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National Uranium Resource Evaluation

**IRON RIVER QUADRANGLE
MICHIGAN AND WISCONSIN**

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U.S. Geological Survey
Golden, Colorado

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NATIONAL URANIUM RESOURCE EVALUATION
IRON RIVER QUADRANGLE
MICHIGAN AND WISCONSIN

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With sections on Interpretation of U.S. Department of Energy Aerial
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This report has not been edited for conformance with U.S.
Geological Survey stratigraphic nomenclature or resource
classification.

This is the final version of the subject-quadrangle evaluation report to be placed on open file. This report has not been edited. In some instances, reductions in the size of favorable areas on Plate 1 are not reflected in the text.

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* This map is available as U.S. Geological Survey Open-File Report 78-342 and may be obtained from the Open-File Services Section, Branch of Distribution, U.S. Geological Survey, Box 25425, Federal Center, Denver, CO 80225.

ABSTRACT

No area within the Iron River 1° x 2° Quadrangle, Michigan and Wisconsin, appears to be favorable for the existence of a minimum of 100 tons of U_3O_8 at a grade of 0.01 percent or better.

INTRODUCTION

PURPOSE AND SCOPE

The geology of the southern Lake Superior region is similar to a number of geologic terranes which contain uranium districts that either are or will be among the most important producing districts in the world. Three of the important districts to which the southern Lake Superior region has some similarities are the nearby Blind River-Elliott Lake district, Ontario; the district containing the uranium deposits around the margin of Athabasca Basin, Saskatchewan; and the East Alligator River district in the Pine Creek geosyncline, Northern Territory, Australia.

The Iron River Quadrangle, Upper Peninsula of Michigan and portions of adjacent Wisconsin (Fig. 1), was evaluated as part of the National Uranium Resource Evaluation (NURE) program to identify areas or geologic units that exhibit characteristics favorable for the occurrence of uranium deposits. Areas and geologic units within the quadrangle were evaluated so that they could be placed into one of three categories developed by the U.S. Department of Energy (DOE); favorable, unfavorable, or unevaluated. Classification as favorable or unfavorable was based primarily on use of the recognition criteria for various classes of uranium deposits, as described in a collection of papers edited by Mickle and Mathews (1978) and prepared for use in the NURE program. Specific papers in this volume are cited below where appropriate.

This study was conducted by the U.S. Geological Survey (USGS) for the U.S. Department of Energy (DOE) in coordination with the Bendix Field Engineering Corporation (BFEC). The evaluation began on January 23, 1978 and ended November 28, 1980. Including preparation of a work plan in an earlier phase of the NURE program work, approximately four man years were expended on literature review, field work, data evaluation, and folio preparation.

CANADA

Figure 1. Location of Iron River Quadrangle.

RESPONSIBILITY

This report is the result of the work of a number of investigators, not all of whom agree on every point of observation or interpretation. However, with the exception of sections dealing with interpretation of aerial radiometric and soil-gas helium data, the interpretations and conclusions presented are solely the responsibility of the principal author.

PROCEDURES

Evaluation of the Iron River Quadrangle was done in three phases. Phase 1 consisted of (1) a search of the literature for information on the general regional geology and the geology of uranium environments, in order to identify environments within the quadrangle that might be hosts for uranium ore deposits; (2) preparation of a map showing all known uranium deposits and all known occurrences of anomalous uranium concentrations in the quadrangle; and (3) preparation of a work plan for the remainder of the investigation, selection of appropriate personnel to accomplish the tasks defined in the work plan, and assignment of specific duties to each. Phase 2 consisted of (1) field evaluation of known occurrences of uranium and attempts to classify each using DOE recognition criteria (Mickel and Mathews, 1978); (2) attempts to delineate the areas, geologic units, or parts of geologic units in which occurrences of specific classes were found; and (3) field study, including a rock sampling program in areas considered potentially favorable. Our investigations were supplemented by and partly planned around results of an aerial radiometric survey conducted by Geometrics, Inc., (1978). A hydrogeochemical and stream-sediment reconnaissance (HSSR) survey conducted by the Union Carbide Corporation Oak Ridge Gaseous Diffusion Plant (ORGDP, 1980) also aided in the evaluation of geologic environments, but unfortunately the HSSR study was not released until essentially all of the field work done for this quadrangle evaluation had already been completed. For this reason, no HSSR anomalies could be checked in the field. Both surveys were done under contracts from the DOE and were specifically designed to aid in the uranium resource evaluation of the Iron River Quadrangle. Phase 3 consisted of evaluation of the information and data collected during phases 1 and 2 and the preparation of this folio. It should be noted that the principal author was involved only in Phase 3 of this study.

GEOLOGIC SETTING

Physiography

The Iron River Quadrangle is largely an upland area of low to moderate relief. Lake Superior has an approximate mean elevation of 183 m and a few small lowland areas occur close to the shore. Most of the quadrangle, however, is characterized by low hills and ridges separated by flat, commonly swampy areas. Most of this upland surface is between 350 and 500 m above sea level. Mount Curwood, summit elevation 603.5 m, is the highest point in the

quadrangle and the highest point in the State of Michigan.

The entire region was glaciated during the Pleistocene, and consequently many of the surface features are of glacial origin. The surface is covered by variable thicknesses of glacial deposits throughout most of the quadrangle. Where these deposits are thick, outcrops are rare to nonexistent and, as a rough estimate, it is probably fair to say that more than 99 percent of the surface is covered by till, lake sediments, or recent alluvium; bedrock is therefore unavailable for inspection without drilling. The general extent and location of bedrock outcrops is shown on the map of Quaternary glacial features, Plate 10B.

Stratigraphy and Geologic History

With the exception of Pleistocene glacial, glaciofluvial, and lacustrine deposits, essentially all of the rocks in the Iron River Quadrangle are thought to be Precambrian in age. The Precambrian section in the region can be divided into three main age groups. These are (1) gneisses, granites, and metavolcanic rock older than 2600 m.y. (Archean or Precambrian W; see footnote 1 on Fig. 2); (2) metavolcanic and metasedimentary rocks between 2600 and 1900 m.y. old (Precambrian X), predominantly the Marquette Range Supergroup; and (3) rocks younger than 1900 m.y. (Precambrian Y), the mafic volcanic rocks and overlying sediments of the Keweenaw Peninsula and the Jacobsville Sandstone. Stratigraphic columns depicting the interrelationships between sedimentary and volcanic units in the quadrangle are presented as Figures 2a, 2b, and 2c. Relative ages of intrusive and plutonic rocks are shown in Figure 2d. Areal distribution of the rock units is shown on the bedrock geologic map, Plate 10A. The culture map, Plate 13, and Figure 3 show geographic and geologic features referred to in the following discussion of stratigraphy and geologic history.

Column 2a. (1)
Marquette range and vicinity

Precambrian (2)	Era	System	Series	Supergroup	Group	Stratigraphic Unit	Lithology	Description
Precambrian (2)	Cenozoic	Quaternary	Pleistocene					Glacial and lake sediments
						Jacobsville Sandstone		Red and brown sandstone with subordinate conglomerate, siltstone and shale
						Michigamme Formation		Mostly light to dark grey greywacke and slate commonly in graded beds. Variably metamorphosed to a variety of pelitic schists and gneisses. Black graphitic pyritic slate abundant in the lower portion of the formation.
						Goodrich Quartzite		White to grey vitreous quartzite, conglomeratic near the base.
						Negaunee Iron-formation		Cherty, gruneritic, hematitic, and magnetic iron-formation
						Siamo Slate		Laminated siltstone and slate.
						Ajibik Quartzite		Vitreous pure to feldspathic quartzite.
						Granitic rocks		Massive to foliated tonalite to granite. Locally, this unit includes amphibolite and migmatite. ~ 2600 m.y.
								Medium to coarse grained tonalite to granitic gneiss, also amphibolitic and pyroxenitic gneiss, migmatite, and massive granitic rock. ~ 3000 m.y.

Figure 2a. Generalized stratigraphic column for the Marquette Range and vicinity of the Iron River Quadrangle, Michigan and Wisconsin.

Column 2b⁽¹⁾
Iron River-Crystal Falls District
including Amasa Uplift and vicinity

Era	System	Series	Supergroup	Group	Stratigraphic Unit	Lithology	Description
Cenozoic	Quaternary	Pleistocene					Glacial and lake sediments
					Fortune Lakes Slate		Slate with interbedded greywacke and minor sideritic slate
					Stambaugh Slate		Laminated cherty magnetic slate
					Hiawatha Greywacke		Massive greywacke and slate
					Riverton Iron-formation		Thin-bedded cherty sideritic iron-formation with minor graphitic and sideritic slate
					Dunn Creek Slate		Mostly slate and siltstone, but includes an upper unit of graphitic pyritic slate
			Barquette Range Supergroup	Paint River Group	Badwater Greenstone		Massive chloritized volcanic rocks, mostly ellipsoidal greenstone, but includes abundant tuff and agglomerate
					Michigamme Formation		Mostly light to dark gray greywacke and slate commonly in graded beds. Variably metamorphosed to a variety of pelitic schists and gneisses. Black graphitic pyritic slate is abundant in the lower portion of the formation.
					Strata near Fence Lake ⁽³⁾		Very poorly exposed unit containing lean magnetic iron-formation, mafic volcanic rocks, and probably slate and greywacke
					Banded iron-formation in the Baraga Group ⁽³⁾		Largely cherty carbonate iron-formation plus more highly metamorphosed iron-silicate bearing equivalents. Includes some ferruginous slate
					Hemlock Formation (North and east of Crystal Falls)		Hemlock: Metamorphosed basalt flows and mafic to felsic tuff and agglomerate with interlayered lean magnetic iron formation, greywacke, and ferruginous slate.
				Chocoma Group	Volcanic rocks in the Baraga Group ⁽³⁾		Baraga Volcanics: Chloritized mafic and intermediate agglomerate, tuff and flows, and more highly metamorphosed amphibolitic equivalents.
					Randville Dolomite (Amasa Oval and Dickinson Co.)		Randville Dolomite: Dolomite and sandy dolomite with interlayers of slate, argillite, and quartzite. Tremolite-bearing dolomitic marble at some localities.
					Saunders Formation (South of Iron River)		Saunders Formation: Dolomite and silicified dolomite
				Dickinson Group	Granitic rocks		Massive to foliated tonalite to granite, locally this unit includes amphibolite and migmatite. 2600 m.y.
					Undivided		Unit includes quartz-sericite schist, magnetic schist, and felsite; these are all thought to be metavolcanic rocks.
					Gneiss		Medium to coarse grained tonalite to granitic gneiss; also amphibolitic and perovskitic gneiss, migmatite, and massive granitic rocks. >1000 m.y.

