation of the iron-formation, and the thickness of the glacial cover combine to make the Amasa Formation uneconomic for "taconite"-type beneficiation.

INTRODUCTION

LOCATION AND EXTENT OF AREA

The Kelso Junction quadrangle covers an area of about 51 square miles in the east-central part of Iron County, Mich., between lat 46°07′30″ and 46°15′00″ N. and long 88°15′00″ and 88°22′30″ W. It includes most of T. 44 N., R. 32 W., the northern part of T. 43 N., R. 32 W., and narrow strips of adjoining townships on the north and west. The south edge of the quadrangle is less than 2 miles north of the city of Crystal Falls, and the west edge is about 3½ miles east of the town of Amasa. Kelso Junction, for which the quadrangle was named, is a rail junction in sec. 1, T. 43 N., R. 32 W., from which tracks of the Chicago, Milwaukee, St. Paul and Pacific R.R. branch northwestward across the quadrangle to Amasa and southwestward to Crystal Falls.

State Highway 141 crosses the southwest corner of the quadrangle, but the main access to the area is provided by several graded all-weather secondary roads that cross or penetrate much of the quadrangle. The northern part of the area is relatively inaccessible, but few places lie more than a mile from main roads, passable logging roads, jeep trails, or private roads to summer camps. Some areas bordering the backwaters of the Michigamme Reservoir, however, are more easily reached by boat than by road.

The location of the Kelso Junction quadrangle and its relation to the regional geologic features of the western part of the northern peninsula of Michigan are shown in figure 1.

TOPOGRAPHY AND DRAINAGE

The topography of the Kelso Junction quadrangle is typical of much of the glaciated area in this part of Michigan. Bedrock hills, ridges, and uplands, generally irregular in shape and partly or completely mantled with glacial debris, are separated by lower swampy areas and lakes. Many of the small swamps are at intermediate elevations. Undulate plains, kettle terrain, and eskers are characteristic of the areas of thicker glacial cover. In general, slopes are moderate, although steep rock bluffs are common in some of the outcrop areas. Most hills rise about 100–150 feet above the surrounding low areas, and relief within the quadrangle is about 260 feet. The highest elevations are hills and areas in the northern part of the quadrangle which are covered with glacial deposits and have elevations of 1,580–1,600 feet. The lowest elevations are somewhat less than 1,340 feet in areas where the Paint River leaves the quadrangle in sec. 17, T. 43 N., R. 32 W., and where the Michigamme River bends into the quadrangle in sec. 1, T. 43 N., R. 32 W.

Streams flow generally southeastward within the quadrangle and are part of the Menominee River system which empties into Lake Michigan. Deer River and its tributaries drain the northern and greater part of the quadrangle, the Paint River drains the southwestern part, and the Michigamme River drains a small area in the southeastern part. Glacial topography dominates the drainage pattern, although in places the major streams apparently are controlled by preglacial bedrock channels. Clements (1899, p. 32–36) has described the Deer River drainage in this area as typical of that on glaciated terrain.

About a dozen permanent lakes lie within the quadrangle and, including the west arm of Michigamme Reservoir, cover about 5 percent of the area. Only five of the lakes are larger than 40 acres, and the two largest, Light Lake and Liver Lake in the north-central part of the quadrangle, are each slightly more than 100 acres. In the east-central part of the quadrangle the west arm of the Michigamme Reservoir floods about 2 square miles along the lower valley of the Deer River.

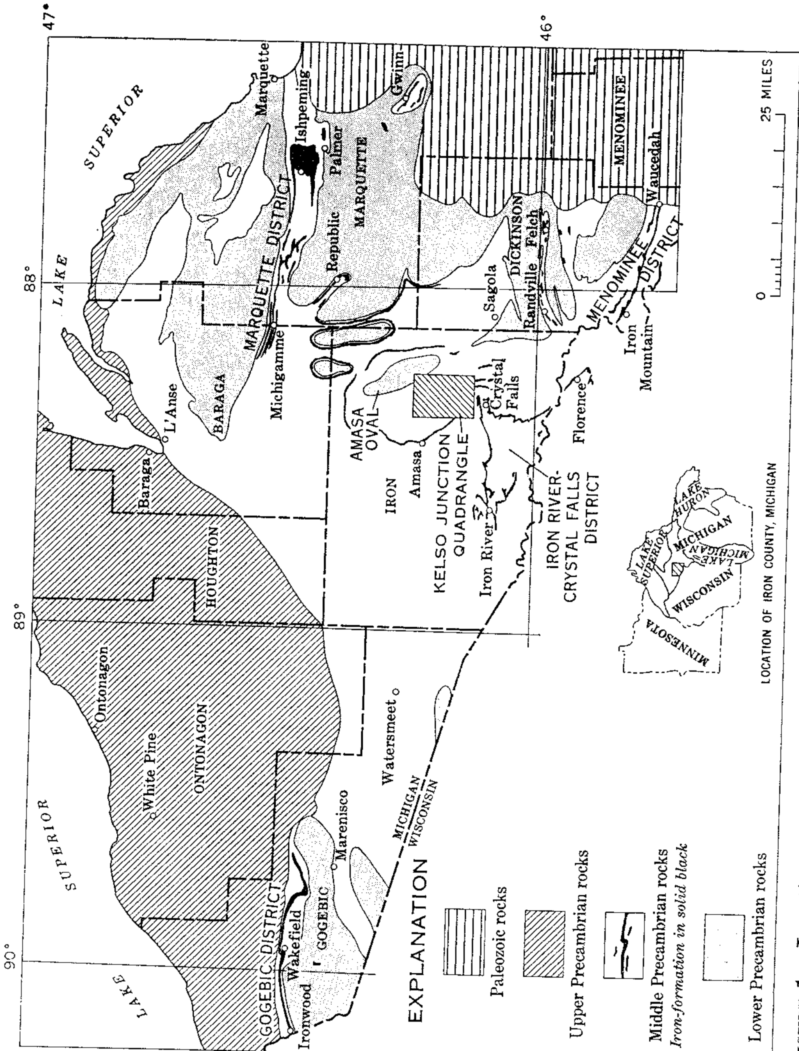

FIGURE 1.—Location of the Kelso Junction quadrangle and its relation to regional geologic features in the western part of the northern peninsula of Michigan.

Swamps are abundant and widespread, range in size from several acres to several hundred acres, and comprise about 20 percent of the land surface in the quadrangle. They commonly border lakes and streams or occupy the headwater areas of small tributaries to the main drainages. Several swamps which have resulted from perched water tables within clayey glacial till lie at intermediate to high elevations with respect to elevations of the streams. Some of the swampy areas and small lakes are in isolated local basins of interior drainage.

GLACIAL FEATURES

Glacial deposits, comprised of glacial till, moraine, or outwash in various thicknesses, mantle the bedrock over most of the quadrangle; bedrock exposures comprise from 10–15 percent of the area. Distribution of the various types of glacial deposits, as determined mainly by Bergquist (1932, 1935) and to a lesser extent by the author, are shown in figure 2. According to Bergquist, these deposits are probably of middle or late Wisconsin age and were associated with the Superior ice lobe.

Drilling in sec. 36, T. 44 N., R. 33 W., revealed that locally the glacial material is at least 175 feet thick. Discontinuous low ridges and rounded hills, generally of modest slope and separated by either low swampy ground or shallow kettle topography, characterize much of the glacial terrain. Bouldery clayey ground-moraine deposits are common in most of the central and northeastern parts of the quadrangle and make up most of the glacial material. The till is more sandy and less clayey in the northwestern part of the quadrangle, especially west of Deer River. Several steep-sided eskers trending southward to southwestward are also present in this vicinity. Sandy outwash covers much of the extreme southern part of the quadrangle. Striae on glacially polished rock exposures throughout the quadrangle indicate a southerly to southwesterly direction of the last ice movement.

PREVIOUS GEOLOGIC WORK

The first publication in which the geology of the Kelso Junction quadrangle was comprehensively described is U.S. Geological Survey Monograph 36, "The Crystal Falls Iron-Bearing District," written by J. M. Clements and H. L. Smyth and published in 1899; the monograph contains brief summaries of previous publications of studies on the geology of the area. In their monograph, Clements and Smyth defined principal stratigraphic formations and presented detailed descriptions of most of the rocks. They divided the Precambrian rocks in the area of the Kelso Junction quadrangle into two groups: older Archean crystalline rocks and younger Lower and Upper Huronian volcanic and sedimentary rocks; this grouping corresponded to the then-accepted division of the Precambrian in the more thoroughly studied Marquette area. If this classification were used, the Margeson

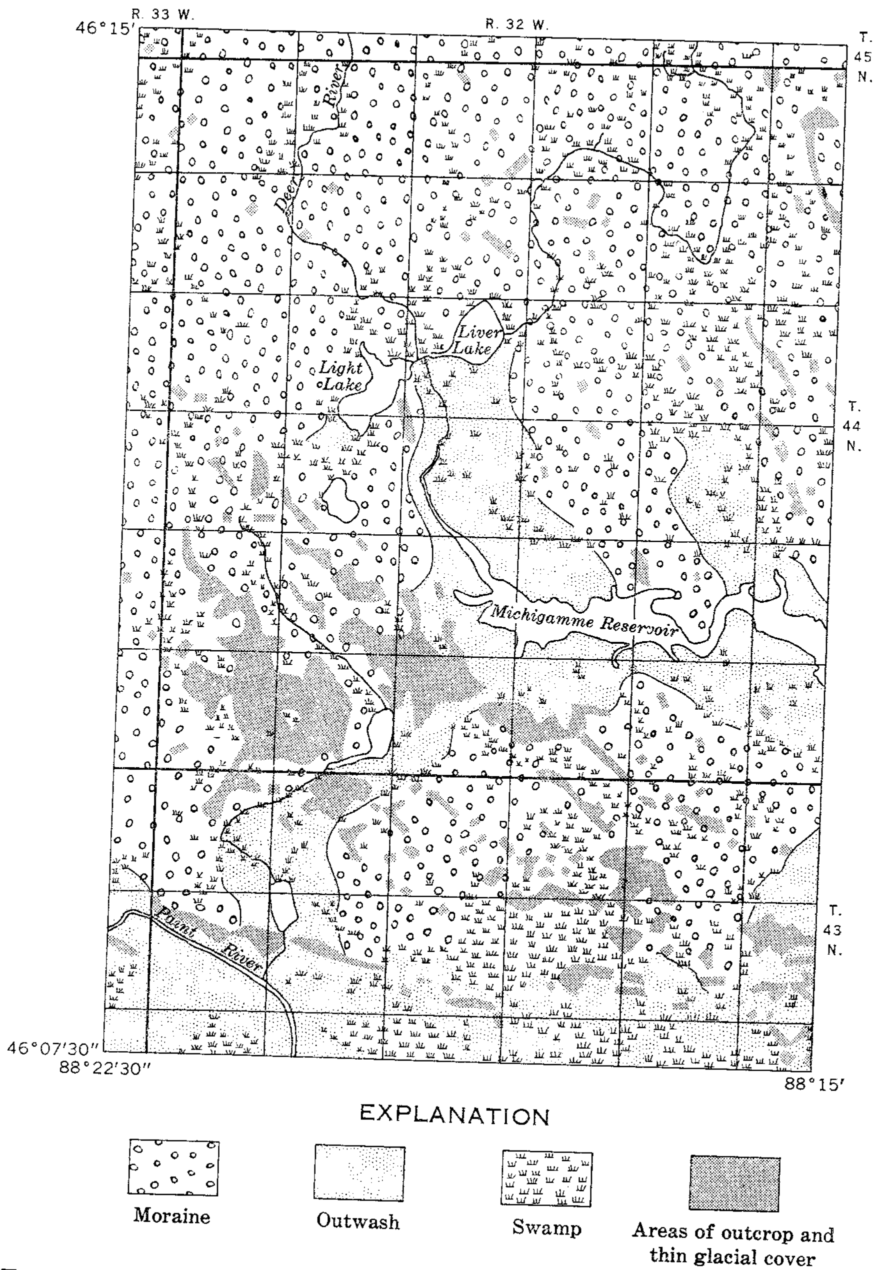

FIGURE 2.—Generalized areas of outcrops, swamps, and glacial deposits in the Kelso Junction quadrangle. Modified from Bergquist, 1935, map 36.

Creek Gneiss would be referred to the Archean, the Randville Dolomite and Hemlock Formation to the Lower Huronian, and the Michigamme Slate, together with the then-undifferentiated iron-bearing Amasa Formation, to the Upper Huronian.

Van Hise and Leith (1911) proposed a threefold division of the Huronian and placed the Randville Dolomite in the Lower Huronian, the Hemlock Formation in the Middle Huronian, and the Michigamme Slate along with the "Vulcan iron-bearing member" of the Michigamme Slate (now the Amasa Formation) in the Upper Huronian. They considered the "Vulcan iron-bearing member" equivalent to the Upper Huronian Vulcan Iron-Formation of the main Menominee iron district and of other districts in Dickinson County.

Allen and Barrett (1915, p. 25–29) supported the correlation of the "Vulcan iron-bearing member" near Amasa with the Vulcan Iron-Formation in Dickinson County, but they argued that both were equivalent to the Negaunee Iron-Formation and therefore Middle Huronian. This correlation was accepted until recently.

"The Geologic Map of Iron County, Michigan," compiled by L. P. Barrett, F. G. Pardee, and W. Osgood (1929), revealed the geology in much greater detail than had previously been shown. Changes that they made from previous maps of the Kelso Junction quadrangle included the addition of an interbedded slate in the Hemlock Formation (apparently projected from the southeast with no direct evidence for its presence within the quadrangle); a continuous belt of "Negaunee formation" and slate (the Amasa Formation) bordering the Hemlock Formation; inferred faults; and several minor changes in geologic contacts. This map was the first one published to show the metamorphic gradient of the area and to indicate the difference in age between the volcanic rocks of the Hemlock Formation and the volcanic rocks (Badwater Greenstone) in the southwest corner of the quadrangle.

