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Uranium and Thorium Occurrences in
Precambrian Rocks, Upper Peninsula of
Michigan and Northern Wisconsin,
With Thoughts on Other Possible Settings

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ERRATUM

"Uranium and Thorium Occurrences in Precambrian
Rocks, Upper Peninsula of Michigan and Northern
Wisconsin, With Thoughts on Other Possible Settings"

by J. Kalliokoski

ERDA Contract AT(05-1)-1651

Report GJBX-48(76)

p. 114 DELETE last sentence

This statement did not originate with D. Sutherland, or
with any other employee of D. S. Robertson and Associates.

The author rewrites this section as follows: "Anomalous
radioactivity has been noted only at this one occurrence that
was shown to me by an employee of D. S. Robertson and Associates."

The author states further: "I surmised that the radio-
activity might be due to pitchblende because this had been
previously recorded from the geologically similar Huron River
showing (p. 108), some 14 miles to the northeast. In my
opinion, and in view of the brecciated character of the radio-
active slate at the Taylor Mine, one should search for other
similar occurrences in this vicinity."

Uranium and Thorium Occurrences in
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Michigan and Northern Wisconsin,
With Thoughts on Other Possible Settings

J. Kalliokoski
Principal Investigator

Title: Evaluation of the Uranium Potential
of the Precambrian Rocks of Michigan,
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Preface

The purpose of this study, as defined, is to evaluate the uranium and thorium potential of the Precambrian rocks of northern Wisconsin and the western half of the Upper Peninsula of Michigan. The emphasis is on uranium deposits, and the study was done in the spirit that the final report should prove useful for individuals and organizations searching for uranium.

The methods employed were the following:

- 1) A review of the geological setting of the principal types of world uranium deposits, followed by a literature search for similar types of geological settings in Michigan and Wisconsin.
- 2) The acquisition and review of all literature concerning the uranium and thorium deposits in this region.
- 3) The field location, inspection, and description of all reported uranium occurrences.
- 4) The collection of uraniferous as well as normal rock samples for possible radiometric and petrologic study.
- 5) The chemical analysis of samples of typical Michigan Precambrian country rocks, and the acquisition of such analyses, particularly for uranium and thorium, to establish background abundances of these elements.

The Michigan portion of the study, presented as Part II of this report, was done by Carol Johnson as part of an M.S. thesis. Because she was unable to complete all of her research by June 1976, the completion date of this contract, her thesis will contain some additional data, and some of her conclusions will be stated in more precise terms than they are in this report.

I have prepared the report on Wisconsin (Part IV) and on certain other subjects that are included as Parts I, III, and V.

In that the length of time available for the completion of this study was rather short, we had to decide on scope and content before deciding on format. For this reason the report is divided into Parts I-V, and some of the Parts are subdivided further into Chapters. Illustrations and tables refer directly to the Part (ex., Figure III-2) or to the Chapter (ex., Figure 3-2). To avoid a protracted period of final editing and typing, we chose to insert shorter reference lists at the end of most Parts and Chapters. The Appendices contain a full bibliography on Michigan uranium occurrences, road logs to the Michigan occurrences, and a list of theses on Wisconsin geology.

In view of the above format, and of our divided responsibilities, certain parts of this report contain some duplications of subject matter, particularly in that topics of regional or local geology in an earlier section are treated in greater detail in a later one.

Prof. R. Ojakangas of the University of Minnesota-Duluth is doing a similar evaluation of Minnesota uranium deposits. We have agreed that, rather than establish the limits of our respective study areas along state boundaries, our common boundary will be at the top of the Freda Sandstone, and our studies will extend up to that surface.

ACKNOWLEDGEMENTS

A project of this type requires the help and cooperation of many individuals and organizations. I would like to recognize the following: Robert C. Reed of the Michigan Geological Survey and M. G. Mudrey, Jr., of the Wisconsin Geological and Natural History Survey, who provided copies of old reports and made files and theses readily available to us; Harlan K. Holen of ERDA, who not only provided us with copies of AEC reports, but made available to us on several occasions his experience extending back to the 50's when he worked with L. P. Barrett out of the AEC Ishpeming office; Mary McNeil of Bendix Field Engineering Corporation who was directly responsible for this contract; Galen C. Waddell, and particularly Don West, of the U.S.B.M. Twin Cities Mining Research Center who made it possible for us to see much core in a very short period of time; D. Sutherland of D. S. Robertson and Associates, Ltd., who helped locate some of the Michigan radioactive occurrences, supplied data on thirty fluorometric analyses of granites for uranium, and supplied or arranged for the analyses of 237 samples collected by Nordeng east of L'Anse, for uranium, lead and zinc; Dale Hendrick of Kerr Addison who gave us seminars on important types of Canadian uranium occurrences, on rather short notice; and to my Graduate Mineral Deposits class who helped me review the geology of important types of uranium deposits in the spring of 1975.

Carol Johnson, the author of Part II, would like to thank the following for their help: T. D. Isham, for field guidance; Drs. D. C. Noble, B. M. Hamil, S. C. Nordeng and A. P. Ruotsala, as well as fellow graduate students, M. Bingham and F. Pirez, of the Department of Geology and Geological Engineering, and L. Babcock of the Institute of Mineral Research, M.T.U., for helpful discussions and guidance; Janet Locatelli of the M.T.U. Library for assistance in obtaining old reports; and to James Dooley and Carl Bunker of the U.S.G.S. who provided information on techniques of autoradiography and gamma ray counting of rocks. Special thanks are extended to J. D. Jones, and especially to Tom Meyers of the Phoenix Memorial Laboratory at the University of Michigan who made the neutron activation analyses. These analyses were made possible under the conditions of some other grants to the Phoenix Memorial Laboratory from ERDA.