Figure 2b. Generalized stratigraphic column for the Iron River-Crystal Falls district including the Amasa Uplift and vicinity of the Iron River Quadrangle, Michigan and Wisconsin.

Column 2c (1)
Western Portion of the Quadrangle

Era	System	Series	Supergroup	Group	Stratigraphic Unit	Lithology	Description
Cenozoic	Quaternary	Pleistocene					Glacial and lake sediments
Precambrian (2)	Precambrian (2)	Precambrian (2)	Keweenaw		Jacobsville Sandstone		Red and brown sandstone with lesser conglomerate, siltstone, and shale. Age uncertain, may in part be equivalent in age to the Freda Sandstone or the Nonesuch shale.
					Freda Sandstone		Reddish medium- to fine-grained arkosic sandstone with lesser siltstone and shale.
					Nonesuch Shale		Grey shale and siltstone with minor sandstone.
					Copper Harbor Conglomerate		Red and brown conglomerate and sandstone; most clasts are felsic volcanic rocks with minor mafic volcanic rocks and very rare Pre-Keweenaw rocks. Locally contains mafic volcanic flows.
					Unnamed formation		Mafic volcanic flows and interlayered felsic flows.
					Portage Lake Volcanics		Mafic flows, largely in thick flow units with amygdular tops. Minor interflow conglomerate.
					Kallander Creek Formation		Predominantly intermediate with subordinate mafic flow rocks.
					Siemens Creek Formation		Predominantly mafic flow rocks.
			Marquette Range Supergroup	Baraga Group	Michigan Formation (South and east of Lake Gogebic)		Michigan Formation: Mostly light to dark grey greywacke and slate, commonly in graded beds. Variably metamorphosed to a variety of pelitic schists and gneisses. Subordinate graphitic pyritic slate.
					Coppes Formation (Lakefield-Lake Gogebic area)		Coppes Formation: Metagreywacke and slate similar to the Michigan Formation. Locally derived conglomerate near base.
					Tyler Formation (Kansas area)		Tyler Formation: Light to dark grey feldspathic sandstone, argillite and minor slate; lenses of iron-formation and iron-rich elastic rocks near base.
					Metavolcanics (Northeast and southwest of Thayer Siding)		Baraga metavolcanics: Very poorly exposed unit believed to be mostly mafic metavolcanic rocks.
					Magnetic iron-formation		Unexposed but magnetically well defined unit composed of lean magnetic iron-formation, graphitic slate, and grunerite-biotite-garnet schist.
				Keweenaw Group	Emperor Volcanic Complex		Emperor volcanics: Metamorphosed mafic to intermediate pyroclastic and flow rocks.
					Ironwood Iron-formation		Ironwood Iron-formation: Interlayered cherty hematitic iron-formation, sideritic iron-formation, and iron-silicate iron-formation.
					Palms Formation		Impure quartzite, argillite, and slate; thin basal conglomerate. Locally the Bad River Dolomite and Sunday Quartzite of the Chocoma Group are mapped with this unit as thin units at the base.
				Chocoma Group	Metasediments		Very poorly exposed unit known mostly from drill core to be black slate, dolomite, quartzite, and cherty iron-formation. Stratigraphic correlations uncertain.
					Granitic rocks		Massive to foliated tonalite to granite. Locally this unit includes amphibolite and migmatite. ~2600 m.y.
					Metavolcanic and metasedimentary rocks		Metamorphosed mafic and intermediate flows and pyroclastic rocks; rare felsic rocks. The metavolcanics contain lean magnetic iron formation in some localities. Also metagreywacke, biotite schist, and fine-grained gneiss.
					Gneiss		Medium to coarse grained tonalite to granite gneiss, also amphibolite and pyroxenite gneiss, migmatite, and massive granitic rock. ~3000 m.y.

Figure 2c. Generalized stratigraphic column for the western portion of the Iron River Quadrangle, Michigan and Wisconsin.

Column 2d. (1)
Intrusive and Plutonic Rocks

Era	System	Series	Supergroup	Group	Stratigraphic Unit	Lithology	Description
Precambrian (2)	Precambrian (2)	Precambrian Y (2)			(4)		
					Diabase		Massive, medium to coarse-grained diabase. Common as west-trending dikes.
					(4)		
		Precambrian X (2)	Marquette Range Supergroup	Peavy Pond Group	Peavy Pond Complex		Medium grained, grey to pink somewhat sheared granitic rock.
					Granitic rocks		Peavy Pond Complex: chiefly hornblende metagabbro but includes metanorite, metadiorite, granodiorite, and granite.
					(4)		
				Baraga Group	Mafic intrusive rocks		Massive to weakly foliated chloritic and amphibolitic derivatives of gabbro and diabase.
					(4)		
				Menominee Group	(4)		
				Chocolay Group	(4)		
		Precambrian W (2)			Granitic rocks		Massive to foliated tonalite to granite. Locally, this unit includes amphibolite and migmatite. ~2600 m.y.
					(4)		

FOOTNOTES TO STRATIGRAPHIC COLUMNS

- (1) Precambrian X, Y, and Z are now more properly termed proterozoic X, Y, and Z; Precambrian W has been replaced by Archean. The older terminology is used in Figures 2a through 2d so that the stratigraphic columns will conform to the geologic map (Pl. 10A).
- (2) Time terms without specific rank.
- (3) Not a formal stratigraphic unit. These informal terms are used to make the stratigraphic columns conform to the geologic map.
- (4) Space indicates no intrusive or plutonic rocks recognized in this time interval.

Figure 2d. Age relationships among crystalline rocks in the Iron River Quadrangle, Michigan and Wisconsin.

Figure 3. Index map to place names and prominent geologic and structural features in the Iron River Quadrangle, Michigan and Wisconsin.

The Iron River Quadrangle is located near the southern boundary of the Canadian Shield tectonic province. The granitic and metavolcanic rocks southwest and west of Lake Gogebic are part of a 2700 m.y. old greenstone-granite terrane defined by Morey and Sims (1976) which is typical of the majority of the Canadian Shield (Sims and others, 1977); the gneisses and granitic rocks in the remainder of the quadrangle are part of an older, granite-gneiss terrane.

Gneisses of this older terrane (3000 to 3500 m.y., Peterman and others, 1976) occur predominantly as gneiss domes in the eastern and southwestern portions of the quadrangle. Outcrops in the gneiss domes are not numerous, but judging from the few outcrops which do exist, domes in the southwestern quarter of the quadrangle are usually medium grey, medium grained, layered feldspathic augen gneiss with lesser amounts of light- to medium-grey, fine- to medium-grained biotite-quartz-feldspar gneiss. Gneisses in the eastern portion of the quadrangle are generally similar but also include the texturally distinct pink, white, or grey Bell Creek Gneiss, a very coarse grained rock of granitic composition which contains pink microcline megacrysts, commonly 4 cm long, set in a matrix of coarse quartz, feldspar, and biotite. Mafic gneiss and amphibolite occur in minor amounts in both the eastern and southwestern terranes. The younger, greenstone-granite terrane is exposed only in the area between Gogebic Station and Wakefield, where granitic rocks of the Puritan Quartz Monzonite (Sims and others, 1977) intrude a sequence of steeply dipping mafic pillow lavas and pyroclastic rocks of felsic to intermediate composition. The metamorphic grade of the volcanic rocks increases from greenschist facies to amphibolite facies as the contact with the quartz monzonite is approached, suggesting that the metamorphism is genetically related to the intrusion (Prinz and others, 1975).

The Puritan Quartz Monzonite consists predominantly of light-grey, buff, or pale-red, medium- to coarse-grained, massive, leucocratic quartz monzonite which may be either equigranular or porphyritic (Sims and others 1977). Granitic pegmatites are also common, usually as small bodies a few centimeters to a few tens of meters in maximum dimension. Small amounts of migmatitic gneiss also occur within the intrusion.

The middle Precambrian or Precambrian X units are a very thick sequence of predominantly metasedimentary and metavolcanic units that change from a generally miogeoclinal assemblage at the base to an assemblage more typical of eugeoclinal conditions in the middle and upper portions of the assemblage. The entire section, the Marquette Range Supergroup, has been estimated to be more than 15 km thick (King, 1976).

The age of these units cannot be determined with any certainty, although some information is available. Certainly they are younger than the granitic rocks they unconformably overlie, and younger than the suture which joins the granite-greenstone and granite-gneiss terranes already described; This makes them younger than about 2600 m.y. (Sims, 1976; Cannon 1978). Conversely, they must be older than the tectonothermal event known as the Penokean Orogeny (Cannon, 1973), and numerous studies indicate that Penokean deformation and

plutonism began approximately 1900 m.y. ago (Aldrich and others, 1965; Banks and Cain, 1969; Banks and Van Schmus, 1971; Goldich, 1972; Stuckless and Goldich, 1972; Van Schmus, 1972, 1974; Van Schmus and others, 1975. See also Klasner, 1978). There is little data with which to better define the depositional age of these Precambrian X strata. A felsic volcanic rock from the Hemlock Formation has yielded an age of 1950 m.y. (Banks and Van Schmus, 1972) based on U-Pb ages of zircons; a similar rock from the Quinnesec Formation has yielded a single date of 1905 m.y. by the same method (Banks and Rebello, 1969). These data suggest that, at least for the Baraga Group, the main period of sedimentation was late in the 2600 m.y. to 1900 m.y. time period. Incomplete data in Van Schmus (1976, p. 612) suggest that the same may be true for the Marquette Range Supergroup as a whole; a similar suggestion has been made by Morey and Goldich (1977). At present, it can be said that the majority of the Precambrian X units were probably deposited between 2100 and 1900 m.y. ago, although some may be older.

The following discussion of Precambrian X sedimentary and tectonic history is taken largely from Sims (1976), Van Schmus (1976), and Larue and Sloss (1980). The reader is referred to these works and to the references contained therein for a more complete treatment of the subject as well as for speculations on the plate-tectonic regime, if any, that pertained at the time.

Sedimentation began with deposition of tillites. This was followed by stable-shelf accumulations, in part shallow-water deposits, now represented by dolomite (or tremolite-bearing dolomitic marble where highly metamorphosed), silicified dolomite, quartzite, and minor agillite, slate, and iron-formation; some of the dolomites contain stromatolitic structures. Together, these deposits comprise the Chocoley Group (Figs. 2b and 2c; Pl. 10A). Following uplift and erosion, sedimentation resumed with deposition of vitreous to feldspathic quartzite, laminated siltstone and slate, dolomite, argillite, and the major iron-formations of the Upper Peninsula, although not the ones of primary economic importance within the Iron River Quadrangle. The Emperor Volcanics, mafic to intermediate pyroclastic and flow rocks, were also emplaced at this time. These strata constitute the Menominee Group and are in turn unconformably overlain by the Baraga Group. Uplift and erosion during the Menominee-Baraga sedimentation hiatus was extensive at some localities; in places the Baraga Group sediments rest directly on the Chocoley Group or directly on Precambrian W gneisses.