Smaller scale geologic compilations by Leith, Lund, and Leith (1935) and Martin (1936) showed the geology in the quadrangle to be virtually as interpreted by Barrett, Pardee, and Osgood (1929). The formal classification advocated for the Precambrian rocks during this time (1929–36), as applied to the rocks in the quadrangle, can be summarized as follows: Granitic gneiss in the northeastern part of the quadrangle (Margeson Creek Gneiss) referred to Archean or Archean-type Laurentian granite; Randville Dolomite assigned to the Lower Huronian; Hemlock Formation or greenstone and Negaunee Iron-Formation and associated slates (Amasa Formation) assigned to the Middle Huronian; Michigamme Slate and associated volcanics (Badwater Greenstone) assigned to the Upper Huronian.

A general restudy of the iron-bearing districts of northern Michigan by the U.S. Geological Survey in cooperation with the Geological

Survey Division of the Michigan Department of Conservation was started in 1943. This work resulted in new geologic interpretations and in revisions of the correlation and terminology of the Precambrian rocks. Gair and Wier (1956) and Bayley (1959a) reported on the geology of the Kiernan and Lake Mary quadrangles, which are adjacent to the Kelso Junction quadrangle on the east and southeast; these reports include detailed descriptions of the rock units and stratigraphic succession and age correlations of the various formations, much of which information also applies to the geology in the Kelso Junction quadrangle. James (1958) introduced new formal names and summarized the stratigraphic nomenclature used by the U.S. Geological Survey for the Precambrian rocks that occur in this part of Northern Michigan. H. L. James, C. E. Dutton, F. J. Pettijohn, and K. L. Wier are preparing a professional paper on the geology and ore deposits of the Iron River-Crystal Falls mining district which in part pertains to the geology of the Kelso Junction quadrangle. A comparison of past and present stratigraphic nomenclature used in the quadrangle is shown in table 1.

TABLE 1.—*Comparison of past and present stratigraphic nomenclature in the Kelso Junction quadrangle*

Clements and Smyth, 1899 (age)	Clements and Smyth, 1899 (unit)	Van Hise and Leith, 1911 (age)	Van Hise and Leith, 1911 (unit)	Barrett, Pardee, and Osgood, 1929 (age)	Barrett, Pardee, and Osgood, 1929 (unit)	Present report (age)	Present report (unit)
Pleistocene	Undivided glacial deposits	Quaternary; Pleistocene	Undivided glacial deposits	Huronian	Diorite, Diabase, and Gabbro (Intrusives of uncertain age)	Precambrian; Middle Precambrian	Quartz porphyry, metagabbro, metadiabase, and associated intrusive rocks
Algonkian; Intrusive	Altered dolerite (diabase)	Algonkian; Huronian series; Upper Huronian	Greenstone intrusives and extrusives (not discriminated from Hemlock formation in all places)	Huronian; Upper Huronian	Michigamme Formation	Middle Precambrian; Animikie Series; Baraga Group	Badwater Greenstone
Algonkian; Upper Huronian	Undivided	Algonkian; Huronian series; Upper Huronian	Michigamme slate, including Vulcan iron-bearing member	Huronian; Upper Huronian	Volcanic rocks of Upper Huronian age. (Not separated from Hemlock Formation.)	Middle Precambrian; Animikie Series; Baraga Group	Michigamme Slate
				Huronian; Middle Huronian	Slate (stratigraphically above and below Negaunee Formation)	Middle Precambrian; Animikie Series; Baraga Group	Amasa Formation
Algonkian; Lower Huronian	Hemlock formation	Algonkian; Huronian series; Middle Huronian	Hemlock formation (volcanic) including iron-bearing slate member	Huronian; Middle Huronian	Negaunee Formation (Iron bearing)	Middle Precambrian; Animikie Series; Baraga Group	Hemlock Formation
Algonkian; Lower Huronian	Mansfield slate			Huronian; Middle Huronian	Hemlock Formation (volcanics with Interbedded Slates of both Middle and Upper Huronian age)	Middle Precambrian; Animikie Series; Chocolay Group	Randville Dolomite
Algonkian; Lower Huronian	Randville dolomite	Algonkian; Huronian series; Lower Huronian	Randville dolomite	Huronian; Lower Huronian	Randville Dolomite	Precambrian; Lower Precambrian	Margeson Creek Gneiss
Archean	Granite	Archean; Laurentian series	Granites and gneisses	Archean	Granite		

WORK METHODS AND ACKNOWLEDGMENTS

The Kelso Junction quadrangle was mapped geologically on 1:12,000 enlargements of the standard 7½-minute topographic map published in 1947 by the U.S. Geological Survey. Fieldwork was done at various times from September 1956 through October 1959. Outcrops were located with respect to topographic or cultural features by pace-and-compass traverses, which were spaced closely enough so that almost every rock exposure is believed to have been found. All known outcrops are shown on the geologic maps and are probably correctly located to within 100 feet. A magnetometer survey was made along the belt of Amasa Formation across the entire mapped area.

Various mining companies helpfully provided maps and drill records and permitted access to drill cores. The cordial cooperation given by individual landowners and by personnel of the M. A. Hanna Co., Pickands Mather & Co., and the Oliver Iron Mining Co. is gratefully acknowledged. Mr. Roger A. Solberg assisted in the magnetic survey for several months in the early part of 1959.

GENERAL GEOLOGY

STRATIGRAPHY

Except for Pleistocene glacial deposits, the Kelso Junction quadrangle is underlain entirely by rocks of early and middle Precambrian age. Lower Precambrian rocks are represented by the Margeson Creek Gneiss, which is present at bedrock surface only in the extreme northeastern part of the quadrangle. Overlying the gneiss are metasedimentary and metavolcanic rocks of middle Precambrian age, which in upward succession toward the southwest are the Randville Dolomite, the Hemlock Formation, the Amasa Formation, the Michigamme Slate, and the Badwater Greenstone. Under the present U.S. Geological Survey terminology as outlined by James (1958, p. 30), these middle Precambrian rocks are all of the Animikie Series—the Randville Dolomite referred to the Chocolay Group and the other units to the Baraga Group. The Menominee Group, which elsewhere in northern Michigan separates the Chocolay and Baraga Groups, is absent from this area. Unconformities are known or inferred between the Margeson Creek Gneiss and the overlying rocks and between the Randville Dolomite and the Hemlock Formation. Minor stratigraphic breaks may exist between some of the other formations. Middle Precambrian igneous rocks, now mainly metagabbro and metadiabase, intrude some of the Animikie formations. Much of the intrusive rock is the western part of the West Kiernan sill (Gair and Wier, 1956; Bayley, 1959a), but separate dikelike or sill-like bodies are present. Minor mafic dikelike masses (some of which may be inclusions) of unknown age occur in the Margeson Creek Gneiss. The stratigraphic and lithologic relationships of the rocks in the quadrangle are shown in table 2. The general geology of the quadrangle is shown on plate 1.

STRUCTURE

The gross structure within the quadrangle is simple. Northeast of the quadrangle the Margeson Creek Gneiss forms the central core of the Amasa oval, a domal uplift, and the overlying Animikie rocks flank the oval in subparallel belts that within the quadrangle generally strike northwestward and dip steeply southwestward. The Iron River-Crystal Falls basin lies directly to the southwest, and the belt of Badwater Greenstone can more properly be considered part of that synclinal structure. Geologic trends in the quadrangle range from about N. 45°–60° W. in the northern part, and locally from east-west to north-south in the southern part. The abrupt change in strike of the Amasa and adjacent formations in the southeastern part of the area is undoubtedly related to the sharp folding at the Crystal Falls apex of the Iron River-Crystal Falls basin. The general divergence of strike may be caused in part by the wedgelike body of the Hemlock volcanics and possibly by local displacement caused by the intrusion of

TABLE 2.—*General succession of geologic units in the Kelso Junction quadrangle*

System and series	Geologic unit	Estimated thickness (feet)	Remarks
Quaternary; Pleistocene	Glacial deposits	0–200(?)	Till, moraine, and outwash of probable Wisconsin age. Glacial material, swamps, and lakes cover 85 percent of quadrangle.
		Unconformity	
Precambrian; Middle Precambrian; Intrusive rocks	Metagabbro and metadiabase		Mainly medium- to coarse-grained dikes and sills. Intrudes rocks as young as Michigamme Slate. Includes differentiated West Kiernan sill, which contains ultramafic, pegmatitic, and granophyric parts. Mafic dikes in Margeson Creek Gneiss may be lower Precambrian.
Precambrian; Middle Precambrian; Intrusive rocks	Quartz porphyry		Massive fine-grained rock which contains blue opalescent quartz phenocrysts. Appears intrusive into Randville Dolomite.
Precambrian; Middle Precambrian; Animikie Series; Baraga Group	Badwater Greenstone	5,000±	Massive fine-grained metabasalt; commonly contains ellipsoidal structures. Present only in southwest corner of quadrangle.
Precambrian; Middle Precambrian; Animikie Series; Baraga Group	Michigamme Slate	5,000	Only outcrops in quadrangle are of thinly banded gray quartzose slate. Known from drill core and exploration records to be mainly slate and graywacke. May contain some interbedded metavolcanic rocks.
		Local unconformity	
Precambrian; Middle Precambrian; Animikie Series; Baraga Group	Amasa Formation	600–1,000	Known in quadrangle only from drill records. Mainly ferruginous slate and minor amounts of cherty iron-formation; locally oolitic. Iron ore mined from this formation but not within quadrangle.
Precambrian; Middle Precambrian; Animikie Series; Baraga Group	Hemlock Formation	15,000	Mainly metabasaltic flows and pyroclastics. Some interbedded sedimentary rocks and minor felsic and rhyolitic metavolcanics. Amygdaloidal and ellipsoidal structures common. Pyroclastics are mainly coarse fragmental breccias, but fine-grained tuffs also are present.
		Unconformity	
Precambrian; Middle Precambrian; Animikie Series; Chocolay Group	Randville Dolomite	1,500–2,000(?)	Known in quadrangle from several small exposures. Medium-grained dolomite with scattered quartz grains.
		Unconformity	
Precambrian; Lower Precambrian	Margeson Creek Gneiss	Unknown	Mainly banded granitic gneiss and nonbanded granitic rock. Present only in northeast corner of quadrangle.

the West Kiernan sill and related masses. A northeast-trending fault in the southwestern part of the area apparently offsets adjacent strata horizontally to almost half a mile. Repetition of the Hemlock Formation or of the intrusive rocks by folding or faulting possibly may account for the seemingly abnormal local thickness of these units.

METAMORPHISM

At least two epochs of regional metamorphism affected the rocks within the quadrangle. Before deposition of the Animikie strata intense metamorphism of lower Precambrian rocks either by igneous intrusion or by migmatization, or by both, produced the Margeson Creek Gneiss.

The latest regional metamorphism was of post-Animikie age, and affected all the Animikie rocks as well as the products of the earlier metamorphism. James (1955) has delineated regional metamorphic zones throughout this part of the northern peninsula of Michigan and has described typical mineral assemblages for the various zones. Within the quadrangle the metamorphic grade increases from the chlorite zone in the southwestern part of the area to the biotite zone in the northeastern part. These zones correspond, respectively, to the muscovite-chlorite subfacies and the biotite-chlorite subfacies of the greenschist facies of the basic igneous rocks of Eskola (1920) and of Turner (1948). That the increase in metamorphic grade northeastward toward the Margeson Creek Gneiss is not related to the igneous aspect of that rock is shown by James' study of the larger surrounding area. The widely distributed mafic igneous rocks in the quadrangle provide good examples of the metamorphic gradient. The approximate contact between the chlorite and biotite metamorphic zones is shown on plate 1.

Isotopic age determinations of metamorphic minerals from rocks of the Animikie Series from nearby localities outside the Kelso Junction quadrangle indicate that major post-Animikie regional metamorphism took place about 1,800–2,000 million years ago, and that minor metamorphic events occurred about 1,350 and 1,100 million years ago (Aldrich and others, 1965).

LOWER PRECAMBRIAN ROCKS, MARGESON CREEK GNEISS

Granitic gneiss underlies the extreme northeastern part of the quadrangle and is exposed in sec. 35, T. 45 N., R. 32 W., and secs. 1, 2, and 12, T. 44 N., R. 32 W. These rocks, which are described in Monograph 36 (Clements and Smyth, 1899), were named the Margeson Creek Gneiss by Gair and Wier (1956) from good exposures along Margeson Creek in the adjacent Kiernan quadrangle. The detailed description of the rocks given by Gair and Wier for the more abundant exposures in the Kiernan quadrangle applies equally well to the Margeson Creek Gneiss in the area of this report.

In the Kelso Junction quadrangle the extent of the gneiss is marked by a general topographic high. Outcrops are generally small and commonly form low isolated knobs; most are along the steeper hillsides

and at the upper change in slope of the high ground, but some are found on the hilltops and in valleys and swamps. Most of the exposed rock is either gray banded granitic gneiss or a more abundant gray to pink nonbanded granitic rock. Both types of rock are present in all the outcrop areas, but because of the close association of the two and because of the scarcity of exposures, they were not mapped separately.

BANDED GRANITIC GNEISS

The banded granitic gneiss consists mainly of alternating light- and dark-gray layers, which range in thickness from a small fraction of an inch to locally as much as 1 foot. Minerals are fine to medium grained, and within some of the layers there is a tendency toward finer compositional banding. Locally, individual layers have the appearance and composition of impure quartzite or graywacke. Biotite or hornblende, or both minerals in various proportions, are dominant in the darker layers and quartz and feldspar in the lighter ones. Composition of most of the banded gneiss ranges from granodioritic to tonalitic.

Exposures of banded gneiss are generally elongate parallel to the banding and range in size from irregular zones several tens of feet long to smaller patches a few feet long. In places the nonbanded granitic rocks sharply truncate the banded gneiss, but more commonly the granite appears to have a lit-par-lit relationship to the gneiss. The well-developed layering in the gneiss and its general composition suggest derivation from sedimentary rocks that were originally bedded.

NONBANDED GRANITIC ROCKS

The nonbanded granitic rocks are gray to pink on fresh surface and are mainly medium- to coarse-grained inequigranular granitic gneiss, which characteristically contains large tabular feldspar phenocrysts or metacrysts alined parallel to foliation. A minor amount of the medium-grained granitic gneiss is equigranular, and the equigranular and inequigranular parts are partly intermixed and apparently grade into each other.

Locally, the granitic rocks are not foliated. The nonfoliated rock, which may be either inequigranular or equigranular, commonly occurs in irregular patches that grade into foliated rocks, and in places, penetrates the foliated rocks as small stringers or lenses. Irregular, discontinuous quartz stringers, which are generally subparallel to foliation and which range in width from a fraction of an inch to as much as several inches and in length from several inches to several feet, are present in most of the exposures. As determined in thin section, the granitic rocks are mainly quartz monzonite or granodiorite, but they range in composition from granite to tonalite. Sodic plagioclase, microcline, and quartz are the dominent minerals. The large crystals of the equigranular rocks are characteristically sodic plagioclase, whereas the phenocrysts or metacrysts of the inequigranular rocks are microcline or, very rarely, albite.

MIDDLE PRECAMBRIAN ROCKS

RANDVILLE DOLOMITE

The Randville Dolomite was named by Smyth (Clements and Smyth, 1899, p. 50, 406) for exposures near Randville, Mich. Smyth (p. 431–432) also correlated exposures of dolomite bordering the Archean (Amasa) oval on the east and south with the Randville Dolomite. Within the Kelso Junction quadrangle a belt of Randville Dolomite is inferred to overlie the Margeson Creek Gneiss. The dolomite bordering the gneiss is known from two small exposures, one in the SW¼ sec. 1, T. 44 N., R. 32 W., within 400 feet of outcrops of gneiss, and the other in the NW¼ sec. 12, T. 44 N., R. 32 W., within 1,200 feet of outcrops of gneiss. Other isolated exposures of dolomite in the western part of sec. 36, T. 44 N., R. 32 W., apparently are entirely surrounded by metavolcanics of the Hemlock Formation, and therefore are believed to reveal an anticlinal structure.

Contacts of the Randville Dolomite with adjacent formations are not exposed in the map area, but from evidence outside the quadrangle the author believes that both the lower and upper contacts are unconformable or discomformable. On the basis of the known thickness of the Randville elsewhere, the width of the dolomite inferred on the map is as much as 2,000 feet, but its actual thickness in this area may be much less. The outcrop in sec. 1 is the northernmost exposure of dolomite on the west side of the Amasa oval, and the formation may thin or be missing entirely toward the north.

The dolomite in sec. 12 is exposed along a break in slope for a distance of about 100 feet, but individual outcrops do not exceed 20 feet and most are smaller. Much of the rock is in loose slabs or blocks, some as much as 15 feet in diameter, and a possibility exists that this entire occurrence of dolomite is glacially transported material. Nearby outcrops to the east and southeast, between this dolomite and the Margeson Creek Gneiss, are of fine-grained quartz porphyry. The quartz porphyry is considered to be intrusive into the Randville Dolomite; but it may be metarhyolitic flow rock near the base of the Hemlock, and if so, the exposed dolomite probably would be glacial erratics and the actual outcrop width of the Randville in this area would be less than 500 feet.

Weathered surfaces of the dolomite are deep buff to brown or gray. Some exposures are blocky in appearance because thin siliceous ribs and narrow shallow cracks, caused by differential weathering, are

closely spaced and are both parallel to and at angles to bedding. Locally, discontinuous quartz veins an inch or less thick cut irregularly through the dolomite. In secs. 1 and 12 the dolomite is relatively pure finely crystalline to dense, and on fresh breaks, light buff to pink. The dolomite in sec. 36 characteristically is gray and has fine silty seams along bedding. Locally, clastic quartz is dominant and the rock is a dolomitic quartzite. Fine-grained phases are slaty in appearance. Thin sections show thoroughly recrystallized mosaics of dolomite and scattered clastic quartz and feldspar grains.

HEMLOCK FORMATION

GENERAL FEATURES

The Hemlock Formation was named for exposures of metavolcanic rocks along the Hemlock River northeast of Amasa by Clements and Smyth (1899, p. 73). Leith, Lund, and Leith (1935) referred to the formation as Hemlock Greenstone, but Gair and Wier (1956) considered the term "greenstone" too restrictive and reinstated the term "formation."

The Hemlock Formation overlies the Randville Dolomite; and the Hemlock along with the West Kiernan sill and associated intrusive rocks underlies about 85 percent of the quadrangle area. Exposures of the upper part of the formation, in the southern and south-central parts of the quadrangle, are numerous; but those of the lower part, in the northern and northeastern parts of the quadrangle, are comparatively scarce.

The Hemlock Formation surrounds the Amasa oval in an asymmetrical belt. The formation attains a maximum mapped width of about 5 miles in T. 45 N., Rs. 32 and 33 W., north of the Kelso Junction quadrangle, where a possible maximum thickness of the metavolcanics was estimated by Clements (Clements and Smyth, 1899, p. 75) to be 23,000 feet. However, northward and southeastward from this area the formation thins gradually. The mapped width is less than 10,000 feet along the northern part of the Amasa oval, and it probably does not exceed 10,000 feet in the southern part of the Lake Mary quadrangle (Bayley, 1959a, p. 25). Eastward, across the Amasa oval, the formation thins within several miles to less than 2,500 feet. Where thinnest, it consists almost exclusively of flows, whereas on the west side, where thickest, pyroclastic rocks are common and in places are preponderant. Both the greater thickness and the pyroclastic lithology toward the west indicate proximity to centers of eruption. The maximum mapped width of the formation in the Kelso Junction quadrangle is about 35,000 feet, of which about 50 percent is probably intrusive rock. The stratigraphic thickness of the volcanics in this area is estimated at about 15,000 feet.

In the Kelso Junction quadrangle the Hemlock Formation consists mainly of altered basaltic lava flows and pyroclastic rocks and minor amounts of rhyolitic and felsic pyroclastics and flows, and very locally, of sediments derived from these volcanic rocks. Exposures of the lower part of the formation are relatively scarce. Near the base in secs. 13 and 14, T. 44 N., R. 32 W., they are of massive greenstone flows, in part amygdaloidal. Exposures of the upper part of the formation are numerous in the northern part of T. 43 N., R. 32 W., and in the southwestern part of T. 44 N., R. 32 W. They are predominantly of metabasaltic pyroclastics interbedded in varying proportions with greenstone flows, in part amygdaloidal; with ellipsoidal greenstone; with slaty bedded greenstone, probably mostly tuffaceous; and with felsic metavolcanic rocks. Intrusive mafic sills or dikes are also well exposed in this area. Schistose porphyritic metarhyolitic volcanic rocks are exposed in sec. 4, T. 44 N., R. 32 W. Exposures in the central part of the map area, in T. 44 N., are scarce and widely scattered. The extent of the Hemlock Formation in this central area is unknown but may not be great, for the few exposures are mainly of basic intrusives which in places contain patches or remnants of slaty greenstone.

Specific types of pyroclastic rocks were not separately distinguished during the present mapping. Much of the pyroclastic rock is a breccia composed of an unsorted mixture of rounded and angular fragments of various compositions that may have originated mainly as an agglomerate. Close association of the breccias with ellipsoidal flows and the common occurrence of zones and beds of moderately to well-sorted and rounded fragments indicate that at least in places the breccia accumulated in water. This is clearly shown in an outcrop area in the south-central part of sec. 19, T. 44 N., R. 32 W., where ellipsoidal flows are overlain toward the southwest by pyroclastic rocks. The lower part of the pyroclastic zone is in part rudely stratified and contains many well-rounded fragments of metabasaltic rock. In the well-bedded upper part some of the medium-grained beds are graded and some of the finer grained beds are crossbedded; both features indicate top directions to the southwest and corroborate the top directions shown by the ellipsoidal greenstone.

Individual tuff beds apparently are not extensive, for they can be traced for only short distances in exposures. Some of the thinner tuff layers may have been deposited as continuous beds on land and water, but the thicker layers probably represent ash falls and fine volcanic debris that were washed, after initial deposition, into small local sedimentary basins.

METABASALT

Metabasaltic flow rocks are widely distributed in the exposures of the Hemlock volcanics. They make up entire outcrop areas, are extensively interbedded with the other volcanic rocks, and locally are apparently engulfed in the mafic intrusives. Generally the metabasalt forms rounded to knobby outcrops, many of which have glacially smoothed surfaces. Weathered surfaces are dark green or gray to greenish black or brown, and freshly broken ones are generally lighter gray or green. Individual flows commonly are 10–50 feet thick, but they can be traced for only short distances. The lack of continuous exposures prevents determination of maximum thicknesses; some flows may be considerably thicker than 50 feet, but many of the flows interbedded with pyroclastics are thinner than 10 feet.

The metabasalt is generally massive and mainly fine grained to dense. Locally, the texture is coarsely diabasic or porphyritic. In places, variation in grain size that may indicate chilling of the tops or bottoms of flows was noted, but in most places it was uncertain whether such rock was an extrusive body or was an intrusive body such as a dike with chilled borders. Amygdaloidal flows are common, generally with the amygdales concentrated near one or both borders, or, less commonly, sparsely distributed within flows. Although in a few places the amygdales clearly mark flow contacts, flow tops cannot generally be determined with any degree of assurance from them. The amygdales, which are commonly composed of quartz, carbonate, or chlorite, range in diameter from about 0.1 inch to as much as 1 inch and commonly are 0.3–0.5 inch. Most are round or oval shaped, but some are distorted to elongated pods in slightly sheared flows and to indistinct smears or blebs in strongly sheared or schistose rocks.

Ellipsoidal structures, indicative of submarine extrusion, are common, especially in flows associated with the pyroclastics; top directions consistently are toward the southwest. In places, the ellipsoids occur in linear zones which are parallel to formational trends, and they probably represent stratigraphic horizons; but elsewhere, they are scattered and have no apparent continuity. Most ellipsoidal greenstone apparently grades into fine-grained metabasalts along strike and is commonly overlain by fragmental volcanic rocks or slaty greenstone of tuffaceous or sedimentary origin. Individual ellipsoids range in diameter from several inches to several feet, but they typically are from 1 to 2 feet. Cross-sectional outlines are generally more or less oval or are elongated "biscuits" which have rounded tops and almost flat bases. Ellipsoids may be either dense throughout or amygdaloidal, but the amygdales are generally concentrated near the edges and occasionally are most numerous near the original upper surface. Many of the ellipsoids contain filled joints, some of which are arranged in a radial pattern suggesting contraction cracks developed during cooling. Fine-grained material of lighter color than the main part of the ellipsoids, probably original palagonitic shells, separates the ellipsoids; these shells, 1 inch to rarely 1 foot thick, generally weather to grooves, but in places stand out as raised rims. Irregular pods of quartz commonly fill the triangular space at the junction of three ellipsoids, and thin, irregular, and discontinuous quartz veins are present in most of the outcrops of metabasalt. Ellipsoidal structures and amygdaloidal textures locally are obliterated by a strong east-west schistosity, particularly in the southeastern part of the quadrangle.

PYROCLASTIC ROCKS

Altered mafic pyroclastic rocks are the most common rocks exposed and apparently make up the greater part of the Hemlock Formation in this area. Altered felsic to intermediate pyroclastic rocks are locally abundant. Much of the rock is volcanic breccia,[1] and is so designated because most of the fragments exceed 1 inch in diameter. Tuffs or tuff breccias are widespread, but they make up only a very small percentage of the rocks.

VOLCANIC BRECCIA

The fragmental texture of the volcanic breccias is best seen on weathered surfaces. Fragments generally are subrounded to angular and range in size from fine ash to blocks several feet across. Some of the larger pieces are tabular slabs as much as 6 feet long. Much of the breccia is a heterogeneous mixture of fragments of different sizes. Those fragments about 1–3 inches in diameter are most abundant; locally, larger or smaller sizes may predominate. More rarely, layers several inches to several feet thick are made up of fragments of similar size. These beds are conspicuous, especially in contrast to adjacent beds that are poorly sorted, and clearly show the general bedding attitude of the volcanic rocks. The proportion of matrix material to coarse fragments differs greatly from place to place. In some places the breccia consists of tightly packed fragments with very little finer grained matrix; whereas in others the coarser fragments, although still constituting the greater volume of rock, are separated by large amounts of finer grained material.

Most fragments in the breccia are of dense metabasalt, although amygdaloidal rock is widely distributed and common, and locally is the principal type. Pieces of slaty greenstone are present, but they generally are scarcer and smaller than those of metabasalt or amygdaloidal rock. In a few places the breccia fragments are mainly of felsic rocks, and the matrix contains numerous crystal fragments and grains of quartz. Tuff breccias consisting chiefly of relatively fine-grained matrix material, and of fragments generally smaller than a quarter of an inch in diameter, make up a small percentage of the pyroclastics.

[1] The term "volcanic breccia" rather than "agglomerate" is used because the latter designation may imply a restricted mode of origin of the fragmental rocks.

TUFFS AND SLATY GREENSTONE

Fine-grained pyroclastics and layered dense greenstone, which probably originally were fine-grained tuff, are interbedded with the volcanic breccias and flows throughout the Hemlock Formation, but they represent only a minor part of that unit. The tuffaceous character is most obvious on weathered surfaces of the fine-grained pyroclastic that contains megascopic fragments. The slaty rocks commonly are thinly laminated—laminations about 1/16–1/4 inch thick making up beds of from several inches to several feet thick. In a few places, individual layers are 1/2–1 inch thick and form beds as much as 10 feet thick. The individual layers and laminations seem to be mainly color differences, but they may be the result of variations in grain size or composition. In some of the laminated or layered slaty greenstone a rude parting has developed parallel to bedding, and although much of the rock is dense and tough and has no pronounced schistosity, locally it is intensely sheared, so that original textures are obscured or obliterated. Slaty greenstone in sec. 10, T. 44 N., R. 32 W., is locally strongly contorted, and slaty cleavage is well developed across the bedding.

SCHISTOSE METARHYOLITE PORPHYRY

Good exposures in the southeastern part of sec. 4, T. 44 N., R. 32 W., and small outcrops in the north-central part of that section indicate that schistose metarhyolite porphyry occurs along a northwestward-trending zone for a distance of at least 1 mile, but the complete extent of this rock is not known. The metarhyolite probably was deposited as flows, or possibly in part as crystal tuffs, and is interbedded with the basaltic volcanics. In the Kiernan quadrangle to the east the Hemlock Formation is known to contain similar metarhyolite, and in the vicinity of Michigamme Mountain the metarhyolite makes up most of the formation (Gair and Wier, 1956, p. 51–54).