In contrast to the stable shelf, miogeoclinal conditions that existed prior to this hiatus in sedimentation, the Baraga Group records the beginning of a more eugeoclinal environment typified by rapid subsidence, deposition of thick turbidite sequences, and abundant subaerial and subaqueous volcanism. The Baraga Group, then, is composed of thick sequences of mafic to felsic flows, tuffs, and agglomerates, thick greywacke-shale units, (the thickest being the Michigamme Formation), siltstone, argillite, and minor feldspathic sandstone. Iron-formation occurs at a number of stratigraphic horizons, and each probably represents a local cessation of clastic sedimentation and volcanism.

The Baraga Group is overlain by the Paint River Group which is preserved only in the Iron River-Crystal Falls area. The Paint River Group is similar to the Baraga Group in that it is composed dominantly of greywacke and slate, but no volcanic rocks are recognized in the section. The Riverton Iron-formation occurs near the base of the section, and from it has come the majority of the iron ore produced within the boundaries of the quadrangle.

At the close of Precambrian X time, all of the rock units previously described were deformed and metamorphosed during the Penokean Orogeny (Cannon, 1973). Three and possibly four stages of deformation have been recognized (Klasner, 1978), the first two being soft-sediment deformation and gravity sliding northward off a postulated Penokean mountain range in central Wisconsin. This was followed by the rise of fault-bound blocks of Precambrian W gneisses and granites, probably in two stages, producing the major large folds of the region. The folds were probably produced as a result of the Precambrian X strata being draped over and between the uplifted blocks and are not thought to be the result of compressional tectonics. During this period of deformation, a regional thermal event resulted in metamorphism ranging from chlorite to, locally, sillimanite grade. James (1955) recognized four distinct thermal nodes in the Upper Peninsula, and these are shown in Figure 4.

The Penokean Orogeny was followed by a long period of erosion or nondeposition. No events are recorded in the rock record until the deposition of the Bessemer Quartzite, followed by the mafic to intermediate volcanic flows of the Powder Mill Group. The age of these units is not well known, but they are thought to be around 1100 m.y. old or slightly older (Chaudhuri, 1975; Sims, 1976). These flows are unconformably overlain by the Jacobsville Sandstone, a fluvial, continental, red-bed sequence locally over 1000 m thick (Kalliokoski and others, 1978). The Jacobsville is thought to be either Upper Proterozoic (White, 1966; Cannon, 1978) or Cambrian (Hamblin, 1961; Dorr and Eschman, 1973) in age. The outcrop belt of the Jacobsville Sandstone is truncated to the northwest by the Keweenaw Fault, a major crustal structure that separates the Jacobsville from the rocks of the midcontinent rift system (King and Zietz, 1971). These latter units, hosts to all of the major copper deposits of the area, consist of the voluminous mafic flows of the Portage Lake Volcanics and an unnamed formation overlain by a sedimentary sequence made up of the Copper Harbor Conglomerate, the Nonesuch Shale, and the Freda Sandstone. These formations are believed to have been deposited in and adjacent to a midcontinental rift, which developed around 1100 m.y. ago (Morey, 1978), and they record the last event in the Precambrian geologic history of the Upper Peninsula.

Figure 4. Generalized geologic map of Northern Michigan, showing metamorphic zones. Modified from James (1955).

INTERPRETIVE AERIAL RADIOMETRIC MAPS OF THE IRON RIVER 1°x2°
QUADRANGLE, MICHIGAN AND WISCONSIN
by
James A. Pitkin and Joseph S. Duval

INTRODUCTION

Interpretive aerial radiometric maps have been made from composite color images of NURE aerial radiometric data for the Iron River Quadrangle. The composite color images were produced by synthesizing different components of the aerial radiometric data. The interpretive maps were produced from the images and show uranium anomalies and radiometric units for the Iron River Quadrangle.

METHOD

The NURE aerial survey of the Iron River Quadrangle acquired high sensitivity gamma-ray spectrometric data along east-west traverse lines spaced 5 km (3.1 m) apart and north-south tie lines spaced 30 km (18.6 mi) apart (Geometrics, 1978). Data channels for the radioelements uranium (U), thorium (Th), and potassium (K) were extracted from the NURE data set and used to prepare the composite images for this report.

Processing of the three radioelement components began with filtering, using a gaussian 9-point moving-average filter. The next step was elimination of all values at or near zero, both positive and negative, to negate the effects of bodies of water, normally zero radiometrically, in the images. Ratios (U/Th, U/K, Th/K) were computed and then all six components (three radioelements and three ratios) were gridded with a standard gridding routine. A grid cell size of 400 m (0.25 mi) was used to obtain maximum resolution along traverse lines, even though line spacing was 5 km (3.1 m). During image interpretation, features between traverse lines were ignored.

Following gridding, the data were converted to image format where the frequency distribution of each component was mapped to a uniform scale of 1 to 255. For a distribution of 100 percent, all low observations (≤ 2 percent of the distribution) were set to 1, all high observations (≥ 98 percent) were set to 255, and all observations > 2 percent and < 98 per cent were assigned a value between 1 and 255 proportional to the magnitude of the count rate of that component. Setting the low observations equal and the high observations equal assumes that little additional information is contained in the knowledge of how high or how low these observations are.

The image format data were written to film by means of an Optronics ^{1/} optical encoder. Each composite image consists of three components that have been assigned a specific color (red, green, blue). The intensity of a color depends upon the numerical value of the component and the density of data on film is linear as a function of input number.

Three composite images were prepared for the Iron River Quadrangle: (1) a uranium image with the components U, U/Th, and U/K; (2) an element image with the components U, Th, and K; and (3) a ratio image with the components U/Th, U/K, and Th/K. These images were examined with the aid of a Zoom ^{1/} transfer scope and an interpretive map was prepared for each image. Plate 3A is uranium anomalies determined from the uranium composite image; Plate 3B is radiometric units determined from the radioelement composite image; and Plate 3C is radiometric units determined from the radioelement ratio composite image.

DISCUSSION OF INTERPRETIVE MAPS

Uranium Anomaly Map

Plate 3A shows areas defined as anomalous in relative uranium concentration as determined from the uranium composite image. On the image, these areas are strongly positive features and are, therefore, considered as anomalous. The compositing of the three uranium components is designed to enhance the uranium contribution to the image, and thereby highlight geochemically the relative occurrence of uranium.

Three anomalies (A, B, and C on Pl. 3A) correlate with known occurrences of uranium mineralization or with anomalous radioactivity measured on the ground (Pl. 2). In each case, the supposition can be made that the uranium concentration and or the anomalous ground radioactivity is of greater areal extent than was originally thought. Anomaly A correlates with anomalous radioactivity in cherty iron-formation and graphitic soil, and uranium in an altered dike and graphitic slates (Occ. Nos. 7 and 8, Apps. A and C; Pl. 2). Anomalies B and C probably correlate with uranium minerals in mine-dump debris, because the reported uranium for both anomalies is in underground iron mines (Occ. Nos. 16 through 21, Pl. 2).

^{1/} The use of trade names is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

The six anomalies within the dashed area labeled anomaly D (Pl. 3A) do not correlate with any of the known occurrences shown in Plate 2, but all of these anomalies are at least partly within the mapped extent of the lower slate member of the Michigamme Formation. This unit is black graphitic pyritic slate with subordinate graywacke and quartzite (Pl. 10A) and contains several uranium occurrences (Pl. 2), including one occurrence at anomaly A. The anomalies of area D could represent radioactive, perhaps uranium, minerals in the slate.

The remaining anomalies on Plate 3A do not correlate with any of the other occurrences of Plate 2 and examination of the glacial (Pl. 10B) and bedrock (Pl. 10A) geologic maps does not help explain their existence.

Map of Radiometric Units Determined From Radioelement

Composite Image, (eu, eTh, K)

Plate 3B shows radiometric units (A through K) that represent a uniform and distinct color or a combination of colors on the composite image. These units reflect relatively uniform radioactive features at the surface of the ground, which in the Iron River Quadrangle result from, singly or in combination, soils, glacial or glaciofluvial deposits, or bedrock outcrops. The fact that a radiometric signature results from probable multiple or heterogeneous geologic sources complicates interpretation of the radiometric data. Also, the Iron River Quadrangle was repeatedly glaciated during the Pleistocene and nearly all bedrock is obscured by the various glacial deposits.

Comparison of the radiometric map (Pl. 3B) with the glacial geologic map (Pl. 10B) shows that the large area of unit A east of Lake Gogebic coincides almost directly with a lake-bed deposit. Three other areas of unit A, west and south of Keweenaw Bay, partly coincide with mapped lake-bed deposits. The lake beds are known to contain appreciable clay, and it is suggested that radiometric unit A indicates the more clay-rich areas.

In the southeast part of the quadrangle, the boundary between unit J, to the north, and Unit I, to the south, coincides with the south border of the Winegar moraine. Just east of this feature, the boundary between units J and H correlates with the boundary between distinctly different parts of the Winegar moraine. That part of the moraine to the west (unit J) is described as being more fine-grained and more clay-rich than that part to the east (unit I). South of the moraine, the areas of units I and H are also finer grained than unit J. This distinction seems to be localized, for other areas of unit J do not correlate directly with more fine-grained or clay-rich deposits.

Radiometric units that are explained by bedrock data include the larger area of unit C at the east-central side of the quadrangle where gneissic rocks (Pl. 10A, unit Wgn) are mapped. Three nearby areas of unit C also partly coincide with mapped areas of gneiss. North of the larger area of unit C,

unit J correlates with granite (Pl. 10A, unit Wg) in an area where the surficial cover is a thin veneer of glacial drift. Another occurrence of granite on the west side of the quadrangle is not expressed by a radiometric unit, probably because of thicker glacial cover.

Several features of the uranium anomaly map (Pl. 3A) also appear on the radioelement unit map (Pl. 3B). The mine dump anomalies labeled B and C on Plate 3A are reflected in unit B of Plate 3B in the southeast part of the quadrangle. The lower slate member of the Michigamme Formation, the host for the anomalies labeled D of Plate 3A, is mostly outlined by unit F of Plate 3B.

Most of the units on the radioelement map, both large (G, H, I, J) and small (B, D, E, K), do not relate to the glacial map or the bedrock map. These units probably represent lithologic features that are part of a glacial deposit or deposits. These deposits most typically have a large variation in grain size, lithology, provenance, and thickness. The few correlations seen occur where the source is known to be homogeneous (clay, granite, gneiss) or the glacial cover is thin, whereas lack of correlation results from the great heterogeneity of glacial deposits.