Clements and Smyth (1899, p. 87–94) described the schistose porphyry in sec. 4 in considerable detail. Almost all the exposed rock is conspicuously banded, but the individual layers rarely exceed a quarter of an inch in thickness and generally are about a sixteenth of an inch or less. In several places the rock is finely laminated and strongly resembles a metasediment. On weathered surfaces the layers range in color from light tans, reds, greens, and grays to bluish black, whereas on freshly broken surfaces the colors are generally of darker shades. In gross appearance the rock is very fine grained and dense.

Whole and broken crystals of pink and colorless feldspar, or less commonly of quartz, are scattered throughout the fine-grained schistose and layered groundmass. Locally, the crystals are abundant and constitute the greater part of the rocks, but, in general, they are subordinate to the groundmass. Most of the crystals are rounded and many appear to have been sheared into oval-shaped clumps around which the layering and foliation bend. A few of the oval areas are composed of aggregates of fragmented or recrystallized feldspar, mosaic quartz, or other metamorphic minerals in various combinations and proportions. Some may represent sheared amygdales.

Phenocrysts of potassium feldspar seem to be more abundant than those of plagioclase. Most are rounded blebs or have only vague crystal outlines, but a few exhibit good tabular form. The crystals are commonly about 1 mm long, or less, although a few are as long as 2 or 3 mm. The feldspars are altered and somewhat replaced by metamorphic minerals of which muscovite, sericite, chlorite, biotite, epidote, and iron oxides are most common. In places, secondary feldspar grains partially surround feldspar phenocrysts and fill the space between fragments of broken phenocrysts. Areas of quartz that appear to have been original crystals show strong strain effects or have recrystallized to mosaics.

The fine-grained groundmass is predominantly quartz intermixed with lesser amounts of feldspar or other minerals. Some mosaic-textured patches or blebs are almost pure quartz, and a few of these quartz-rich areas exhibit vague perlitic structures. Well-alined secondary micaceous minerals in the groundmass—muscovite, sericite, chlorite, and biotite—impart schistosity to the rock. Other secondary or accessory minerals include carbonate, epidote, leucoxene, sphene, rutile, apatite, iron oxides, and pyrite.

A chemical analysis of a typical specimen of schistose metarhyolite porphyry from sec. 4 is shown in table 3. Except for a relatively lower K:Na ratio, the analysis is similar to the analyses of metarhyolite from the Hemlock Formation in the Kiernan quadrangle (table 3, col. 3). The chemical composition is closely comparable to some compositions shown by Clarke (1924, p. 439–440) for rhyolites and quartz porphyries and to the average compositions listed by Daly (1933, p. 9). A semiquantitative spectrographic analysis of the schistose metarhyolite porphyry specimen is given in table 6.

AMASA FORMATION

Ferruginous strata which overlie the Hemlock volcanics along the west side of the Amasa oval were named the Amasa Formation by Royce (1936, p. 86) for the town of Amasa, which is about 3½ miles west of the northwest corner of the Kelso Junction quadrangle. This formation is probably correlative with the middle Precambrian Fence River Formation (Gair and Wier, 1956, p. 57), which occupies a similar stratigraphic position on the east side of the Amasa oval, but the connection around the oval has never definitely been made.

TABLE 3.—*Chemical analyses, in percent, of metarhyolite porphyry and quartz porphyry*

[n.d., not determined]

	1[1] (Lab. No. 157309)	2[1] (Lab. No. 157310)	3
SiO_2	72.7	71.9	74.20
Al_2O_3	10.1	11.6	12.33
Fe_2O_3	1.3	1.2	1.15
FeO	3.1	3.7	1.81
MgO	1.8	.5	.64
CaO	1.4	1.0	.38
Na_2O	1.0	2.4	.32
K_2O	3.9	4.3	6.82
H_2O	1.7	1.0	[2]1.18
TiO_2	.47	.45	.65
P_2O_5	.08	.09	.16
CO_2	2.1	.27	.25
MnO	.07	.06	.02
S	$<$.05	$<$.05	n.d.
Total	99.7	98.5	99.90

[1] Laboratory report No. WR-526.
[2] Sum of H_2O+ and H_2O-.

1. Field No. KW-19-60. Schistose metarhyolite porphyry from Hemlock Formation. Outcrop 600 ft north and 600 ft west of SE cor. sec. 4, T. 44 N., R. 32 W. Rapid-rock analysis; analysts: P. L. D. Elmore, I. H. Barlow, S. D. Botts, and Gillison Chloe, 1961.
2. Field No. KW-20-60. Quartz porphyry, believed intrusive into Randville Dolomite. Outcrop 400 ft south and 1,300 ft east of NW cor. sec. 12, T. 44 N., R. 32 W. Rapid-rock analysis; analysts: P. L. D. Elmore, I. H. Barlow, S. D. Botts, and Gillison Chloe, 1961.
3. Average of 4 analyses of metarhyolite from Hemlock Formation in Kiernan quadrangle (Gair and Wier, 1956, p. 54).

The Amasa Formation is not exposed within the Kelso Junction quadrangle and is known there only from exploratory drilling. The extent of the drilling for which reliable records are available is shown in figure 3. Except for the Lakeland and Crystal Falls explorations, which lie mainly within the Michigamme Slate, the drilling was directed toward exploration of the Amasa Formation.

All drilling except that of the McCusker exploration was diamond drilling, and logs for most holes are fairly detailed and include iron analyses of the sludge for each 5-foot run of the more ferruginous parts. However, records for some of the earlier drilling are brief and much generalized. Information about the McCusker churn-drill holes consists of a sketch map and a cross section showing the locations of holes with respect to a contact between ferruginous slate and greenstone and a single iron analysis for each of holes 2 through 13. Abbreviated drill core of the six Corcoran holes in sec. 6, T. 43 N., R. 32 W., and of the Lakeland holes in secs. 8 and 17, T. 43 N., R. 32 W., was examined; all other exploration data are from mining-company records.

In addition to this information, data for exploration in secs. 10, 14, and 15, T. 43 N., R. 32 W., were found on map compilations of unknown origin in mining-company files. This information consists

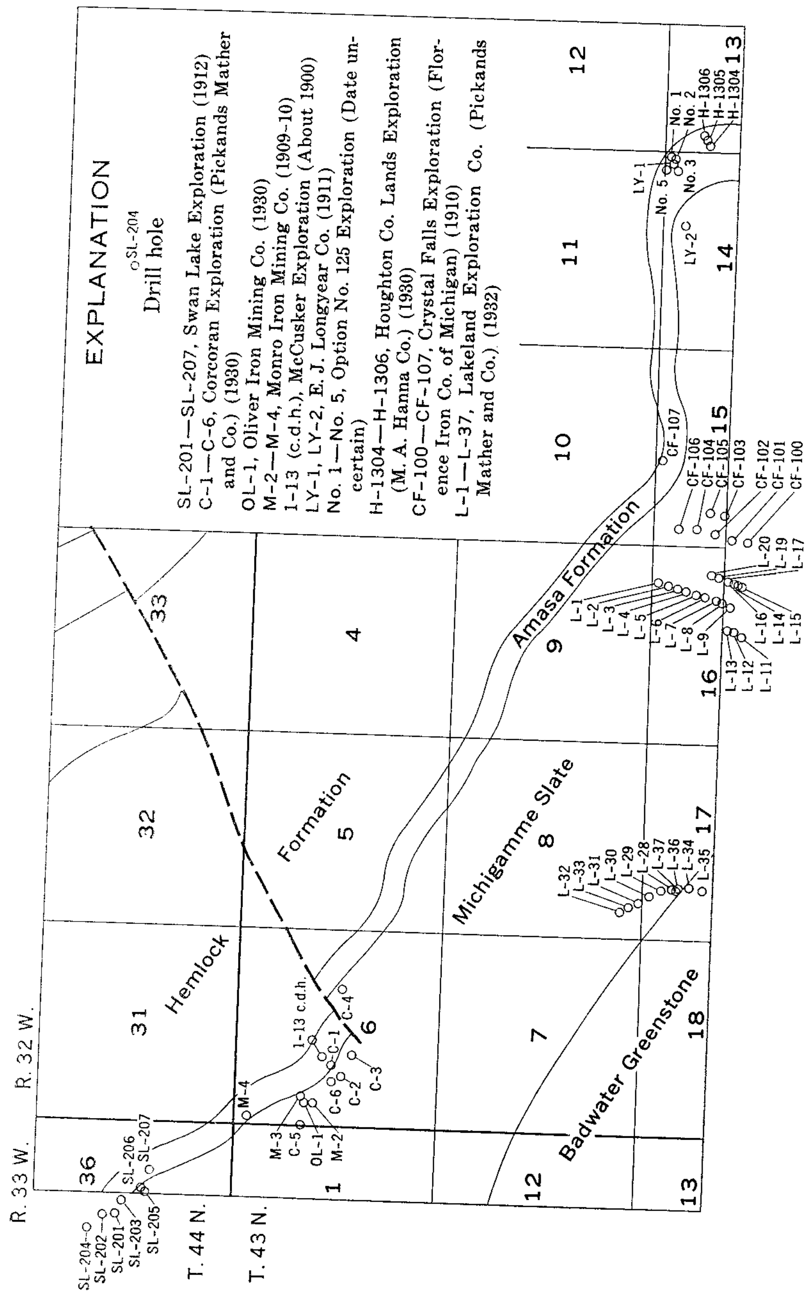

FIGURE 3.—Drilling explorations in the southern part of the Kelso Junction quadrangle and vicinity.

of several maps which show the location of test pits or drill holes with an abbreviation of the lithology presumably encountered at bedrock surface and, for some, the distance to bedrock. The explorations are shown unlabeled on plate 2; although they were used to help locate the contacts of the Amasa Formation, uncertainty remains as to whether some are drill holes or are test pits, or whether they are located accurately or even exist.

Exploration along the belt of the Amasa Formation across the quadrangle was confined to the northwest and southeast ends, and nothing is known about the lithology of the central part between the two general areas of exploration. Drilling in the northwestern area was in sec. 6, T. 43 N., R. 32 W., and sec. 36, T. 44 N., R. 33 W. Of the seven SL holes in sec. 36, all but SL–205 penetrated ferruginous strata. Hole SL–205 and the upper part of SL–206 are recorded as having cut red, gray, or black slate presumably of the overlying Michigamme Slate. The other holes reportedly penetrated cherty iron-formation and minor amounts of slaty iron-formation and ferruginous slate. About the first 100 feet of ledge rock in SL–201 was logged as ferruginous conglomerate. Tuffaceous material in SL–202 and SL–207 and decomposed amygdaloidal greenstone in SL–203 were noted as interbedded with iron-formation. Sludge analyses for the SL drill holes ranged from about 10 percent iron to nearly 50 percent, with the values commonly in the upper half of that range.

In sec. 6, short holes OL–1 and M–2 and the upper part of M–3 are recorded as being in gray slate, apparently the Michigamme. Hole M–3 reportedly passed into ferruginous slate and jasper (of the Amasa Formation) and ended in light-green rock that is probably interbedded volcanic material or dike rock. Hole M–4 was logged as entirely in ferruginous slate. Some sludge and a few core analyses were made of what probably were the more ferruginous parts of M–3 and M–4; iron content ranged from about 25 to 40 percent.

The six holes of the Corcoran exploration are angle holes, and all are relatively long. Abbreviated core from this exploration was examined, and the drill logs are fairly detailed and include sludge analyses for each 5-foot run. Hole C–1 starts in iron-formation, but the other five start in the Michigamme Slate and then enter the Amasa Formation, thus accurately locating the contact between the two units. Apparently, only C–1 passed through the Amasa Formation into underlying volcanic rocks of Hemlock Formation, although all the C holes penetrated greenstone that seems to be interbedded with the Amasa Formation. Holes C–2 and C–3 reportedly pass entirely through an amygdaliodal greenstone flow, 100 feet thick, which lies about 300 feet above the base of the iron-bearing rocks. The sludge analyses recorded for the various rock types are distinctive: in general, the iron content of the graywacke and red, gray, and black slate of the

Michigamme Slate is less than 10 percent; for the iron-bearing strata of the Amasa Formation—reported mainly as cherty or slaty iron-formation and locally as ferruginous slate, specular slate, bands of hematite or specular hematite, granular chert, chert containing clastic quartz, oolitic chert, and oolitic jasper—the range in iron content is from about 15 to 30 percent; and for the interbedded greenstone, about 10 percent.

Each of the McCusker churn-drill holes, numbers 2 through 13, is represented by a single analysis, and the range in iron content is from about 25 to 65 percent. The 65-percent iron value is abnormally high and all the analyses may represent selected high-grade samples. No analysis is given for hole 1; therefore, it probably was in greenstone of the Hemlock Formation rather than in the Amasa Formation, and under that assumption the contact of the two formations has been placed between holes 1 and 2. A cross section included with mining-company exploration records of the six Corcoran drill holes shows this geologic contact between McCusker holes 5 and 6.

The drilling data of the Swan Lake and Corcoran explorations provide fairly detailed information about the Amasa Formation in this area, and various lithologies of the iron-bearing strata are noted on the drill logs. Some slaty, oolitic, and jaspery or cherty zones seem to be rather distinctive; but even between the more closely spaced holes, correlations are rather doubtful, and specific zones cannot be traced with certainty. Hole C–1 indicates that the lower part of the formation may be less cherty than the upper. Greenstone flows, possibly at more than one horizon, apparently are locally interbedded with the ferruginous strata. The formation, including the interbedded greenstone, is about 600–700 feet thick in the central part of sec. 6, T. 43 N., R. 32 W.; approximately this thickness has been inferred across most of the mapped area. In the southeastern part of the quadrangle the width has been gradually increased to match the mapped width of the unit in the adjacent Crystal Falls quadrangle where the greater width is probably caused mainly by repetition by folding or faulting and possibly to a lesser degree by increased stratigraphic thickness. The presence of the formation across the central part of the quadrangle, between the two general areas of exploration, is a reasonable inference considering the sedimentary character of the unit. The position of this inferred belt on the map is controlled mainly by magnetic anomalies that are caused by magnetic rocks in the bordering Hemlock Formation. The Amasa Formation is virtually nonmagnetic within the Kelso Junction quadrangle, although in places in the adjacent areas, both to the north and to the south, it is moderately to strongly magnetic.

The Amasa Formation appears to be offset along a northeastward-trending fault in sec. 6, T. 43 N., R. 32 W. Distribution of exposures, magnetic anomalies within the underlying Hemlock volcanics, and

exploratory drilling indicate a horizontal displacement of about 1,000 feet, the eastern segment having moved relatively northeast.

In the southeastern area of exploration, drilling was done in secs. 10, 13, 14, and 15, T. 43 N., R. 32 W. Holes H–1304, H–1305, and H–1306 in sec. 13 apparently are in the lower part of the Amasa Formation and reportedly enter oxidized, reddish to bluish, slaty iron-formation interbedded in places with chert or quartzite. Much of the slaty iron-formation is described as being finely banded and as containing crystals of martite. Analyses of the sludge at 5-foot intervals showed a range in iron content of from about 15 to nearly 35 percent. The log information for holes LY–1 and LY–2 in sec. 14 is less detailed. Hole LY–1, which also apparently was drilled in the lower part of the Amasa Formation, is listed as being mainly in cherty carbonate slate, cherty iron carbonate slate, and iron-formation, from which three analyses from widely separated parts of the hole each showed less than 25 percent iron. Hole LY–2 evidently lies entirely within the Michigamme Slate, as only talcose slate and gray carbonate slate are noted. Logs of Option No. 125, holes 1–3 and 5 (near LY–1), record various combinations and repetitions of gray slate, red slate, black slate, iron slate, sandstone, quartz, paint rock, jasper, ochre, and ore, all of which here are referred to the Amasa Formation. No analyses are given. Hole CF–107 in sec. 15 reportedly passed through about 10 feet of paint rock and slate and then into about 100 feet of greenish-gray schist. The paint rock and slate probably represents the Amasa Formation, and the schist, the Hemlock Formation. Several unlabeled holes in secs. 10 and 14 also were used to help control the placing of the geologic contacts. Those that reportedly ledged in ore, slate and ore, jasper, iron slate, or red slate are inferred to lie mainly within the Amasa Formation; whereas those reportedly in greenstone, slate, or quartzite are inferred to lie mainly within adjacent strata. According to the available information, the Amasa Formation in this southeastern area apparently has no clearly defined iron-formation unit; the ferruginous strata seem interbedded with, or gradational into, the Michigamme Slate.

The contact between the Amasa Formation and the underlying Hemlock Formation is not exposed within the quadrangle, but it has been examined in underground workings of the Warner mine several miles to the northwest near the town of Amasa. Near the shaft on the 11th, 12th, and 13th levels, amygdaloidal greenstone of the Hemlock Formation is conformably overlain by massive fine-grained graywacke that apparently is the basal part of the Amasa Formation. Within a short stratigraphic distance the graywacke becomes increasingly ferruginous and interbedded with ferruginous slate and oolitic iron-formation that make up the ore horizon of the Amasa Formation in the Warner mine. Within the Kelso Junction quadrangle, in sec. 6, T. 43 N., R. 32 W., the contact is intersected by drill hole C–1. According to the recorded drill log, about 50 feet of graywacke which contains scattered pebbles of red slate and greenstone separates iron-rich beds from underlying greenstone that may be assigned to the Hemlock Formation. Records of other drill holes, however, show that greenstone and iron-formation are interbedded locally. The contact, therefore, is considered to be one mainly of gradation and interbedding.

The contact of the Amasa Formation with the overlying Michigamme Slate was observed in the workings of the Cayia mine, which are about 2 miles south of the Kelso Junction quadrangle. There, slaty and cherty iron-formation is overlain conformably, with no interbedding, by gray slate and graywacke. Although much of the iron-formation near the contact is brecciated or fragmental, the contact is sharp, with no indication of a major stratigraphic break. Eight drill holes within the map area cross the contact between the Michigamme Slate and the Amasa Formation, and all the drill logs note an abrupt change from slate and graywacke to iron-formation. Some of the drill logs record chert layers interbedded with the slate, which is suggestive of an interbedded or gradational contact, but some of the chert is listed as being fragmental.

Leith, Lund, and Leith (1935, p. 13) reported that at the Hemlock and Michigan mines, in the vicinity of Amasa, a coarse conglomerate at the base of the slate-graywacke unit overlies a truncated fold in the iron-formation. Conglomerate, presumably from this stratigraphic position, is present on the dumps of those now-abandoned mines. Leith, Lund, and Leith (p. 13) also stated that the unconformity "can be seen in diamond-drill cores along the same horizon south of these mines * * *" and "The presence of this conglomerate has now been demonstrated by intermittent exploration along a belt nearly 10 miles in extent." However, the records now available of the drilling that was done between Amasa and the Kelso Junction quadrangle give little indication of this conglomerate. In one drill hole near the Porter mine, in sec. 22, T. 44 N., R. 33 W., 117 feet of ferruginous conglomerate overlying ferruginous slate which contains seams of ore was reported; in drill hole SL–201, adjacent to the quadrangle in sec. 36, T. 44 N., R. 33 W., the upper 100 feet of the hole was recorded as being in ferruginous conglomerate that overlies cherty iron-formation. These two drill holes apparently are the only references to conglomerate along this belt of the Amasa Formation; drill core available from recent drilling near the Warner mine, secs. 9, 10, 15, and 16, T. 44 N., R. 33 W., shows no conglomerate at this contact horizon.

The Amasa Formation is known to extend several miles south of the Kelso Junction quadrangle, as revealed by mining in the Crystal Falls quadrangle and by drilling in sec. 35, T. 43 N., R. 32 W.; but it may

disappear within a short distance to the southeast along the strike, as Bayley (1959a, p. 26) stated that the formation apparently does not enter the Lake Mary quadrangle. He described an occurrence of structurally conformable Hemlock Formation and Michigamme Slate that are separated by less than 50 feet of gneiss with no evidence of the Amasa Formation being present.

The existence of an overlying conglomerate at one or more localities northwest of the Kelso Junction quadrangle, with apparent absence of the Amasa Formation to the south, suggests that, despite the observed conformable relationship at the Cayia mine, the contact is one of regional disconformity. Within the confines of the quadrangle, however, this break probably is of minor importance.

MICHIGAMME SLATE

The Michigamme Slate was named for extensive exposures of slate and graywacke in the vicinity of Lake Michigamme, which is about 20 miles northeast of the Kelso Junction quadrangle (Van Hise and Bayley, 1895, p. 598; Van Hise and Leith, 1911, p. 267). The Michigamme Slate is areally continuous from the Lake Michigamme area to the northwestern flank of the Amasa oval and into the mapped area. It overlies the Amasa Formation across the southern part of the quadrangle in a belt that has a probable minimum thickness of slightly less than 5,000 feet.

Bedrock exposures of the slate in the quadrangle are limited to two small areas along the southern margin of a metagabbro dike—in the NE¼ sec. 7 and in the NW¼ sec. 8, T. 43 N., R. 32 W. Much of the drilling along the belt of Amasa Formation penetrated the lower part of the Michigamme Slate, and the Lakeland and Crystal Falls explorations drilled into the central and upper parts of the unit. The Lakeland exploration includes a line of 10 drill holes in secs. 8 and 17, T. 43 N., R. 32 W., along a cross-strike distance of about 2,000 feet, and a group of 25 holes in sec. 16, T. 43 N., R. 32 W. (of which only 10 are within the quadrangle), over a cross-strike distance of about 4,000 feet. Holes L–34 and L–35, the two southernmost holes in sec. 17, are in the overlying Badwater Greenstone. Abbreviated core from some of these holes was examined.

The exposures in secs. 7 and 8 are mainly of light-gray to dark-greenish-gray fine-grained dense slate that is banded to thinly laminated. The banding probably is caused by slight color differences, although some of the light-colored layers are cherty in aspect. Megascopically, the slate resembles some of the banded tuffaceous slate of the Hemlock Formation, but in thin section it is seen to be composed mostly of small grains and fragments of quartz and minor amounts of sericite and chlorite. The slate is folded and, in places, extremely contorted.

The drill records, drill core, and outcrops show that the Michigamme Slate in this area is chiefly fine-grained gray, red, and black slate interbedded with fine- to medium-grained graywacke. Proportionally more of the reddish rock, such as red slate, red graywacke slate, and variegated gray- and red-banded slate, was reported from within the lower part of the formation. Logs from drill holes in sec. 16 reported gray carbonate slate, lean cherty carbonate, dark-red slaty iron-formation, and lean slaty chert in the middle and upper parts of the formation. These logs may not have reliably distinguished between cherty carbonate and light-gray slate or between slaty iron-formation and reddish slate. The drill core from within the upper part of the unit in sec. 17 consists mostly of gray to black slate and minor amounts of graywacke. Some of the graywacke is feldspathic. The black slate is in part graphitic and locally contains much disseminated fine pyrite. In sec. 17, graphitic slate apparently is characteristic of the upper part of the formation. Iron analyses of sludge for each 5-foot interval are listed in the drill logs of the Lakeland exploration holes L–23 through L–37. Iron values range from slightly less than 5 to almost 15 percent, but commonly are less than 10 percent. No obvious correlation of rock type to iron content exists, although in a general way graphitic slate has the intermediate values of iron content and gray slate has the higher and lower values.

Vein quartz, fault gouge, and sheared or fragmental material reported in holes L–36 and L–37 in sec. 17, and sheared quartzose conglomerate that contains pebbles of greenstone reported in hole L–26 south of the map area in the SE¼ sec. 16, suggest some faulting along the contact between the Michigamme Slate and overlying Badwater Greenstone. Definite evidence as to the relation between the two formations is lacking in this area, but Van Hise and Leith (1911, p. 318) noted that near Gibbs City, several miles west of the Kelso Junction quadrangle, the upper part of the Michigamme Slate is interbedded with the greenstone.

BADWATER GREENSTONE

The Badwater Greenstone is named for extensive exposures of mafic volcanic rocks that overlie the Michigamme Slate in the vicinity of Badwater Lake in southwestern Dickinson County, Mich. (James, 1958, p. 37). The formation extends into southeastern Iron County (James and others, 1959) and occupies the extreme southwestern part of the Kelso Junction quadrangle.

Badwater Greenstone crops out in the east-central part of sec. 12, T. 43 N., R. 33 W., and was penetrated in the Lakeland exploration drilling in the northwestern part of sec. 17, T. 43 N., R. 32 W. The exposures are mainly dense fine-grained massive metabasalt. Ellipsoidal structures are common, and the few that show reliable top directions indicate that tops are toward the south. Locally, some of the rock is rudely schistose or foliated in a general east-west direction. Individual flows are not apparent, but a few small zones of slightly brecciated aspect may represent original scoriaceous material between flows. The greenstone is virtually identical to the metabasalt of the Hemlock Formation. Some of the material from drill holes L–34 and L–35 may be of intermediate or felsic composition, but most is metabasalt.

This belt of Badwater Greenstone attains a probable maximum thickness of about 15,000 feet a few miles west of the quadrangle and apparently pinches out completely just south of the central part of the quadrangle in sec. 15, T. 43 N., R. 32 W. The rapid change in thickness of the greenstone along strike probably is caused primarily by depositional variations, although the thinning may be caused in part by undetermined structural deformation.

INTRUSIVE ROCKS

WEST KIERNAN SILL

Mafic igneous rocks, which consist mainly of metadiabase and metagabbro, are present throughout much of the central part of the Kelso Junction quadrangle. These rocks are part of the West Kiernan sill, so named for exposures in the adjacent Kiernan quadrangle to the east (Gair and Wier, 1956).

Scarcity of exposures causes an uncertainty about the form and extent of the West Kiernan sill within the Kelso Junction quadrangle, but widely scattered outcrops indicate an irregular intrusive body that lies mostly within the lower part of the Hemlock Formation. The northern limit of the sill is arbitrarily shown as slightly north of the northernmost known outcrops of intrusive rocks, but whether the sill terminates in the northwestern part of the quadrangle or extends farther to the northwest is not known. In the west-central part of the quadrangle a narrow tongue extends northwestward for almost 2 miles from the main body, and an apparently detached mass of similar dimension lies adjacent to this protrusion. In sec. 13, T. 44 N., R. 32 W., a small body of intrusive rock also seems to be isolated from the main mass. The distribution of the outcrops of intrusive rocks suggests that the rocks may have been emplaced as separate or contiguous intrusions rather than as one simple sill-like body.

In the Kiernan and Lake Mary quadrangles the West Kiernan sill is a clearly defined unit that attains a maximum thickness of about 6,000 feet, and it is probably about the same thickness where it enters the southeastern part of the Kelso Junction quadrangle. In the central part of the quadrangle, widely scattered outcrops of the intrusive rock extend across a surface width of about 20,000 feet, but this does not necessarily indicate an increase in the thickness of the sill. Outcrops of metavolcanic rock are present within this belt, and the Hemlock Formation may underlie considerably more of this area of poor exposures than is shown on the map. The main reason for the greater outcrop width of intrusive rock, however, probably is structural. Known fold axes project into this general area from the adjacent Kiernan quadrangle, and a major northwest-trending anticline is indicated by the presence of Randville Dolomite in sec. 36, T. 44 N., R. 32 W. Ultramafic rock, characteristic of the basal differentiate of the sill (Bayley, 1959a, b), crops out in secs. 15, 22, 26, and 27, T. 44 N., R. 32 W., along a narrow belt parallel to the general northwest geologic trend. The ultramafic rocks lie well within the inferred limits of the intrusive mass, and may be at the present erosion surface along an anticlinal axis. Local folding is indicated by patches of strongly contorted slaty greenstone within exposures of the intrusive rock along the apparent edge of the sill in sec. 10, T. 44 N., R. 32 W.

The rocks of the West Kiernan sill have been described in detail in previous publications (Bayley, 1959a, b; Gair and Wier, 1956). In the Lake Mary quadrangle, where the sill is fairly well exposed throughout its entire thickness, Bayley (1959a, p. 66–75) distinguished five distinct zones, from bottom to top: (1) basal ultramafic, (2) normal metagabbroic, (3) intermediate or transitional, (4) granophyric, and (5) metadiabasic (chilled) border. He concluded that the rock types resulted from differentiation of gabbroic magma by crystal fractionation and gravity sorting during crystallization while the sill was a horizontal sheet. Some of these zones were found to be of restricted occurrence along the length of the intrusive body. In the Kiernan quadrangle (Gair and Wier, 1956) the sill consists mainly of metagabbro and metadiabase corresponding to the content of the normal metagabbroic zone, although differentiation is apparent from the local concentration of granophyre, pegmatitic metagabbro, and metapyroxenite along the southwest edge (upper part) of the sill. Distinct individual zones were not noted. In the Kelso Junction quadrangle, rocks of the five differentiated types described by Bayley can be recognized in separate outcrops, but, except locally, delineation of zones is not feasible because of scarcity of exposures and because of probable complexities caused by structural deformation and by splitting and termination of parts of the intrusive body.