Map of Radiometric Units Determined From Radioelement Ratio Composite Image,
(eu/eTh, eU/K, eTh/K)

Plate 3c shows color features determined in the same manner as the radioelement map (Pl. 3B), and obviously has less detail or fewer units than the radioelement maps. The ratios were computed from components (K, U, Th) that have similar attenuation coefficients for the absorption of gamma rays in air. The compositing of the ratios could have a canceling effect that smooths the data and results in features that are not as obvious or even not seen on the element image. Also, the lack of detail in the ratio image possibly indicates that the total radioelement geochemistry is more uniform than the element image shows, reflecting the mixing effect of repeated pulses of glaciation.

The ratio map has a gross pattern of units that suggests correlation with several lobes of Pleistocene glaciation. The Ontonogan lobe originated in Lake Superior and moved southward where it included most of unit C, the northern part of unit D, and northwestern part of unit E. The Keweenaw Bay lobe originated in Keweenaw Bay and moved to the southwest where it occupied most of unit E. Unit D, which occupies most of the southeast part of the Quadrangle, includes areas covered by both lobes and the Green Bay lobe, which originated to the east.

The only specific correlation on the ratio map is the areas of unit B in the southeast part, where the association with areas of gneiss (Pl. 10A, unit Wgn) is similar to the areas of unit C on the radioelement map (Pl. 3B).

CONCLUSIONS

The uranium anomaly map (Pl. 3A) correlates with three areas of known uranium mineralization or anomalous ground radioactivity. A cluster of six anomalies may indicate good uranium potential for they lie within the outcrop of a black graphitic pyritic slate that has a known occurrence of uranium. Other areas defined as anomalous on the anomaly map cannot be explained at present.

The radiometric unit maps (Pls. 3B and 3C) show little direct correlation with mapped geologic units, either glacial or bedrock. The mixing action of repeated glacial advances results in correlations only where the source is homogeneous (clay, perhaps gneiss) or the covering glacial deposits are thin (granite, perhaps gneiss, slate). Glacial units are more commonly defined on the basis of genesis rather than lithology.

INTERPRETATION OF DOE HYDROGEOCHEMICAL AND STREAM SEDIMENT RECONNAISSANCE DATA

As part of the NURE program, a systematic water and stream sediment sampling program was conducted in the Iron River Quadrangle by the Union Carbide Oak Ridge Gaseous Diffusion Plant (ORGDP) under contract to DOE. The results of this sampling program were released too late for any follow-up studies to be conducted by the USGS, but knowledge gained during this assessment for uranium favorability allows a few additional conclusions to be drawn in addition to those presented in the Union Carbide report (ORGDP, 1980).

The ORGDP ground-water data show a distinct, strong anomaly in uranium, uranium/specific conductance, uranium/sulfate, and a number of other parameters in a fairly large area east of Lake Gogebic underlain by the Jacobsville Sandstone. This area also contains a group of air radiometric anomalies as defined by Geometrics (1978). The Geometrics anomalies all lie within the USGS radiometric unit A (Pl. 3B), and the match between the boundaries of radiometric unit A and the glacial lacustrine silt and clay deposits shown on Plate 10B (unit gsc) is remarkable. Because the air radiometric data reflects the upper meter, at most, of the ground surface, there is no doubt that the high uranium values recorded by Geometrics must be related to uranium contained in these clayey lake sediments. The ORGDP ground-water anomalies also lie within these lacustrine beds, and it seems reasonable to ascribe the anomalous uranium in the ground water to the same source as the apparent air radiometric anomalies: the Pleistocene lacustrine beds.

The geochemical anomaly defined by the ground-water data extends, discontinuously, northward from these lake deposits across the Keweenaw fault into an area underlain by Keweenaw volcanic and sedimentary rocks and covered by Pleistocene ground moraine. The northern portion of this ground-

water anomaly is not well explained by either the bedrock or surficial geologic maps (Pls. 10A and 10B).

RECONNAISSANCE SOIL-GAS HELIUM SURVEY OF THE IRON RIVER
1°x2° QUADRANGLE, MICHIGAN AND WISCONSIN
by G. M. Reimer

In May, 1980, a soil-gas helium survey was conducted in the Iron River Quadrangle. The technique used is described briefly below. A more extensive discussion is contained in Reimer and others (1979).

Soil-gas samples were collected using a hollow steel probe, 6 mm in diameter and 1.2 m in length. The tip of the probe is closed and holes are drilled into the side to admit the gas. The other end of the probe is fitted with a syringe injection guide containing a rubber septum. The probe is pounded into the ground by means of a dead-weight hammer sliding between two pounding collars. The probe, having a dead volume of about 1 cm³, is purged of atmosphere by withdrawing about 10 cm³ of gas in a plastic hypodermic syringe. The sample is then collected and the syringe needle is capped. Approximately 12 cm³ of gas is enough for a quadruplicate analysis.

Samples were analyzed using a small Dupont 1/ mass spectrometer tuned for a mass-to-charge ratio of 4 (He). The mass spectrometer and associated electronics are mounted in the cab of a four-door pickup truck. A recorder, stabilized power supply, voltage monitor, and reference gas outlets are located in a chassis adjacent to the spectrometer; a generator, liquid nitrogen supply, and hardware are located in the bed of the truck. Normally, samples are analyzed with this equipment soon after they are collected. However, equipment problems required that the Iron River samples be analyzed at the laboratory in Denver after the survey was completed.

About 2.5 cm³ of the gas contained within the sample-collecting syringe is injected into an evacuated gas reservoir through a rubber septum. Gas then passes through a variable leak valve into the spectrometer. The instrument responses to He and pressure are monitored by a two-channel strip-chart recorder.

Results of the survey are shown in Figure 5 and Plate 4. The western-central portion of the quadrangle has a higher helium concentration than the remainder of the quadrangle. Three distinct local anomalies occur, two trending with the Jacobsville Sandstone contact and one within an area known to have some uranium mineralization (the Graphite Quarry Occurrence, No. 8 in Apps. A and C and on Pl. 2). From geologic and geophysical information those localized anomalies are thought to have good potential for uranium occurrences.

Figure 5. Histogram of helium soil gas concentration for the Iron River 1° x 2° Quadrangle. Helium concentrations are in parts per billion (ppb) with respect to air at 5240 ppb.

ENVIRONMENTS FAVORABLE FOR URANIUM DEPOSITS

DEFINITIONS OF FAVORABLE, UNFAVORABLE, AND UNEVALUATED

Under the guidelines supplied by the DOE, all ground within the quadrangle must be assigned to one of three categories: (1) favorable, (2) unfavorable, or (3) unevaluated. Use of the category unevaluated is restricted to areas that were inaccessible during the tenure of the project. This category includes National Parks, National Monuments, and National Recreation Areas, as well as some areas that were impractical to visit because of lack of access.

For NURE evaluations, the term favorable is applied only to formations or geologic environments (1) that can be demonstrated, using the DOE recognition criteria, to have geologic characteristics similar to ground elsewhere in the quadrangle or elsewhere in the world where significant uranium resources occur, and (2) that can be demonstrated to have significant uranium mineralization, as indicated either by uranium occurrences, by radiometric anomalies, or by geochemical anomalies. By analogy with the similar favorable ground elsewhere, it must be inferable that the favorable ground in the quadrangle has the potential to contain at least 100 tons of U_3O_8 at a grade of at least 0.01 percent at a depth of less than 1500 m.

The term unfavorable is applied to ground where favorability as defined above, cannot be demonstrated. Designation of an area, map unit, or environment as unfavorable does not imply that the author of this report predicts the absence of the minimum endowment of U_3O_8 in that area. Rather, use of the term implies only that the author has no strong, positive evidence of favorability. In particular, it should be noted that the existence of a credible geologic model for uranium mineralization and a reasonable geologic similarity between environments in the Iron River Quadrangle and environments known to host uranium deposits is not, of itself, judged to be sufficient evidence for an environment to be classified as favorable. Some measurable supporting evidence of a mineralizing process must be available.

Because time and resources available for this study were limited and the area to be covered was vast, geologically complex, and largely unexposed, and particularly because our understanding of the geologic factors controlling the formation and preservation of many types of uranium deposits is inadequate, much ground was of necessity classified based on too little information.

Based on the preceding definitions, there are no environments favorable for uranium mineralization in the Iron River Quadrangle.

ENVIRONMENTS UNFAVORABLE FOR URANIUM DEPOSITS

Although no favorable environments exist within the quadrangle, there are a number of terranes which are somewhat similar to terranes known to contain significant uranium resources. Most notable among these are the areas adjacent to the Precambrian unconformities in the quadrangle, particularly those near the unconformity below the Jacobsville Sandstone. Three other types of deposits (quartz-pebble conglomerates, veins in metamorphic rocks, and deposits associated with igneous rocks) might also be expected to occur in the Precambrian rocks of the Upper Peninsula, and four additional environments (marine black shales, uraniferous phosphates, volcanic rocks, and banded iron-formation) are worthy of consideration because there are uranium occurrences in those environments within the quadrangle.

In the following sections, each of the eight environments listed above is evaluated in turn and the arguments on which their unfavorable classification is based are explained.

QUARTZ-PEBBLE CONGLOMERATE UNFAVORABLE ENVIRONMENT--CLASS 120

The quartz-pebble conglomerate (QPC) environment is obviously an important environment to assess given the existence of the Blind River-Elliott Lake uranium district only 450 km to the east. In 1979, this district produced close to 5000 tons of U_3O_8 (Albino, 1980).

As pointed out by Jones (1978), the origin of these deposits is still uncertain, but most geologists familiar with this type of deposit believe that they formed as placers. Whether or not this is the case, the deposits are stratabound and confined to a distinctive pyritic, oligomictic quartz-pebble conglomerate lithology (Hills, 1980). The first point to be considered in assessing the Iron River Quadrangle for favorability for QPC-type deposits is correlation of the Precambrian sedimentary units in the Upper Peninsula with the Huronian sequence which contains the deposits around Elliot Lake. To date, it has not been possible to correlate the two through radiometric means. All that is known is that the uranium-bearing strata of the Huronian Supergroup unconformably overlie Precambrian W (Algoman) units that have been dated at 2500 m.y. (Van Schmus, 1965; Wanless and others, 1965) and are cut by intrusive rocks as old as the Nipissing Diabase dated at 2155 m.y. (Van Schmus, 1965). As discussed earlier, Precambrian X units in the Upper Peninsula of Michigan are known to be later than about 2600 m.y. and pre-Penokean, about 1900 m.y. (VanSchmus, 1976). There is a suggestion that they may be post-2100 m.y. and pre-1900 m.y., but this is not firmly established. Therefore, the evidence is permissive of age equivalency with the suggestion that, if the units are equivalent at all, the lowest portion of the section in Michigan correlates with the upper part of the Huronian. A similar suggestion is made by R. W. Ojakangas (written commun. 1980) who, tentatively, would correlate the lowest tillites in the Michigan section (Fern Creek and

Enchantment Lake Formations) with the upper part of the Huronian Supergroup in Ontario (Gowganda Formation).