Exposures of the sill commonly are rounded knobs and ridges similar to those of the greenstone of the Hemlock Formation. Weathered surfaces are dark colored, generally in shades of gray, green, or brown, and fresh breaks are commonly a lighter grayish green. Locally,

igneous textures are megascopically distinct, especially on glacially polished surfaces, although much of the rock is massive and original textures are vague.

ULTRAMAFIC ROCKS

Ultramafic rocks are exposed in secs. 15, 22, 26, and 27, T. 44 N., R. 32 W., along a narrow southeastward-trending zone. They were described as picrite porphyry or porphyritic limburgite by Clements (Clements and Smyth, 1899, p. 212–221). Their stratigraphic position with respect to the other intrusive rocks is not exactly known, but they are restricted to the northeastern, and presumably lower, part of the sill. Inclusions of Hemlock Formation in some exposures of ultramafic rock indicate that the ultramafics may lie at or near the base of the sill.

The color of the ultramafic rock on fresh breaks is grayish green to greenish black and therefore is darker than that of the other parts of the sill. The rock is medium to coarse grained and is generally porphyritic, with the phenocrysts commonly about a quarter of an inch in length and less commonly about half an inch. On some surfaces the phenocrysts weather to a light grayish tan and are in sharp contrast with the dark matrix. Most phenocrysts are round or oval and probably represent original olivine crystals, but a few exhibit vague square or rectangular outlines and likely are pseudomorphs after pyroxenes.

The ultramafic rocks probably originally included dunite, peridotite, and pyroxenite. They now are altered extensively and are composed almost entirely of secondary minerals, mainly serpentine (antigorite?) and amphiboles, and subordinate amounts of chlorite, talc, carbonate, magnetite (some of which appears primary), and leucoxene. Many of the pseudomorphs are composed mainly of serpentine but contain magnetite in various amounts. Magnetite commonly exhibits a distinctive mesh structure characteristic of altered olivine, but it also is present in subparallel streaks and scattered patches. Clusters of fibrous amphiboles form irregular cores within many of the separate areas of serpentine outlined by the networks of magnetite. Other pseudomorphs consist of aggregates of serpentine, chlorite, talc, carbonate, and magnetite in different combinations and proportions. The groundmass is commonly a mass of fine-grained chlorite and includes minor amounts of other secondary minerals.

The ultramafic character of these rocks also is shown by analyses listed in table 4. Although samples 1–3 are from localities in the Kelso Junction quadrangle as far as 1½ miles apart, the extremely close agreement of the analyses indicates that all three samples represent about the same stratigraphic horizon in the basal part of the sill. Sample 4 is from about an equivalent stratigraphic position in the Lake Mary quadrangle, but the analysis shows somewhat different values for some of the elements. For example, MgO content is considerably less and Al_2O_3, and CaO somewhat greater than that in the samples from the Kelso Junction area, but the variations probably reflect only slight differences in stratigraphic position of the samples or are the normal variations to be expected. Nockolds' (1954) average of 23 analyses of peridotites is shown for comparison.

TABLE 4.—*Analyses of ultramafic differentiate from West Kiernan sill and average of 23 peridotite analyses by Nockolds (1954)*

[- - -, not reported. All analyses are chemical, in percent, except those marked by an asterisk (*), which are semiquantitative spectrographic in parts per million, of the element]

	1 (Lab. No. 157312)	2 (Lab. No. 157313)	3	4	5
SiO_2	38.3	38.2	37.36	39.01	43.54
Al_2O_3	4.6	4.1	4.76	6.56	3.99
Fe_2O_3	6.3	6.2	6.61	11.49	2.51
FeO	7.4	6.8	6.12	5.30	9.84
MgO	30.0	30.2	31.11	23.84	34.02
CaO	1.1	1.6	1.19	3.57	3.46
Na_2O	.02	.01	Trace	.00	.56
K_2O	.04	.02	Trace	.02	.25
H_2O	10.1	10.3	[1] 11.02	[1] 7.76	[2] .76
TiO_2	1.0	.85	.79	2.04	.81
P_2O_5	.09	.08	.06	.19	.05
CO_2	.05	.21	None	.08	---
MnO	.18	.20	Trace	.11	.21
CuO	.009	.015	---	*125	---
CoO	.004	.004	---	*40	---
Cr_2O_3	.46	.66	.62	*2,400	---
NiO	.76	.66	.04	*390	---
S	<.05	<.05	---	---	---
Total	100.4	100.1	99.68	99.97	100.00

[1] Sum of H_2O- and H_2O+.
[2] H_2O+.

1. Field No. KW-24-60, laboratory report No. WR-526, 1961. Ultramafic differentiate. Outcrop 700 ft south and 100 ft east of NW cor. sec. 26, T. 44 N., R. 32 W. Rapid-rock analyses by P. L. D. Elmore, I. H. Barlow, S. D. Botts, and Gillison Chloe, except for wet chemical-method determinations of CuO, CoO, Cr_2O_3, and NiO, laboratory report No. WG-14, by Joseph Budinsky, J. Harris, and Joseph Dinnin.
2. Field No. KW-25-60, laboratory report No. WR-526, 1961. Ultramafic differentiate. Outcrop 1,300 ft. north and 2,600 ft east of SW cor. sec. 15, T. 44 N., R. 32 W. Rapid-rock analyses by P. L. D. Elmore, I. H. Barlow, S. D. Botts, and Gillison Chloe, except for wet chemical-method determinations of CuO, CoO, Cr_2O_3, and NiO, laboratory report No. WT-8, by Joseph Budinsky, J. Harris, and Joseph Dinnin.
3. Picrite porphyry. NE¼ sec. 22, T. 44 N., R. 32 W. (Clements and Smyth, 1899, p. 219).
4. Metaperidotite. Lower part of West Kiernan sill in the Lake Mary quadrangle (Bayley, 1959b, p. 428).
5. Average of 23 analyses of peridotite (Nockolds, 1954).

NORMAL METAGABBROIC ROCKS

Metagabbro and metadiabase, in amounts corresponding to those of the normal metagabbro zone, make up most of the sill and the nearby apparently separate intrusive bodies. The rocks are generally massive in gross appearance, but relict diabasic, gabbroic, and ophitic textures and crystalloblastic accumulations of secondary minerals are common. Rhythmic layering, in which light-colored feldspathic layers alternate with dark-colored layers which contain more mafic minerals, was found in several exposures in the central part of the sill in secs. 34 and 35, T. 44 N., R. 32 W. On differentially weathered surfaces the layering

is represented by discontinuous subparallel low ribs and shallow troughs. Individual layers commonly are less than 1 inch thick, but may be as much as several inches. Similar layered rocks occur in the middle part of the normal metagabbro zone in the Lake Mary quadrangle, where adequate exposures clearly show the differentiated character of the sill; Bayley (1959b, p. 414) suggested that these rocks resulted from stratification by gravity sorting with upward enrichment in feldspar and downward concentration of mafic minerals.

Of the metagabbroic and metadiabasic rocks, pyroxene and calcic plagioclase were the major primary minerals, and magnetite, ilmenite, and apatite the minor ones. The rocks now are altered almost completely to secondary minerals, of which sodic plagioclase, amphiboles, and chlorite are the most abundant. Subordinate or accessory alteration minerals commonly include some of the following: Epidote, clinozoisite, micas, serpentine, carbonate, potassium feldspar, quartz, iron oxides, leucoxene (and sphene?), stilpnomelane, and pyrite.

The metagabbroic rocks range from dark feldspar-poor rocks that mineralogically approach the ultramafics to light feldspathic rocks that probably are gradational into the transitional and granophyric rocks present in the upper part of the sill. Bayley (1959b, p. 414–415) found that in the Lake Mary quadrangle from the lower to the upper part of the normal metagabbroic zone the amount of original plagioclase and the size of plagioclase crystals increase and the amounts of amphibole-chlorite-serpentine and sphene-rutile-magnetite decrease. In the Kelso Junction quadrangle, mineralogic differences cannot be so clearly related to stratigraphic position, perhaps largely because of inadequate exposures.

TRANSITIONAL ROCKS

Bayley (1959a, p. 72) noted that in the Lake Mary quadrangle rocks mineralogically and texturally gradational between normal metagabbro and granophyre occur in a zone of variable thickness within the upper part of the West Kiernan sill. In the Kelso Junction quadrangle similar transitional rocks are present at about the equivalent stratigraphic position, but so far as could be determined from scarcer exposures, the rocks are not so abundant nor the zone so clearly defined. The transitional rocks represent a rather abrupt change from normal metagabbro to granophyre, in which the ratio of feldspars to mafic minerals increases, and apatite, titaniferous magnetite (leucoxene-sphene), and stilpnomelane become more abundant. The appearance of granophyric texture and free quartz marks the grading of transitional rocks into granophyre.

GRANOPHYRE

Granophyre is present in exposures in the upper part of the main sill, from about sec. 12, T. 43 N., R. 32 W., northwestward to sec. 32, T. 44

230-075—66——4

N., R. 32 W. It apparently is not restricted to a specific zone, but is in discontinuous, irregular, and various-sized masses mainly at or near the upper edge of the sill but in a few places a thousand feet or more below the contact. Exposures of granophyre along the upper edge of the sill are found chiefly where the intrusive rock protrudes into the Hemlock Formation; namely, in the west-central part of sec. 33, T. 44 N., R. 32 W., near the mutual corners of secs. 2, 3, 10, and 11, T. 43 N., R. 32 W., and in secs. 11 and 12, T. 43 N., R. 32 W. The significance of the apparent localization of granophyre in these areas is not known, but the intrusive contact appears to be concordant with the overlying volcanics, and the "bulges" may have resulted from local doming during emplacement of the sill.

The distinguishing characteristic of the granophyre is the micrographic intergrowth of quartz and feldspar. Sodic plagioclase, potash feldspar, and quartz are the most abundant minerals; sericite, chlorite, biotite, stilpnomelane, hornblende, epidote, carbonate, iron oxides, leucoxene, sphene, apatite, and pyrite are commonly the accessory ones. Granophyric intergrowths most commonly are interstitial to feldspar or quartz crystals but also wholly or partially rim feldspar crystals and occupy discrete separate areas. Quartz occurs as mosaic aggregates and as isolated subhedral to anhedral crystals. The accessory minerals, except for apatite and possibly some of the iron oxides, occur as scattered alteration products within the feldspars and largely make up the matrix material interstitial to the areas of granophyre, feldspar, and quartz. Leucoxene and sphene, apparently derived from titaniferous magnetite, or ilmenite, form skeletal crystals and irregular patches. Sphene commonly borders areas of partly altered magnetite.

METADIABASIC ROCKS (CHILLED ZONE)

A chilled border zone at the contact of the West Kiernan sill was observed in the Lake Mary quadrangle (Bayley, 1959a, p. 75), but has not been definitely seen in the Kelso Junction quadrangle. In the Kelso Junction quadrangle, fine- to medium-grained rock is poorly exposed at several places along the upper edge of the sill; this rock may represent either a chilled zone of the sill or metamorphosed wallrock. In some exposures in which identifiable volcanic rocks are in direct contact with granophyric or normal metagabbroic rocks, the contact is clearly defined but very irregular. In the outcrop area just east of Light Lake, however, metagabbro is intermixed with fine- to medium-grained rock that apparently is Hemlock Formation. The two types of rock grade into each other, so that it is difficult or impossible to distinguish extrusive from intrusive rocks or to delineate the contact. Locally, remnants or inclusions of volcanic rocks are clearly engulfed in metagabbro.

MAGNETITE-RICH DIFFERENTIATE

Test pits in the upper part of the sill, in the NW¼ sec. 12, T. 43 N., R. 32 W., explored intrusive rock which contains abnormal amounts of magnetite, but surrounding exposures and the lack of strong or extensive aeromagnetic anomalies indicated that the magnetite-bearing rocks are of limited extent. Outcrops near the test pits are mainly of transitional or granophyric-type rocks, although immediately adjacent to the pits some outcrops are of normal metagabbro. Specimens from the test-pit dumps show a wide range in magnetite content—from a few percent to more than 50 percent. The magnetite is chiefly in rounded crystal grains that range in diameter from about 0.2 to 3 mm and which commonly occur in small clusters or aggregates scattered throughout the rock. Much of the magnetite is poikilitically distributed within large altered feldspars and in what probably originally were pyroxenes but now are amphiboles. Some of the magnetite is titaniferous and shows partial alteration to sphene or leucoxene. In some specimens chlorite and biotite (or stilpnomelane?) are important minor constituents. Other accessory minerals include apatite, epidote, carbonate, and pyrite.

Iron enrichment during late stages of differentiation of basaltic magmas has been noted in many differentiated bodies (Wager and Deer, 1939; Walker, 1940; Walker and Poldervaart, 1949; Hotz, 1953), and the local concentration of magnetite probably results from a similar differentiation trend in the upper part of the West Kiernan sill. A chemical analysis of a moderately magnetic specimen from one of the test pits in sec. 12 is given in table 5, and semiquantitative spectrographic analyses of the same sample and of other specimens of the iron-bearing intrusive rock are listed in table 6.

TABLE 5.—*Chemical analyses, in percent, of magnetite-bearing differentiate from upper part of West Kiernan sill*

[Rapid-rock analysis by P. L. D. Elmore, I. H. Barlow, S. D. Botts, and Gillison Chloe, U.S. Geological Survey, 1961, laboratory report No. WR-526. Asterisk (*) denotes wet-chemical analysis by Joseph Budinsky, J. Harris, and Joseph Dinnin, laboratory reports Nos. WG-14, WT-8]

Laboratory No. 157312; field No. KW-15-60

SiO_2	34.1	TiO_2	5.42
Al_2O_3	3.4	P_2O_5	.38
Fe_2O_3	13.1	CO_2	<.05
FeO	22.3	MnO	.38
MgO	8.5	S	.38
CaO	7.6	*CuO	.010
Na_2O	.13	*CoO	.010
K_2O	.10	*Cr_2O_3	.03
H_2O	3.0	*NiO	<.03
		Total	98.9

OTHER INTRUSIVE ROCKS

METAGABBRO DIKE IN THE MICHIGAMME SLATE

A quartz-bearing metagabbro dike within the area of Michigamme Slate is marked by a narrow belt of outcrops that trend northwestward for about 3 miles from near the common corner of secs. 9, 10, 15, and 16 to near the NW cor. sec. 7, T. 43 N., R. 32 W. The extent of the intrusion is not known, but because the outcrops end so abruptly, the limits of the dike are shown as practically the same as the area of exposures. The dike crosses the regional strike at a low angle.

Most outcrops are conspicuous rounded knobs of dark massive rock that resemble the coarser grained parts of the West Kiernan sill. Parts of some of the exposures break down to coarse angular rubble, apparently the result of frost action. Weathered surfaces commonly show gabbroic or coarse diabasic texture. In places the rock is medium to fine grained, but no systematic grain-size variation with respect to the edges of the dike was observed. Mineralogically, the dike rock is similar to some of the upper parts of the West Kiernan sill; mineral assemblages and apparent compositions range from normal metagabbro to transitional and granophyric rock types. The dike probably originated during the later stages of the West Kiernan sill igneous activity.

In thin section the rock is seen to be extensively altered. Outlines of original plagioclase laths are still visible, but now the crystal areas are composed largely of mixtures of epidote, clinozoisite, albite, chlorite, and stilpnomelane. Fine-grained secondary plagioclase borders some of the altered feldspars. Pale-green hornblende derived from original pyroxenes is present as large rectangular and stubby subhedral grains. Most grains also contain chlorite, biotite, and stilpnomelane, which, together with fine-grained quartz and feldspar, also occupy interstitial areas. Quartz grains, as well-defined crystals and as irregular patches scattered among the other minerals, generally make up from several to 10 percent of the rock. Rude granophyric intergrowths of quartz and feldspar were observed in several thin sections. Apatite, as prismatic euhedral crystals, is a common accessory mineral. Other accessory minerals include calcite, magnetite, leucoxene, sphene, and pyrite. Magnetite is commonly surrounded by or is intergrown with leucoxene.

METADIABASE ASSOCIATED WITH WEST KIERNAN SILL AND HEMLOCK FORMATION

At scattered localities within the area of intrusive rocks, for example, the NW¼ sec. 24, T. 44 N., R. 32 W., the SW¼ sec. 29, T. 44 N., R. 32 W., and the SW¼ sec. 2, T. 43 N., R. 32 W., fine-grained to dense metadiabase forms narrow dikes which range in thickness from less than 1 foot to several feet. In some of the dikes a decrease in grain size from the center toward the edges was noted. The dike rocks are premetamorphic, but their exact age is not kown. Similar metadiabase occurs at a few places within outcrop areas of the Hemlock Formation, and possibly also represents dikes.

SCHISTOSE METADIABASE IN MARGESON CREEK GNEISS

About 2,500 feet north and 1,500 feet east of the SW cor. sec. 1, T. 44 N., R. 32 W., a fine-grained schistose metadiabase dike that cuts Margeson Creek Gneiss is poorly exposed in the bottom of a valley. The dike is several feet thick, dips steeply, and strikes northeastward. Schistosity is subparallel to the strike of the dike. Clements and Smyth (1899, p. 46, fig. 5) cited this locality as an example of differential erosion of weaker dikes which results in the forming of low areas in a more resistant granite gneiss terrane. However, the network of dikes shown by them apparently is schematic, as rocks are not exposed in most of the low areas, so that the underlying rock type is not known. In fact, the exposed dike causes rapids in the small stream in the main valley floor and seems equally as resistant to erosion as the gneiss.

The dike rock now is principally biotite-quartz schist that also contains variable amounts of hornblende. Common accessory minerals are calcite, epidote, chlorite, iron oxides, sphene, and pyrite. The age of the dike is unknown. Similar basic dikes in the Margeson Creek Gneiss are found in the Kiernan quadrangle to the east (Gair and Wier, 1956, p. 63).

QUARTZ PORPHYRY IN RANDVILLE DOMOLITE

In the NW¼ sec. 12, T. 44 N., R. 32 W., quartz porphyry crops out about 800–1,000 feet west of exposures of Margeson Creek Gneiss and close to an exposure of Randville Dolomite. Contacts with the Randville are not exposed, but the porphyry is thought to be intrusive rather than extrusive because of its apparent limited extent and because no evidence of volcanism associated with the deposition of the Randville Dolomite exists elsewhere in the region. The porphyry is similar in appearance and composition to schistose metarhyolite porphyry flows of the Hemlock Formation in sec. 4, T. 44 N., R. 32 W., and may be related to that magmatic episode. Quartz porphyry is also known to intrude the Margeson Creek Gneiss a short distance to the east in the Kiernan quadrangle (Gair and Wier, 1956, p. 67). A chemical analysis of the quartz porphyry from sec. 12 is listed in table 3.

The quartz porphyry is dark gray, fine grained, and massive, has a definite schistosity, and is characterized by blue opalescent quartz phenocrysts and platy blebs or streaks of biotite. The quartz phenocrysts range in diameter from about 0.2 to 1 mm and commonly are from 0.3 to 0.4 mm. Most of the phenocrysts have wavy extinction and embayed borders. They are sparsely distributed and make up not more than a few percent of the rock. The matrix material is chiefly fine-grained mosaic-textured quartz, but contains small amounts of sodic plagioclase and potassium feldspar. Quartz and feldspar grains range in diameter from about 0.01 to 0.06 mm. Biotite is a common minor constituent and is scattered throughout the groundmass as individual crystals, in small aggregates to about 0.1 mm in diameter, and in oval blebs to about 1 cm in length. Sericite and muscovite are generally associated with the biotite and are abundant in some specimens. The micas also occur in thin discontinuous veinlets apparently along tiny fractures or seams. Calcite in flaky patches as much as 0.1 mm in diameter is widely distributed and in places may make up several percent of the rock. Magnetite partly altered to hematite, or titaniferous magnetite partly altered to leucoxene or sphene, forms the cores of some of the biotite blebs. Small crystals and aggregates of the iron oxides also are scattered throughout the groundmass of much of the rock.

Foliation in the quartz porphyry results from a strong alinement of the micas and the occurrence of these minerals in parallel to subparallel veinlets and streaky blebs. Foliation strikes northwestward and dips steeply, similar to the attitude of the regional foliation and the trend of contacts of adjacent formations.

SPECTROGRAPHIC ANALYSES

Semiquantitative spectrographic analyses of metamorphosed igneous rocks from the Kelso Junction quadrangle are listed in table 6. Included for comparison are tabulations by Turekian and Wedepohl (1961), which show distribution in the earth's crust of elements in granitic, basaltic, and ultrabasic "igneous" rock. Most of the specimens are from differentiated parts of the West Kiernan sill. Samples 1–3 are of granophyre from the upper part of the sill; 4–6 are of a magnetite-rich differentiate from near the upper edge of the sill; 7–9 are of "normal" metagabbro from the upper part of the sill; 10 is of "normal" metagabbro from the central part of the sill; and 11–17 are of ultramafic rocks from the basal part of the sill. Samples 18–22 are of quartz-bearing metagabbro from a dike that probably is associated with the late stages of differentiation of the sill. Sample 23 is extrusive metarhyolite porphyry from the Hemlock Formation, and sample 24 is quartz porphyry that presumably intrudes the Randville Dolomite.

Cobalt, chromium, and nickel show a characteristic concentration in the early-forming ultramafic differentiates: barium, beryllium, gallium, niobium, strontium, yttrium, zirconium, and rare-earth metals—cerium, dysprosium, lanthanum, neodymium, samarium, and ytterbium—show a greater concentration in the later forming upper part of the sill and in the quartz-rich metagabbro dike. Titanium is relatively abundant in all the analyses; it occurs in sphene and leucoxene derived from titaniferous magnetite. The reported zero value for phosphorus in all but two of the specimens is attributable to the low detectability limit of around 2,000 parts per million in the spectrographic method, as apatite was present in thin sections of all the specimens of the quartz-bearing metagabbro, as well as in many of the specimens of granophyre and metagabbro from the upper part of the sill. Boron is found in all the rocks except granophyre; but this may not be significant, as it is present in most specimens in amounts only slightly greater than the detectable limit. Tin, in very minor amounts, is restricted mainly to the magnetite-rich differentiate. Copper, molybdenum, lead, and scandium are detected in most of the analyses but not in any apparent pattern. In a general way, the distribution of elements in the West Kiernan sill is similar to that reported by Wager and Mitchell (1951) in the Skaergaard intrusion.

MAGNETIC SURVEYS

AEROMAGNETIC SURVEY

An aeromagnetic survey of part of the northern peninsula of Michigan that included the Kelso Junction quadrangle was made in 1949 by the U.S. Geological Survey in cooperation with the Geological Survey Division of the Michigan Department of Conservation. J. R. Balsley was in charge of the aeromagnetic survey and Jean Blanchett supervised the compilation of the magnetic data. An AN/ASQ–3A flux-gate-type magnetometer installed in a DC–3 airplane was used to make total-intensity measurements at about 500 feet above the ground. Traverses were flown east and west at quarter-mile intervals, and north-south base-line traverses were flown for control in adjusting the measurements to a uniform magnetic datum.

The aeromagnetic data within the Kelso Junction quadrangle are shown on plate 3 as a series of "nested" total-intensity profiles. An index map shows flight lines, along which the positions of aeromagnetic crests are marked with dots, the relative size of which indicates the intensity of the aeromagnetic anomaly. The aeromagnetic crests are also shown on the ground-magnetometer data sheet (pl. 2) and the larger ones, on the general geologic map (pl. 1). Crest locations probably are plotted to an accuracy of within 500 feet.

The dominant aeromagnetic feature within the quadrangle is the strong positive anomaly along the southern (stratigraphically upper) part of the Hemlock Formation. It extends entirely across the quadrangle and is most prominent on profiles 94 through 106. It is caused by magnetic volcanic breccia and basaltic flows, although not all the breccia or flows are magnetic. On profiles 99 and 100 in sec. 6, T. 43 N., R. 32 W., and on 105 and 106 in sec. 15, T. 43 N., R. 32 W., subsidiary magnetic crests lie over areas of Amasa Formation or Michigamme Slate, but the ground magnetic survey (pl. 2) clearly shows that these highs are related to the Hemlock volcanics. This illustrates the "spreading" of an anomaly with the increase in vertical distance from the magnetic source and the influence of large variations in the magnetic intensity within rocks lying adjacent to flight profiles, especially where the flightpaths are parallel or subparallel to a somewhat irregular and discontinuous belt of magnetic rock.

Stratigraphically lower within the Hemlock Formation a much weaker aeromagnetic zone trends northwestward from about sec. 33, T. 44 N., R. 32 W., to beyond the limits of the quadrangle. In secs. 19 and 29, T. 44 N., R. 32 W., the anomaly lies close to the contact of the Hemlock with intrusive rocks of the West Kiernan sill, but because the intrusive rocks along the contact are not especially magnetic elsewhere, the source of the anomaly probably is volcanic rock of the Hemlock Formation. Several weaker and less distinctive magnetic highs are scattered throughout the remaining area of Hemlock volcanics and within the area presumably underlain chiefly by the West Kiernan sill. These anomalies are in general irregularly distributed, but some appear to be subparallel to the dominant northwest geologic trend. The low broad character on the profiles suggests that they represent slight bulk magnetic susceptibility differences of masses of the various volcanic or intrusive rocks. No attempt was made to determine the specific cause of these small anomalies.

Within the lower part of the West Kiernan sill, moderate to strong aeromagnetic anomalies apparently are related to ultramafic rocks. The closest correlation is the large magnetic high on profiles 84–86 with the outcrop area in secs. 15 and 22, T. 44 N., R. 32 W. The distinctive crests on profiles 78 and 79 occur in the vicinity of poor exposures of mafic rocks near the center of sec. 9, T. 44 N., R. 32 W., although most of the exposures in this general area are of the normal metagabbro. A small anomaly also is present on profile 90 in the vicinity of the ultramafic exposures in secs. 26 and 27, T. 44 N., R. 32 W. The ultramafic rock here is strongly magnetic, and the lack of larger crests on the nearer profiles indicates that the flight traverses did not pass directly over the areas of outcrop. The absence of other magnetic highs northwest of profile 77 along the general trend of the ultramafic belt suggests that the sill may not extend much farther to the northwest.

A low broad aeromagnetic anomaly roughly parallels the inferred belt of Randville Dolomite in the northeastern part of the quadrangle. The cause is not known, for neither the dolomite nor the underlying Margeson Creek Gneiss is generally magnetic.

Small, but clearly defined, magnetic crests on profiles 101 through 105 in the southern part of the quadrangle coincide with the outcrop limits of the metagabbro dike that intrudes the Michigamme Slate. The metagabbro is the chief cause of these magnetic highs, and the broad character of the crest on profile 102 indicates a possible greater width of the dike in that area than is apparent from the outcrop data. A small anomaly on profile 104 in sec. 7, T. 43 N., R. 32 W., lies near the contact between the Michigamme Slate and the Badwater Greenstone. The Michigamme Slate seems virtually nonmagnetic in this general area, so that the magnetic high more likely is related to the metavolcanic rocks of the Badwater Greenstone.

Parts of profiles 78 and 79, and possibly of 77, were distorted because of instrumental or recording difficulties; the distortions make it impossible to tell whether some of the smaller crests are true anomalies or not. The larger amplitudes, although they may be modified, probably represent actual anomalies of unknown origin.

GROUND MAGNETOMETER SURVEY

A ground magnetometer survey (pl. 2) was made along the inferred belt of the iron-bearing Amasa Formation in an effort to determine its magnetic characteristics and, if possible, to locate its geologic contacts more precisely. Two vertical-component tripod-mounted Askania magnetometers, both with a sensitivity of about 28 gammas per scale division, were used during the course of the survey. Magnetic readings were generally made at 50- or 100-foot intervals along paced traverses spaced 300–400 feet apart, although in places station and traverse spacings were varied somewhat according to the complexity of the magnetic pattern. Where the magnetic declination varied erratically within short distances because of proximity to magnetic rocks, sundial compasses were used to control the directions of traverses. Traverses and stations were located with respect to land boundaries, trails and roads, topographic features, and rock exposures, and the individual stations are probably plotted within an error of less than 100 feet.