Physical continuity of a unit between the two terranes would demonstrate some degree of age equivalency with great certainty. Middle Precambrian units can be traced eastward from the Iron River Quadrangle and units in the Huronian Supergroup have been traced westward in the subsurface through geophysical techniques until the gap between the two is only a few hundred kilometers (W. F. Cannon, written commun. 1980). The gap has not yet been closed, however, and in summary, no correlation of the Huronian units with those in the Iron River Quadrangle has yet been demonstrated.

The age of the units in Michigan and whether or not they correlate with the Huronian units in Canada are important questions, for if QPC-type deposits are in fact placers and the uranium-bearing minerals in them are detrital grains, then in order for detrital uraninite to survive, the host rocks would have to be older than the oxygenation of the atmosphere (commonly called the oxyatmoverion) inferred by Cloud (1968) to have taken place 1800 to 2000 m.y. ago. In the view of many geologists, the appearance of Superior-type banded iron-formations (BIF) marks the end of the era of formation of placer uranium deposits (Roscoe, 1973; Hills, 1980). Because BIF occurs close to the base of the Precambrian X section in the Upper Peninsula of Michigan, the inference is that most, perhaps all, of the section may be too young to host placer uranium deposits.

Another factor contributing to the unfavorable assessment given to the quadrangle is the lithology of the conglomerates present. Uranium-bearing conglomerates in Canada, Africa, Brazil, and elsewhere (as described by Roscoe, 1969; Pretorius, 1975; Jones, 1978 and many others) are typically oligomictic, pyrite-bearing conglomerates with uranium minerals, chiefly uraninite, occurring with gold and other heavy minerals in the chloritic or sericitic matrix. Clasts are almost restricted to quartz, chert, and quartzite. Whether this lithologic association is a function of depositional environment, source terrane or, if the deposits are not in fact placers, some obscure lithologic restriction on hydrothermal mineralization processes is irrelevant as far as favorability evaluation is concerned. The known deposits are restricted to this rock type, and very little, if any, of this type of conglomerate exists within the Iron River Quadrangle. Particularly in the lower portions of the section (the section below the lowest iron-formation) the conglomerates are typically polymictic and contain abundant granitic and other feldspar-bearing clasts. Units which are more quartz-rich (such as the Sturgeon Quartzite or the Ajibic Quartzite) are not conglomeratic and no unit contains significant pyrite.

In summary, the conglomerates in the Iron River Quadrangle may be too young to host placer uranium deposits, and even if they are not, lithologies like those which host QPC-type deposits elsewhere do not appear to exist within the quadrangle in any abundance. Whereas there are numerous occurrences of primary uranium minerals in both the upper and lower Huronian Supergroup in Canada (the economic deposits are in the lower portion of the

section), there are no occurrences at all in Michigan or even any occurrences of anomalous radiation in quartzite where the radiation emanates from uranium. Because there is no positive reason to classify the Precambrian clastic rocks otherwise, they are classed as unfavorable for QPC-type deposits.

MARINE BLACK SHALE UNFAVORABLE ENVIRONMENT--CLASS 130

Great thicknesses of black shale or black slate occur in the Iron River Quadrangle. The thickest sequences occur in the lower portion of the Michigamme Formation, but black pelitic units are also found both higher and lower in the section (Figs. 2a, 2b, and 2c). None of these units is considered to be a likely host for a uranium deposit of the prescribed size and grade because only rarely do black slates in the quadrangle contain uranium even approaching 100 ppm U_3O_8 .

Vickers (1956c, p. 64) reported that L. P. Barrett collected a sample of ferruginous slate float just east of the quadrangle which contained 0.17 percent U_3O_8 (cU), and Barrett (1953, p. 10) reported that 12 samples of black slate collected from the Graphite Quarry uranium occurrence (see Occ. No. 8 Appendix C) contained an average of 0.0079 percent U_3O_8 (79 ppm), but these are the only slate or shale samples from the entire upper Peninsula that exceed or approach the DOE cutoff grade. Barrett (1953) stated that the average of all the slate samples he collected averaged 0.003 percent uranium (30 ppm), but more recent analyses suggest that average uranium contents may be even lower. The slate and shale samples collected for this study averaged 4.7 ppm uranium with a high of 12.5 ppm (except for those samples collected at the Graphite Quarry Occurrence), Johnson (1977) reported analyses for two samples of anomalously radioactive slate from the Tyler Formation just west of the quadrangle at only 8 and 10 ppm uranium, and Trow (1979) found that Baraga Group metasediments penetrated by a 333-m drill hole, located about 20 km north of Amasa, averaged only 2.5 ppm acid soluble U_3O_8 .

In general, then, it seems that black shales and slates in the quadrangle are not enriched in uranium and the environment is classified as unfavorable.

URANIFEROUS PHOSPHORITE UNFAVORABLE ENVIRONMENT--CLASS 140

Phosphorite-bearing units within the quadrangle do not contain sufficient uranium to be classed as an environment favorable for the existence of a resource of the specified grade. Although selected specimens of carbonate-apatite may contain more uranium than the 100 ppm cutoff (for example, the 215 ppm U reported from the Big Eric's carbonate-apatite occurrence), commonly only a small proportion of the sedimentary unit is actually carbonate-fluorapatite. Carbonate-fluorapatite is the phosphorus-bearing phase and the mineral which carries essentially all of the uranium in this type of deposit (Jones, 1978). Johnson and others (1978) in their bulk sampling program of the thickest known section of phosphate-bearing strata (exposed a short

distance east of the quadrangle) found that the richest beds could contain as much as approximately 40 percent apatite, but their surface samples averaged only 6.95 percent P_2O_5 (equivalent to about 15 to 20 percent apatite) and diamond drilling conducted in 1977 showed that apatite decreased with depth. In contrast, McKelvey and Carswell (1955, as reported in Jones, 1978, p. 33) determined that phosphate beds with greater than 31 percent P_2O_5 commonly contain 100 to 200 ppm uranium. With the most completely sampled outcrop of phosphate-bearing rock in the vicinity of the Iron River Quadrangle indicating less than 7 percent P_2O_5 , and with P_2O_5 content decreasing with depth, prospects for a significant thickness of rock with more than 0.01 percent uranium are not encouraging and the environment has been classified as unfavorable.

ORTHOMAGMATIC, PEGMATITE, AUTHIGENIC, ALLOGENIC, AND OTHER UNFAVORABLE ENVIRONMENTS ASSOCIATED WITH PLUTONIC IGNEOUS ROCKS--CLASSES 310, 320, 360, 370, AND OTHER 300 CLASS UNFAVORABLE ENVIRONMENTS

There is little or no positive evidence suggesting that Precambrian W gneissic and granitic rocks in the quadrangle are favorable for uranium deposits; they are therefore classed as unfavorable. All of the uranium occurrences related to plutonic rocks in the quadrangle (Nos. 5, 8, 10, 11, 12, and 22, Apps. A and C; Pl. 2) are insignificant and the total volume of mineralized rock at all six occurrences put together is probably less than one cubic meter. Some whole-rock analyses made in the 1950's and quoted in the more recent literature (Kalliokoski, 1976) suggested that some granitic and gneissic rocks were significantly enriched in uranium (for example, 0.002 percent to 0.008 percent eU_3O_8 , as much as 0.004 percent cU_3O_8 ; Vickers, 1956c), but the analyses quoted in Johnson (1977) and the ones made for this study (App. B) do not indicate values this high. For example, considering all the rocks analyzed from the Southern Complex, (the granites and gneisses south of the Marquette Range; Fig. 3), the average uranium content of samples not collected at uranium occurrences is 7 ppm U, an insignificant enrichment over the uranium contained in an average granite (4 to 5 ppm). On the basis of isotopic studies conducted on samples from a drill hole located 150 m east of the Iron River Quadrangle, Stuckless and others (1980) concluded that the low Th/U ratios in the Compeau Creek Gneiss (average 0.86) suggested that this unit had not lost any appreciable amount of labile uranium. Loss of uranium would be required if it were to be concentrated elsewhere as an ore deposit.

On the basis of these tentative arguments, the environment is classified as unfavorable, but there is an additional factor which should be taken into account when appraising the reliability of this assessment. Consider the gneiss domes in the east-central portion of the quadrangle, particularly the Smith Creek and Wilson Creek uplifts of Cannon and Klasner (1976a) (Fig. 3, Pl. 10A). The core of the Smith Creek uplift occupies an area of roughly 30 km^2 and only two outcrops are known, both very close to the southern end of the dome. In the core of the Wilson Creek Uplift, an area of about 9 km^2 , there are no outcrops at all and the presence of Precambrian W units is inferred mainly from magnetic and gravity data. Although these inferences are

in all probability valid, one must realize that as well as the uncertainties about whether a particular rock type is favorable for a certain class of uranium deposit, the existence of the rock itself is, in some cases, also in doubt.

HYDROALLOGENIC (CLASS 540) AND OTHER UNFAVORABLE VOLCANOGENIC ENVIRONMENTS

One occurrence of anomalously radioactive volcanic rocks exists in the quadrangle (the Bergland Occurrence, No. 23, Apps. A and C) and two others have been reported but could not be confirmed (M & W Hunting Co., No. 24 and the Indiana Copper Mine, No. 25, Apps. A and C). At the Bergland Occurrence, mapping and petrographic studies by Johnson (1977) indicate that the radioactivity is associated with an altered vitric tuff composed predominantly of quartz, sericite, and clay with minor carbonate and fluorite. A grab sample taken from the area of highest radioactivity (fractures near the basal contact) contained 185 ppm U (sample MCK-137, App. B), but radioactivity over most of the area is much lower and the unit probably averages 20 to 40 ppm U or less (estimates from data of Beroni and Paterson, 1956). An overlying red felsite contains less than 5 ppm U (sample MCK-136, App. B) and in all probability, only an insignificant volume of rock at the Bergland Occurrence contains more than 100 ppm U_3O_8 .

Considering uranium favorability in the Upper Peninsula on a more regional scale, the only tectonic setting which even remotely resembles the recognition criteria of Pilcher (1978) is that associated with the Keweenaw units exposed in the northwestern portion of the quadrangle. Pilcher (1978) describes all classes of volcanogenic uranium occurrences as being formed in either basin-and-range or rift-system environments. The Keweenaw units are the result of deposition in and adjacent to a continental-rift system (Sims, 1976), and whereas there is no compelling reason to believe that tectonics and crustal processes were the same in the Precambrian as in the Phanerozoic, the Keweenaw rocks appear to occur in the most favorable setting of any in the quadrangle.

There are four formations in the Keweenaw made up predominantly of volcanics: the Siemens Creek Formation, the Kallander Creek Formation, the Portage Lake Volcanics, and the unnamed formation which immediately overlies it. In attempting to assess the uranium favorability of these formations, the most important factor to consider is probably the composition of the potential host rocks. Composition is the parameter which most directly records the rocks' chemical history, and it is obviously the chemical history in which a uranium mineralization event will be most clearly reflected.

All of the volcanogenic uranium environments described by Pilcher (1978) are characterized by rocks of generally trachytic or rhyolitic composition, rocks with high Na_2O content and with silica greater than 72 weight percent. Rocks of this composition are rare or nonexistent in the Iron River Quadrangle, and even those silica-rich rocks which do exist are not particularly enriched in uranium. Of the four formations mentioned

previously, only the Siemens Creek and Kallander Creek Formations contain any significant abundance of felsic rocks (Hubbard, 1975b, Table 3). In the Kallander Creek Formation, rhyodacites contain as much as 68 weight percent silica, but they are commonly quite soda-poor, containing an average of only about three percent Na_2O (Hubbard, 1975b, Table 2). Felsic units in the Siemens Creek Formation are similar, and silica-rich rocks in the quadrangle are not notably enriched in uranium. Considering the samples collected for this study plus those collected and analyzed by Johnson (1977), the most uraniferous samples (other than the one collected at the Bergland Occurrence) contains 26 ppm U, and the average for all 32 samples is only 6 ppm. It does not appear, therefore, that felsic volcanic rocks are likely to contain deposits of the specified size and grade.

There are, however, some uranium occurrences and deposits that appear to be genetically associated with mafic volcanic rocks. For example, uranium occurs in scapolite-pyroxene-amphibole gneiss at the Phillips Mine, Camp Smith, New York. This association is postulated to be uranium occurring in metamorphosed, submarine spilitic flows (Grauch, 1978), and the occurrences of uranium with metamorphosed submarine tuffs and graphitic sediments in northern Sweden may be similar (Adamek, 1975). However, in both these cases, massive-sulfide deposits or occurrences also appear to be genetically related to the volcanics, and to date no massive sulfides have been found in the Keweenaw volcanic units in Michigan although some have been extensively explored by drilling and test pitting in the search for native copper. Because only a single uranium occurrence of very small dimensions is known in the felsic volcanic rocks of the Iron River Quadrangle (as opposed to literally hundreds of showings of anomalous radiation around other Precambrian uranium deposits in felsic volcanic rocks; for example the Kitts and Michelin deposits, Labrador; Gandhi, 1978) and because both the felsic and mafic volcanics in Michigan lack features similar to the rocks which host known deposits, the environment is classified as unfavorable.

UNCONFORMITY-RELATED URANIUM DEPOSIT UNFAVORABLE ENVIRONMENT--CLASS 710, SUBCLASSES 711 and 712

As pointed out by Mathews (1978b), recognition criteria for areas favorable for the existence of unconformity-related uranium deposits are not really very well defined because not enough is known about this type of deposit to enable anyone to put forward recognition criteria that are more than preliminary and generalized. Even though there is a little more known about this type of deposit than there was when Mathews published in 1978, there are still many unanswered questions and debate about the origin of unconformity-related deposits continues.

An example of the fundamental nature of the unanswered questions concerning unconformity-related deposits is contained in the class name itself: what is the significance, if any, of the unconformity and are the specific lithologies above and below the unconformity important? Some investigators (Langford, 1977; Hoeve and others, 1980) have concluded that the

deposits formed when uranium was leached from the overlying sandstones and deposited near graphitic horizons in the sub-unconformity strata. If this model is applicable, then both the lithology of the cover rocks and the unconformity itself are required elements for a deposit of this class. However, other workers advocate a largely hydrothermal origin for the deposits (Binns and others, 1980) or an origin through development of karst topography and precipitation of uranium from solutions composed largely of meteoric water (Ferguson and others, 1980). In either of these latter two cases, the existence of the unconformity and lithology of the cover rocks may be completely irrelevant and have nothing at all to do with the formation of the uranium deposits.

Given that very little is really known about what features of unconformity environments are good guides to areas favorable for the occurrence of uranium deposits, some approach that does not require this information to assess favorability must be used. The approach chosen here is, without knowing whether the criteria are relevant or not, simply to compare the Jacobsville unconformity to general features known or inferred from the Alligator River Uranium Field, Australia, and the Athabasca Basin uranium deposits, Canada. Other possible unconformity-related uranium deposits such as the prospects in the Thelon Basin near Baker Lake in the Northwest Territories, Canada, are ignored here because almost nothing about geologic relationships at these prospects has been published.

Table 1 is modeled in part on the recognition criteria used by Mickel and Mathews (1978) and compares regional geologic features known or inferred for the Jacobsville unconformity in the Iron River Quadrangle with features present in the unconformity uranium districts of Canada and Australia. Only criteria of a regional scale are used (for example tectonic setting, depositional environment) because the more local criteria (such as mineralogy, alteration, or texture) are specific to the uranium deposits themselves and therefore are not relevant for a regional assessment. Note that the rocks below the unconformities in both Canada and Australia consist of arkoses, carbonates, and evaporites metamorphosed to amphibolite-grade gneisses, schists, and marbles. In Michigan, the units in close proximity to the unconformity are greenschist facies slate, greywacke, and volcanics. The Canadian and Australian rocks were presumably deposited in a stable-shelf, shallow-water, miogeoclinal environment whereas those in the eastern portion of the Iron River Quadrangle were deposited in a rapidly subsiding basin more typical of eugeoclinal conditions; those in the western portion were erupted into a continental rift-system environment. If one considers the environment in which they were deposited, the lithology, the metamorphic grade, and, in part, the age of the units below the unconformity, the rocks in Michigan are very different from those in Canada and Australia.

Table 1. GENERALIZED GEOLOGIC CHARACTERISTICS OF ROCKS
IN THE VICINITY OF THREE PROTEROZOIC UNCONFORMITIES

Feature	Sub-Kombolgie Unconformity; East, Alligator River Uranium District ¹	Sub-Athabasca Unconformity - Athabasca Basin Uranium District ²	Sub-Jacobsville Unconformity- Iron River 1° x 2° Quadrangle ³
Tectonic Setting	Precambrian Shield	Precambrian Shield	Precambrian Shield.
Age+			
Pre-*	2470-1870 m.y., possibly 2200-2000 m.y. ⁴	2480-1735 m.y. ⁵	About 1200 m.y. in the west, between 2100(?) and 1900 m.y. in the east. ⁷
Post-°	1648 ± 29 m.y. ⁴	1350 ± 50 m.y. ⁶	Either about 1000 m.y. ⁸ or Cambrian (500-570 m.y.). ⁹
Lithology			
Pre-	Mica and quartzo-feldspathic gneiss and schist, calcareous and carbona- ceous locally. Thick dolomite- magnesite marbles near the base, possibly evaporites.	Dominately meta-arkose, quartz- feldspar schist, and massive granulite, but including calc- silicate units, lenses of massive carbonate, and evaporites. Minor amphibolites present may have been mafic volcanics.	Dominately mafic and inter- mediate flows in the west, slate and graywacke in the east.
Post-	Medium- to coarse-grained, moderately well sorted, subangular to subrounded, buff to white quartz sandstone. Conglomerates common near the base.	Fine- to coarse-grained, poorly to well sorted, buff, white, pink, red purple, or black clay-rich quartz sandstone. Minor siltstone and mudstone; conglomerates common near the base.	Fine- to medium-grained, poorly cemented, red or gray quartz-rich sandstone. Minor conglomerate.
Depositional Environment			
Pre-	Probably stable continental shelf, shallow water marine and perhaps in part supratidal. Felsic volcanic units present a few hundred kilometers west may be correlative.	Largely obscured by deformation and metamorphism, but lithologies suggest stable continental margin.	Postulated early flood basalts in extensional (rifting?) environment to the west, prob- ably a eugeoclinal, rapidly subsiding basin environment to the east.

Table 1. GENERALIZED GEOLOGIC CHARACTERISTICS OF ROCKS
IN THE VICINITY OF THREE PROTEROZOIC UNCONFORMITIES
(Continued)

Feature	Sub-Kombolgie Unconformity; East Alligator River Uranium District ¹	Sub-Athabasca Unconformity - Athabasca Basin Uranium District ²	Sub-Jacobsville Unconformity- Iron River 1° x 2° Quadrangle ³
Post-	Fluvial	Fluvial grading to marine at the top.	Fluvial
Metamorphic Grade			
Pre-	Amphibolite	Amphibolite	Largely lower greenschist to greenschist.
Post-	Not metamorphosed	Complex diagenetic and alteration history but not metamorphosed.	Not metamorphosed.

¹Primary references include:

Needham and others, 1980; Stuart-Smith and others, 1980; Ferguson, 1980; Needham and Stuart-Smith, 1980; Hegge and others, 1980; Crick and Muir, 1980; and Frishman, unpublished data.

²Primary references include:

Sibbald and others, 1976; Lewry and Sibbald, 1977; Hoeve and Sibbald, 1978; Hoeve and others, 1980; and Kirchner and others, 1980.

³Primary references include:

Cannon, 1973; Klasner and Cannon, 1974; Van Schmus, 1976; Sims, 1976; Morey and Sims, 1976; Cannon, 1978, Klasner, 1978; and Larue and Sloss, 1980.

⁴Page and others, 1980.

⁵Sibbald and others, 1976.

⁶Ramaekers and Dunn, 1976.

⁷Van Schmus, 1976.

Table 1. GENERALIZED GEOLOGIC CHARACTERISTICS OF ROCKS
IN THE VICINITY OF THREE PROTEROZOIC UNCONFORMITIES
(Continued)

⁸White, 1966.

⁹Dorr and Eschman, 1973.

+Sedimentation age or bracket within which the time of deposition must lie. Where bracket ages are listed for the pre-unconformity strata, the older bracket is formed by the age of the granite-gneiss terrane which the metasediments overlie; the younger bracket by the oldest discernible metamorphic event that affects the pre-unconformity rocks.

*"Pre" = sub-unconformity metasediments and metavolcanics.

°"Post" = rocks above the unconformity or "cover rocks."

Table 2 is a summary and presents the author's opinion of how well the sub-Jacobsville unconformity compares with the sub-Kombolgie and sub-Athabasca unconformities. An obvious conclusion to be reached from Table 2 is that the Jacobsville Sandstone is more similar to the Athabasca and Kombolgie Formations than Precambrian X and Y units in Michigan are to the sub-unconformity rocks in Canada and Australia. Whether or not the Jacobsville unconformity is a favorable environment for unconformity-related deposits probably depends on whether the deposits were formed primarily through processes related to the sub-unconformity strata or through processes related to the overlying, quartz-rich sandstones. As pointed out previously, this question still is a matter of debate and, quite simply, nobody knows. In Australia, however, essentially all of the ore is found below the unconformity and some of it may be older than the Kombolgie Formation (Hills and Richards, 1976). In Canada, although at some deposits all of the ore appears to be in the Athabasca Formation, a significant proportion of the ore is in the sub-unconformity strata at the majority of deposits, and it would be hard to argue that the rocks below the unconformity have played absolutely no role in the process of ore genesis.