Magnetic readings were corrected for diurnal variation and for instrumental and temperature drift by checking into base stations at intervals generally not exceeding 3 hours and by reoccupying previous stations at the beginning and end of most traverses. Magnetic readings were discontinued during periods of noticeable magnetic storms. Errors in gamma values between adjacent stations are probably less than 25 gammas, although between widely separated stations they may be several times this amount.

The survey covered an area of about 5 square miles in a strip from about ½–1 mile wide entirely across the quadrangle along the inferred position of the Amasa Formation. The surveying was done at various times from the fall of 1956 through the spring of 1959, most of it during the winter months when swamps and lakes were frozen. About 4,500 magnetic stations were occupied. The zero value is an arbitrary datum equivalent to about 57,950 gammas of absolute vertical intensity as determined from absolute magnetic base stations established in southeastern Iron County, Mich., by the U.S. Bureau of Mines (Bath, 1951).

The Hemlock volcanics, especially where exposed, cause strong magnetic anomalies within the area of the ground survey. A zone of irregular, discontinuous magnetic highs marks the upper part of the volcanics across the map area. Some of the exposed volcanic breccia and massive basaltic flows are strongly magnetic in hand specimens, and the volcanic rocks undoubtedly are the chief cause of the anomalies.

No magnetic anomalies are associated with the known and inferred areas of the iron-bearing Amasa Formation. The iron-bearing Amasa is virtually nonmagnetic within this quadrangle, although locally both northward and southward the formation is moderately to strongly magnetic. The lack of magnetism probably is due to deposition of an original nonmagnetic iron-formation facies.

The ground survey included the eastern part of the metagabbro dike that intrudes the Michigamme Slate. In general, small to moderate magnetic highs lie along the northern edge of the dike. In the east-central part of sec. 8 and the west-central and southeastern parts of sec. 9, T. 43 N., R. 32 W., small highs lie north of the exposures of metagabbro. It is not known whether these anomalies are caused by unexposed parts of the metagabbro dike or by local areas of slightly magnetic rocks within the Michigamme Slate. South of the dike in the NW¼NE¼ sec. 16, T. 43 N., R. 32 W., a small anomaly of unknown cause lies within the area of Michigamme Slate.

GEOLOGIC HISTORY

The oldest rock in the quadrangle is the Lower Precambrian Margeson Creek Gneiss. The gneiss likely represents original sedimentary and volcanic deposits, which were deformed, metamorphosed, intruded by felsic material, and granitized during a major orogeny that predated the middle Precambrian. Mafic dikes may have intruded the gneiss during the latter phase or at the end of this period of deformation.

Deep erosion followed, probably causing almost complete peneplanation over a wide area, and then general submergence after which the chiefly chemical sediments of the Randville Dolomite of middle Precambrian Animikie age were laid down in a shallow marine environment. Gentle uplift ended the carbonate deposition, and subsequent erosion locally may have removed some of the upper part of the Randville Dolomite. General subsidence preceded deposition of the rocks of the Menominee Group, first of clastic material and then of iron-rich chemical precipitates, but it is not known if the Kelso Junction area was within the basin of deposition during this time; if the rocks of the Menominee Group were deposited, they were removed by erosion during a widespread but gentle uplift in post-Menominee, pre-Baraga time.

An epoch of volcanism followed, now represented by the Hemlock Formation of the Baraga Group which was deposited disconformably on the erosion surface of the Randville Dolomite. Ellipsoidal flows and graded beds of slate and tuff indicate marine deposition for much of the volcanic material, but massive flows and thick masses of pyroclastics probably accumulated, at least in part, on land. Local shallow marine basins adjacent to or partly surrounded by low-lying volcanic terrane was the likely geologic setting during Hemlock time. Centers of eruption may have been within or near the Kelso Junction quadrangle. With the wane of volcanic activity the iron-bearing clastic and chemical sediments of the Amasa Formation were deposited conformably on the Hemlock volcanics, apparently with some interbedding of the two formations. Soon after deposition the Amasa Formation was locally truncated, overlain by a conglomerate in the vicinity of the village of Amasa to the north, and possibly stripped away entirely in the Lake Mary quadrangle to the south. Under continuing conditions of sedimentation the slate and graywacke of the Michigamme Slate were deposited over a large area; they represent a time of general submergence for this part of Michigan. Volcanism resumed, and the Badwater volcanics, mainly submarine flows in this area, were deposited conformably on the Michigamme Slate. The Badwater Greenstone is the youngest unit of the Animikie Series now found in the quadrangle, but sedimentation continued in this general vicinity with the accumulation of the thick conformable sequence of sediments of the middle Precambrian Paint River Group now preserved to the southwest in the Iron River-Crystal Falls-Florence area.

Animikie sedimentation was terminated by a widespread orogeny. At some time before this deformation, gabbroic magma of the West Kiernan sill intruded the Hemlock volcanics and differentiated while in a horizontal sheet, and a gabbroic dike, probably associated with the sill, intruded the Michigamme Slate. The exact time of this emplacement is not known, but it may have been during Badwater time. Mafic dikes in the Margeson Creek Gneiss also may have been intruded during this time of late Animikie volcanic activity. All the intrusive rocks in the quadrangle are metamorphosed and therefore predate a period of intense regional metamorphism which was of post-Animikie and pre-Keweenawan age. One center of metamorphism lay northeast of the Kelso Junction area inasmuch as the metamorphic grade increases across the quadrangle in that direction. Post-Animikie deformation resulted in the development of the Amasa oval (fig. 1), an elongate domal uplift along an axis of northwesterly trend. The Kelso Junction quadrangle is on the southwestern flank of this structure, part of the core of which is represented by Margeson Creek Gneiss in the northeast corner of the map area.

The truncated structure of the Amasa oval is now mantled by glacial deposits of Pleistocene age, leaving a gap in the rock record of more than 1 billion years. The extent of Paleozoic and younger sedimentation is not known, but remnants of flat-lying Ordovician and Upper Cambrian strata in nearby areas are evidence of at least one post-Ordovician, pre-Pleistocene erosional interval. Continental ice sheets of Pleistocene age advanced over the land surface, locally scouring into bedrock but probably not greatly modifying the bedrock surface within the Kelso Junction quadrangle. As the last ice front wasted away, glacial debris as much as 200 feet thick covered most of the land surface. This glacial terrain, probably only slightly modified since the retreat of the last ice sheet, forms much of the present topographic expression in the quadrangle.

ECONOMIC GEOLOGY

IRON

The iron-bearing Amasa Formation is known or inferred to be present as a steeply dipping unit about 600 feet wide and more than 6 miles long across the Kelso Junction quadrangle. It has been explored locally within the quadrangle by drilling, but no commercial ore deposits have been discovered. However, iron ore has been mined from the formation both to the northwest and to the south beyond the margins of the quadrangle. Statistics compiled by the Geological Survey Division of the Department of Conservation of the State of Michigan show that a total of about 7,240,000 tons [2] has been shipped from nine mines that have operated in the Amasa Formation. Almost half of these shipments came from the Warner mine, in secs. 9 and 16, T. 44 N., R. 33 W., which closed in 1957 and was the last producing mine in the formation. The mined ore was classed as direct-shipping nonbessemer hematite.

Although no ore deposits were revealed by drilling within the Kelso Junction quadrangle, much of the formation has not been tested across the central part of the map area. Any undiscovered deposits would likely be similar to the relatively small and low-grade ore bodies mined

[2] Iron ore shipments are in gross tons.

from other parts of the formation, most of which probably would not be considered of economic value under present mining conditions. Nevertheless, considering that production exceeded 2 million tons from the Hemlock mine (near Amasa) and 3 milliion tons from the Warner mine, drilling the unexplored parts of the formation may be justified.

Increasing emphasis in the iron-mining industry is being given to beneficiation of low-grade iron-formation, and the trend is toward mining and treating near-surface low-grade deposits in preference to underground higher grade material. At present, suitability of iron-formation for treatment depends chiefly on the iron and gangue minerals being coarse enough for economical separation. The low metamorphic grade with the resulting fine grain size of the iron minerals, the evident deep oxidation, and the general glacial cover of plus 100 feet preclude considering the Amasa Formation within the quadrangle as a possible commercial iron source at present.

A strongly magnetic rock that apparently is a magnetite-rich differentiate of the West Kiernan intrusive has been test pitted in the NW¼ sec. 12, T. 43 N., R. 32 W. A sample containing coarse magnetite, probably representative of the rock exposed on the pit dumps, analyzed slightly more than 26 percent iron. (See table 5.) This magnetite body is too small to be of commercial interest, and because of the absence of significant aeromagnetic anomalies, it is unlikely that larger occurrences of economic value of this type material are present nearby.

OTHER METALS

Semiquantitative spectrographic analyses listed in table 6 show the presence of cobalt, copper, and nickel in the ultramafic differentiates of the West Kiernan intrusive, but values are too low to be of economic importance or to warrant further investigation.

NONMETALS

Sand, gravel, and crushed rock suitable for concrete aggregate and road building are present at numerous places in the quadrangle, but they have only very local value because similar material is almost everywhere available in this part of Michigan.

REFERENCES CITED

Aldrich, L. T., Davis, G. L., and James, H. L., 1965, Ages of minerals from metamorphic and igneous rocks near Iron Mountain, Michigan: Jour. Petrology, v. 6, no. 3, p. 445–472.

Allen, R. C., and Barrett, L. P., 1915, Contributions to the pre-Cambrian geology of northern Michigan and Wisconsin: Michigan Geol. and Biol. Survey Pub. 18, Geol. Ser. 15, p. 13–164.

Barrett, L. P., Pardee, F. G., and Osgood, W., 1929, Geologic map of Iron County: Michigan Geol. Survey Div., Dept. Conserv.

Bath, G. D., 1951, Magnetic base stations in the Lake Superior iron districts: U.S. Bur. Mines Rept. Inv. 4804.

Bayley, R. W., 1959a, Geology of the Lake Mary quadrangle, Iron County, Michigan: U.S. Geol. Survey Bull. 1077, 112 p.

——— 1959b, A metamorphosed differentiated sill in northern Michigan: Am. Jour. Sci., v. 257, p. 408–430.

Bergquist, S. G., 1932, Glacial geology of Iron County, Michigan: Michigan Acad. Sci. Papers, v. 16, p. 363–372.

——— 1935, Valley-train deposits in the northern peninsula of Michigan: Michigan Acad. Sci. Papers, v. 20, p. 439–447.

Clarke, F. W., 1924, The data of geochemistry [5th ed.]: U.S. Geol. Survey Bull. 770, 841 p.

Clements, J. M., and Smyth, H. L., 1899, The Crystal Falls iron-bearing district of Michigan: U.S. Geol. Survey Mon. 36, 512 p.

Daly, R. A., 1933, Igneous rocks and the depths of the earth: New York, McGraw-Hill Book Co., 508 p.

Eskola, Pentti, 1920, The mineral facies of rocks: Norsk geol. tidsskr., v. 6, p. 143–194.

Gair, J. E., and Wier, K. L., 1956, Geology of the Kiernan quadrangle, Iron County, Michigan: U.S. Geol. Survey Bull. 1044, 88 p.

Hotz, P. E., 1953, Petrology of granophyre in diabase near Dillsburg, Pennsylvania: Geol. Soc. America Bull., v. 64, no. 6, p. 675–704.

James, H. L., 1955, Zones of regional metamorphism in the Precambrian of northern Michigan: Geol. Soc. America Bull., v. 66, no. 12, pt. 1, p. 1455–1487.

——— 1958, Stratigraphy of pre-Keweenawan rocks in parts of northern Michigan: U.S. Geol. Survey Prof. Paper 314–C, p. 27–44.

James, H. L., Dutton, C. E., Pettijohn, F. J., and Wier, K. L., 1959, Geologic map of the Iron River-Crystal Falls district, Iron County, Michigan: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–225.

Lake Superior Iron Ore Association, 1938, Lake Superior iron ores: Cleveland, Ohio, 364 p.

Leith, C. K., Lund, R. J., and Leith, Andrew, 1935, Pre-Cambrian rocks of the Lake Superior region, a review of newly discovered geologic features, with a revised geologic map: U.S. Geol. Survey Prof. Paper 184, 34 p.

Martin, H. M., compiler, 1936, The centennial geologic map of the northern peninsula of Michigan: Michigan Geol. and Biol. Survey Pub. 39, Geol. Ser. 33.

Nockolds, S. R., 1954, Average chemical compositions of some igneous rocks: Geol. Soc. America Bull., v. 65, no. 10, p. 1007–1032.

Royce, Stephen, 1936, Geology of the Lake Superior iron deposits: Lake Superior Mining Inst. Proc., v. 29, p. 68–107.

Turekian, K. K., and Wedepohl, K. H., 1961, Distribution of the elements in some major units of the earth's crust: Geol. Soc. America Bull., v. 72, no. 2, p. 175–191.

Turner, F. J., 1948, Mineralogical and structural evolution of the metamorphic rocks: Geol. Soc. America Mem. 30, 342 p.

Van Hise, C. R., and Bayley, W. S., 1895, Preliminary report on the Marquette iron-bearing district of Michigan: U.S. Geol. Survey 15th Ann. Rept., p. 477–650.

Van Hise, C. R., and Leith, C. K., 1911, The geology of the Lake Superior region: U.S. Geol. Survey Mon. 52, 641 p.

Wager, L. R., and Deer, W. A., 1939, The petrology of the Skaergaard intrusion, Kangerdlugssuak, east Greenland: Medd. om Grønland, v. 105, no. 4, 335 p.

Wager, L. R., and Mitchell, R. L., 1951, The distribution of trace elements during strong fractionation of basic magma—a further study of the Skaergaard intrusion, east Greenland: Geochim. et Cosmochim. Acta, v. 1, no. 3, p. 129–208.

Walker, Frederick, 1940, Differentiation of the Palisades diabase, New Jersey: Geol. Soc. America Bull., v. 51, no. 7, p. 1059–1105.

Walker, Frederick, and Poldervaart, Arie, 1949, Karroo dolerites of the Union of South Africa: Geol. Soc. America Bull., v. 60, no. 4, p. 591–701.

U.S. GOVERNMENT PRINTING OFFICE 1966