Based on these tenuous and in part subjective arguments, the Jacobsville unconformity is classified as an unfavorable environment. It is clear, however, that (1) not enough is known about the genesis of these deposits to know what geologic features are important guides to favorable environments, and (2) not enough is known about the Jacobsville unconformity for an objective comparison to the Australian and Canadian uranium districts to be made.

Because so little is known about the genesis of unconformity-related deposits, there is no reason to restrict the search for favorable environments to unconformities overlain by fluvial sandstones. If the existence of miogeoclinal rocks below the unconformity is important, for example, we might consider the favorability of the unconformity which separates the Chocoday Group from the overlying Baraga Group. However, inspection of the geologic map (Pl. 10A) discloses that Chocoday Group sediments are not widespread in the Iron River Quadrangle. They occur only around the Amasa Uplift (Fig. 3) and in two thin belts in the southeast corner of the quadrangle. Furthermore, although there are a number of uranium occurrences within a few kilometers of the Jacobsville unconformity (Nos. 1, 2, 3, 5 and 6; possibly Nos. 4 and 22; Pl. 2), the only occurrences at all close to the Chocoday-Baraga unconformity are the three orthomagmatic or authigenic occurrences associated with biotite segregations (Nos. 10, 11, and 12). All of these occurrences are insignificant, and the detailed portion of the soil-gas helium survey done in this portion of the quadrangle disclosed no anomalies (Pl. 4). Because there really is no more convincing data for favorability along the Chocoday-Baraga unconformity than a geologic model, and a rather ill-defined model at that, this environment is also classed as unfavorable.

Table 2--Regional geologic characteristics in the vicinity of the
sub-Jacobsville unconformity compared to
characteristics in the vicinity of the sub-Kombolgie
and sub-Athabasca unconformities (based on Table 1).

Geologic Characteristics	Pre-unconformity rocks - east	Pre-unconformity rocks - west	Post-unconformity rocks
Tectonic Setting	++	++	++
Age	+	--	-
Lithology	-	--	++
Depositional Environment	--	--	++
Metamorphic Grade	--	--	++

VEIN-TYPE DEPOSITS IN METAMORPHIC ROCKS UNFAVORABLE ENVIRONMENT--CLASS 720

As is the case with unconformity-related deposits, Mathews (1978b) notes that the origin of vein-type deposits in metamorphic rocks is not known and that because of their uncertain origin, recognition criteria for favorable environments are generalized. All known deposits of this class occur in Precambrian rocks, although the reason for this apparent restriction is also unknown. As pointed out by Mathews (1978b), host-rock lithology and metamorphic grade are quite variable. Vein-type deposits occur in metasedimentary and meta-igneous rocks, in pelitic and arkosic lithologies, in carbonates, in intermediate and silicic volcanics, and in rocks in which the metamorphic grade ranges from zeolite to granulite facies. Obviously, lithology, metamorphic grade, and host-rock texture are completely nondiagnostic for this type of deposit and no area within the Iron River Quadrangle can be said to be more or less favorable than any other based on these parameters.

Considering structure, all known deposits are associated with steeply dipping faults or fracture systems. Keeping in mind that the existence and location of most of the faults in the Iron River Quadrangle are inferred on the basis of magnetic or other geophysical data, this implies that faults in the quadrangle are a more favorable location for this class of deposit than are other areas. However, there are no data which point to any particular fault or indicate that any particular fault orientation is more favorable than any other, and undoubtedly there are also numerous unmapped faults and fracture sets in the quadrangle.

Because no specific area in the quadrangle can be singled out as being more favorable than any other, the entire area is classed as unfavorable for this type of deposit. An additional point worth noting, although not directly related to uranium resource evaluation, is that whether or not the Iron River Quadrangle is a favorable or unfavorable locale for vein-type deposits to occur, it is an extremely unfavorable place to try to discover such a deposit. Whereas mineralized veins may in some cases be quite long, they commonly are extremely narrow and short. Some deposits have a surface expression, including whatever alteration halo may be present, of less than 1 m. The difficulty of discovering such a feature in an area heavily mantled with glacial debris is great and exploration for this type of deposit in such a terrane stands little chance of success.

URANIUM IN BANDED IRON-FORMATION; VEIN-TYPE DEPOSITS IN SEDIMENTARY ROCKS UNFAVORABLE ENVIRONMENT--CLASS 730

The uranium occurrences in the Iron River and Crystal Falls iron mining districts form a distinct, perhaps unique, class of uranium occurrence. These occurrences (Nos. 13 through 21, Apps. A and C; Pl. 2) are reported to be the largest and richest concentrations of uranium in the quadrangle, but in all probability, the iron-formations of the district do not contain enough uranium

for the environment to be classified as favorable.

Of these nine occurrences, two are reported to be on mine dumps but could not be located in 1979. The remaining seven occurrences are in the underground workings of abandoned, flooded iron mines and the workings are now inaccessible. Therefore, assessment of the favorability of this environment must be based on information available in the literature. Fortunately, one of these occurrences is fairly well described (Vickers, 1956c; James and others, 1968, p. 114 and 116-118) and the data available are sufficient to make the assessment fairly reliable.

The most fully described occurrence is in the Sherwood Mine on the 1200-foot level and the 55 sub above 1200 level. Anomalous radioactivity was detected at five different locations and all of them lie within oxidized cherty iron-formation adjacent to the contact with the overlying graphitic slate. At four of the five areas, the section is overturned and the graphitic slate forms a structural footwall. No anomalous radioactivity was detected in the black slate, in unoxidized iron-formation, or except for locality "B" of James and others (1968), in oxidized iron-formation overlain by graphitic slate. Vickers (1956c) concluded that, at this and other, similar uranium occurrences in the Upper Peninsula, uranium and associated elements were derived from the carbonaceous slates by supergene processes.

Using the equivalent U_3O_8 data in James and others (1968) and a cutoff "grade" of 0.007 percent (70 ppm), very generous assumptions about the continuity and form of the mineralization suggest there may be as much as 10 tons U_3O_8 present at the known occurrences in the Sherwood Mine. Undoubtedly there are undiscovered uranium occurrences in the iron mines of the Iron River and Crystal Falls districts. As pointed out by James and others (1968), where the slate adjacent to the Riverton Iron-Formation is pyritic as well as graphitic, it burns spontaneously when exposed to air. When the districts were active, nearly all the mines had areas sealed off from the active workings to control mine fire. Mine plans were no doubt designed to minimize excavation of this contact whenever possible, so underground exposures of the favorable horizon are probably somewhat less numerous than they might be. However, underground workings in the two districts are very extensive. Iron was mined continuously from 1882 to 1978, and total production through 1961 was close to 160 million tons (James and others, 1968). Dumps and active mines were assiduously searched for anomalous radioactivity in the 1950's (Barrett, 1953; Vickers, 1956c) and only the nine occurrences listed in Appendix A of this study were found. Consequently, because the conditions which favor formation of this type of occurrence are quite restricted (apparently they form only along the contact between iron-formation and graphitic slate and only where the section is overturned), because, compared to the surface of the rest of the quadrangle, exposures underground are numerous and only a small number of occurrences were located, and because the environment is unlike any known to contain significant, or even insignificant, uranium resources, the environment is classified as unfavorable.

UNEVALUATED AREAS AND ENVIRONMENTS

The only completely unevaluated areas in the quadrangle are those covered by the waters of Lake Superior and the islands of the Huron National Wildlife Refuge (Pls. 1 and 12); Wildlife Refuges are excluded from the NURE evaluation program. Other areas, such as the Sturgeon River Wilderness Study Area and the U.S. Forest Service RARE II areas are included with the evaluated, unfavorable environments. However, these areas were not investigated with as much intensity as was the remainder of the quadrangle, and consequently the assurance with which they are classified as unfavorable is lower than it is for most of the quadrangle.

RECOMMENDATIONS TO IMPROVE EVALUATION

Obviously the most pressing need to improve the assessment of uranium resources in the Iron River Quadrangle is more subsurface geologic information. Even a brief glance at the outcrop map, Plate 10B, will indicate how little information can be obtained from the surface. The amount of drilling needed for a thorough evaluation, however, is so large that it is prohibitive. A compromise would be to selectively test the most favorable targets. Although there are differences, perhaps significant ones, between the Precambrian unconformity in Michigan and those in Canada and Australia, this environment is probably the most important one to test because the potential returns are so large. The four developed deposits in the East Alligator River District alone contain almost 330 thousand tons of proven U_3O_8 at a grade comfortably higher than the average mined in the United States. Some areas of the Jacobsville unconformity look more promising than others, and a Landsat study or study of high-altitude air photos might define further favorable areas. A relatively small number of holes drilled to test for the presence of chloritized or graphitic shear zones would materially improve the reliability of the Jacobsville assessment.

A few additional techniques might also be useful. The reconnaissance helium survey already completed (Pl. 4) indicated two anomalous areas near the Jacobsville unconformity. A more detailed survey in those areas plus additional widely spaced samples in the area around and north of Lake Gogebic might add useful information.

When Union Carbide conducted the HSSR study in the Iron River Quadrangle, they observed that the analysis of stream sediments was of quite limited utility (ORGDP, 1980). This is to be expected in a terrane blanketed with Pleistocene glacial deposits. However, lake-bottom sediment geochemistry has proven to be a useful exploration tool in Canada and might also indicate anomalous terranes in Michigan, if any exist.

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IRON RIVER, MICHIGAN/ WISCONSIN

PLATE 1.--AREAS UNEVALUATED FOR URANIUM DEPOSITS

By David Frishman, U.S. Geological Survey

PLATE - AREAS UNAVAILABLE FOR JOURNAL DEPOSITS

IRON RIVER, MICHIGAN/ WISCONSIN

URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BAS. MAP CONTROL FROM U.S.G.S

EXPLANATION

	CLASSIFICATION			
	Sedimentary	Plutonic	Volcanic	Other
Minor prospect or mineral occurrence	□	△	○	☆
Prospect or mine, production unknown	◻	▲	◐	⊛
Significant prospect or mine reporting minor production	◼	▴	◑	⊞
Mine having production over 200,000 pounds U ₃ O ₈	■	▴	◑	⊞
Not visited	□Y	△Y	○Y	☆Y
Not found	□X	△X	○X	☆X
Mining District	-----			

PLATE 2.--URANIUM OCCURRENCE MAP

Compiled by
David Frishman, U.S. Geological Survey

PLATE 2 - TITANIUM COORDINATION
OF
TITANIUM
WITH
VITAMIN B₁₂

IRON RIVER, MICHIGAN/ WISCONSIN

EXPLANATION

- Uranium anomalies
- Anomaly zone
A
B
C
D

 Anomalies discussed in text

PLATE 3A.--URANIUM ANOMALIES DETERMINED FROM URANIUM
(EU,EU/TH,EU/K) COMPOSITE IMAGE

By James A. Pitkin and Joseph S. Duval, U.S. Geological Survey

PLATE 3A - URANIUM ANOMALIES DETERMINED FROM URA-200
FIELD MEASUREMENTS
URANIUM ANOMALIES DETERMINED FROM URA-200
FIELD MEASUREMENTS

IRON RIVER, MICHIGAN/ WISCONSIN

EXPLANATION

A
B
C
D
E
F
G
H
I
J
K

Radiometric map units
see text for explanation

URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BASE MAP CONTROL FROM USGS

PLATE 3B.--RADIOMETRIC UNITS DETERMINED FROM RADIOELEMENT (EU, ETH, K) COMPOSITE IMAGE

By James A. Pitkin and Joseph S. Duval U.S. Geological Survey

IRON RIVER, MICHIGAN/ WISCONSIN

EXPLANATION

A
B
C
D
E

Radiometric map units
see text for explanation

URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BASE MAP CONTROL FROM USGS

PLATE 3C.--RADIOMETRIC UNITS DETERMINED FROM RADIOELEMENT RATIO (EU/ETH, EU/K, ETH/K) COMPOSITE IMAGE

By James A. Pitkin and Joseph S. Duval, U.S. Geological Survey

PLATE NO. 1
Faint, illegible text in the top left corner.

PLATE NO. 1
Faint, illegible text in the bottom center, likely bleed-through from the reverse side of the page.

IRON RIVER, MICHIGAN/ WISCONSIN

EXPLANATION

• Sample locality

Soil-gas helium contour in ppb above or below the atmospheric helium value (5240 ppb)
Contour interval is 5 ppb

Contoured by R.R. Wahl

PLATE 4.--CONTOUR MAP SHOWING SOIL-GAS HELIUM LEVELS

By
G.M. Reimer, U.S. Geological Survey

PLATE 1 - CONTINUED FROM PREVIOUS PAGE

PLATE 1 - CONTINUED FROM PREVIOUS PAGE

PLATE 1 - CONTINUED FROM PREVIOUS PAGE

PLATE 1 - CONTINUED FROM PREVIOUS PAGE

IRON RIVER, MICHIGAN/ WISCONSIN

URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

BASIC MAP CONTROL FROM USGS

PLATE 5.--ROCK SAMPLE LOCALITY MAP

Compiled by David Frishman, U.S. Geological Survey

EXPLANATION

- Rock Sample Locality

All numbers are prefixed by MCK
unless indicated otherwise.

Analytical results are shown in
Appendix B-1.

PLATE 1

PLATE 2

PLATE 3

PLATE 4

PLATE 5 - ROCK SAMPLES ONLY

PLATE 6 - ROCK SAMPLES ONLY

IRON RIVER, MICHIGAN/ WISCONSIN

URANIUM RESOURCE EVALUATION
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PLATE 6.--DRAINAGE MAP

em END MORaine - Chiefly calcareous sandy to clayey till and ice-contact stratified sand and gravel. Topography hummocky with numerous poorly-drained depressions and lakes. Lines separating units indicate moraines of different composition.

gm GROUND MORaine - Chiefly calcareous red sandy to silty till in the northern and western part and grey brown sandy till in the southeastern part. A thin veneer of sand or gravel lies on the till in many places.

lgm LINEATED GROUND MORaine - Similar in composition to ground moraine described above; surface is drumlinized, fluted, or formed into irregular ridges that parallel the direction of ice movement.

gls GLACIAL LACUSTRINE SAND - Chiefly medium-grained sand.

gsc GLACIAL LACUSTRINE SILT AND CLAY - Calcareous clayey silt and silty clay with abundant sand grains and sparse pebbles; contains abundant small, white, calcareous concretions.

gsg GLACIOFLUVIAL SAND AND GRAVEL - Ice-contact stratified drift and outwash; composed of medium-grained sand and pebbly medium-grained sand with much smaller amounts of sandy gravel and gravel. Much of the area has a hummocky topography with numerous poorly drained depressions. Swamps and lakes are abundant in the southwestern areas. Glacial features include outwash plains, ice channel fills and kame terraces.

● BEDROCK - Areas of exposed bedrock or areas with numerous bedrock outcrops.

○ UNCLASSIFIED - Area of rough topography with local relief of 15 to 30 m. The topography is mainly that of the bedrock surface and the area contains an abundance of unmapped bedrock exposures. A thin veneer of drift is present and consists of gravel and sand and grey and brown till.

Note: the order in which units are listed bears no relationship to their relative ages.

PLATE 10B.-- GENERALIZED MAP OF QUATERNARY GLACIAL GEOLOGY OF THE IRON RIVER 1° x 2° QUADRANGLE, MICHIGAN AND WISCONSIN

Generalized by David Frishman from an unpublished map by W. L. Peterson, U.S. Geological Survey.

THE HON. THE SECRETARY OF THE
TREASURY, LONDON.

IRON RIVER, MICHIGAN/ WISCONSIN

PLATE 11.--GEOLOGIC MAP INDEX

Compiled by Alice Weis, U.S. Geological Survey

INDEX

1. BAYLEY, 1999, 1:24,000.
2. CANNON, 1973, 1:250,000.
3. CANNON, 1977, 1:62,500.
4. CANNON AND KLASNER, 1976B, 1:62,500.
5. CANNON, KING, AND HILL, 1973, 1:62,500.
6. CLEMENTS AND SMYTH, 1899, 1:125,000.
7. DUTTON, 1969, 1:6,000.
8. DUTTON AND BRADLEY, 1970, 1:500,000.
9. DUTTON AND LINEBAUGH, 1967, 1:125,000.
10. FRITTS, 1969, 1:48,000.
11. GAIR AND WIER, 1966, 1:24,000.
12. HUBBARD, 1974, 1:62,500.
13. JAMES, CLARK, LAMEY, AND PETTIJOHN, 1961, 1:24,000.
14. JAMES, DUTTON, AND WIER, 1967, 1:6,000.
15. JAMES, DUTTON, PETTIJOHN, AND WIER, 1968, 1:24,000.
16. JAMES AND WIER, 1960, 1:6,000.
17. JAMES, PETTIJOHN, AND CLARK, 1970, 1:6,000.
18. JOHNSON AND WHITE, 1969, 1:62,500.
19. KLASNER AND CANNON, 1975A, 1:24,000.
20. KLASNER AND CANNON, 1975B, 1:24,000.
21. PETTIJOHN, 1970, 1:4750.
22. PETTIJOHN, 1972, 1:4,500.
23. PETTIJOHN, GAIR WIER, AND PRINZ, 1969, 1:6,000.
24. PRINZ, 1967, 1:10,000.
25. PRINZ AND HUBBARD, 1975, 1:62,500.
26. SNIDER, 1976, 1:250,000.
27. TRENT, 1973, 1:62,500.
28. WHITLOW, 1974, 1:62,500.
29. WIER, 1967, 1:24,000.
30. WIER, 1971, 1:6,000.

STATE OF GEORGIA
COUNTY OF CHATHAM

The map displays a grid with latitude and longitude coordinates. Key locations and features are labeled as follows:

- M-1**: A large, irregularly shaped area in the upper left.
- M-12**: A point located in the upper right quadrant.
- M-13**: A point located near the bottom left.
- M-14**: A point located near the bottom left.
- M-15**: A point located near the bottom right.
- M-2**: A point located in the middle right.
- M-3**: A point located in the middle left.
- M-4**: A point located near the top right.
- M-5**: A point located in the bottom right.
- M-6**: A point located near the bottom left.
- M-7**: A point located near the bottom left.
- M-8**: A point located near the bottom left.
- M-9**: A point located near the bottom left.
- M-10**: A point located near the bottom left.
- M-11**: A point located in the middle right.
- F-1**: A rectangular area in the bottom left.
- F-2**: A rectangular area in the top left.
- F-3**: A rectangular area in the top right.
- C-1**: An irregularly shaped area in the middle left.
- C-2**: An irregularly shaped area in the middle left.
- C-3**: An irregularly shaped area in the middle right.
- B-1**: An irregularly shaped area in the middle right.
- J-1**: A point located in the top right corner.

- B FOREST SERVICE WILDERNESS AREAS, WILDERNESS STUDY AREAS, AND PRIMITIVE AREAS
 - B-1 STURGEON RIVER WILDERNESS STUDY AREA
- C FOREST SERVICE RARE II AREAS AND OTHER RESTRICTED AREAS
 - C-1, C-2, AND C-3 RARE II AREAS
- F INDIAN LANDS
 - F-1 LAC DU FLAMBEAU INDIAN RESERVATION
 - F-2 ONTONAGON INDIAN RESERVATION
 - F-3 L'ANSE INDIAN RESERVATION
- J NATIONAL WILDLIFE RESERVES AND REFUGES
 - J-1 HURON NATIONAL WILDLIFE REFUGE
- M STATE WITHDRAWALS
 - M-1 PORCUPINE MOUNTAIN STATE PARK
 - M-2 CRAIG LAKE STATE PARK
 - M-3 LAKE GOGEBIC STATE PARK
 - M-4 BARAGA STATE PARK
 - M-5 BEWABIC STATE PARK
 - M-6 TO M-10 STATE SCIENTIFIC AREAS
 - M-6 TROUT LAKE CONIFER SWAMP
 - M-7 ESCANABA LAKE HEMLOCKS
 - M-8 HIGH LAKE SPRUCE BALSAM LAKE
 - M-9 JOHNSON LAKE BARRENS
 - M-10 PLUM LAKE--STAR LAKE HEMLOCK FOREST
 - M-11 VAN RIPER STATE PARK
 - M-12 TWIN LAKES STATE PARK
 - M-13 POWELL MARSH WILDLIFE AREA
 - M-14 PRESQUE ISLE: WISCONSIN STATE FISH AREA
 - M-15 MICHIGAN TECHNOLOGICAL UNIVERSITY-FORD FORESTRY CENTER

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BASE MAP CONTROL FROM USGS

PLATE 12.--GENERALIZED LAND STATUS

IRON RIVER, MICHIGAN/ WISCONSIN

URANIUM RESOURCE EVALUATION
ISSUED BY THE U.S. DEPARTMENT OF ENERGY

5 0 5 10 15 20 25 MILES

BASE MAP CONTROL FROM U565

5 0 5 10 15 20 25 KILOMETERS

PLATE 13.--CULTURE MAP