Both of us appreciate the careful work of Mr. P. Ostlender who did all of the drafting, and Julene Erickson who typed the various versions of this report.

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PART I

PRECAMBRIAN GEOLOGY OF NORTHERN
MICHIGAN AND WISCONSIN

J. Kalliokoski

Part I

Precambrian Geology of Northern Michigan and Wisconsin

J. Kalliokoski

Introduction

This section will provide a summary of the Precambrian geology of northern Michigan and Wisconsin. In Parts II and III of this report some aspects of Michigan geology will be discussed more fully, and in Part IV there will be a similar, more detailed treatment of Wisconsin geology.

An excellent summary of the regional geology was prepared recently by Van Schmus (1976). The reader can find much excellent general information on northern Michigan in the appropriate chapter of the textbook "Geology of Michigan" by Dorr and Eschman (1973) and in the thesis by Bodwell (1972). For Wisconsin the most comprehensive reports are those by Dutton and Bradley (1970), and the "Guidebook to the Precambrian Geology of Northeastern and North-central Wisconsin" of the 19th Annual Institute on Lake Superior Geology, Madison, 1973. All of these publications are accompanied by extensive bibliographies.

Archean Rocks

The oldest Precambrian rocks in Michigan and Wisconsin consist of granitic, felsic, and mafic gneisses, greenstone, and granites. Until recently they were considered to comprise a single Archean terrain. However, Morey and Sims (1976) have pointed out that these rocks represent two

somewhat distinct assemblages (Part II, Figure 2-1). The northern one consists of the typical greenstones and granites that commonly show 2.7 to 2.75 b.y. dates wherever these rocks have been studied in the Superior Province of the Canadian Shield. The southern assemblage is interpreted to be (Sims, et al., 1975) the eastern extension of the far older rocks of the Minnesota River valley that have shown dates as old as 3.8 b.y. (Goldrich and Hedge, 1974).

In Michigan the older gneissic terrain would include the gneisses in the "Southern Complex", the gneisses near Marenisco and Watersmeet. The latter gneisses probably extend southwest into Wisconsin. These ancient gneisses may be quite widespread in Wisconsin as suggested by the recent dating of such rocks by Van Schmus and Anderson (1976) from near Stevens Point.

The younger Archean greenstone-granite terrain is represented by rocks of the "Northern Complex" of Michigan, and by the greenstones of the Wakefield area that extend southwest into Wisconsin.

Middle Precambrian Rocks (1,850-1,950 m.y.)

After a long tectonic history, followed by uplift and erosion, the Archean terrain became covered by Middle Precambrian rocks. In the Marquette Trough of Michigan these younger rocks are predominantly sedimentary, but volcanic rocks increase in abundance southward. In Wisconsin sedimentary rocks of this age appear to be rare, except for iron formation in the northwest and north-central parts of

the state. So far the stratigraphic relationships among the Wisconsin volcanic rock belts and occurrences is unknown.

Complicating the regional stratigraphic and structural relationships are a series of major faults that extend along the eastern portion of the Michigan-Wisconsin boundary, between the sedimentary-volcanic terrain on the north and the predominant volcanic terrain on the south. Movement along these faults, perhaps in Penokean time, has been south-side-up.

In northeastern Wisconsin are a series of plutons ranging in composition from diorite to granite that Van Schmus and others (1975b) have found to be of the same age as the volcanic rocks, and consider to be genetically related to them. These workers propose that all of these rocks in Michigan and Wisconsin, the sedimentary, volcanic and plutonic, represent a major orogenic suite, related to the Penokean Orogeny, with continental margin sediments in the north and volcanic-plutonic rocks to the south. The details of this hypothesis require more study.

A major tectonic feature of the Penokean Orogeny was the pronounced basement control on the development of major anticlines and synclines (Bodwell, 1972; Cannon, 1973). This tectonic style appears to have extended to the Middle Precambrian rocks of northwestern Wisconsin.

The formation of the four distinct metamorphic nodes in Michigan and northern Wisconsin (Part II, Figure 2-2) are additional thermal and dynamothermal aspects of the Penokean Orogeny (Klasner, 1972) related in time to the intrusion of

the Peavy complex in Michigan and the plutons in northeastern Wisconsin (Van Schmus, 1976).

Middle Precambrian Rocks (1,800 m.y.)

Slightly younger rocks consisting of granites and rhyolites, without Michigan counterparts, are found in central Wisconsin as inliers under the Paleozoic cover (Van Schmus, et al, 1975b).

Middle Precambrian Quartzites (1,800(?)~1,500(?) m.y.)

The succeeding rock sequence, resting on 1,800 m.y. old rhyolite near Baraboo, Wisconsin, is represented by quartzites and quartz-pebble conglomerates with minor shales and limestones, that occur as separate, and in some instances as infolded, outlying remnants resting on an older basement. All of these rocks, possible correlatives, denote original accumulation on a subsiding shallow-water continental shelf (Dott and Dalziel, 1972). These rocks are discussed more fully in Part IV of this report.

Middle Precambrian Rocks (1,500 m.y.)

The period of crustal quiescence represented by the sedimentation of the quartzites was followed by the intrusion of the Wolf River Batholith and the Wausau syenite complex, both dated at 1,500 m.y. (Van Schmus, 1975a). The Hager Quartz Porphyry of this batholith intrudes the McCaslin Formation, giving a possible lower age limit for the various quartzites. Because it contains several uranium

occurrences, the Red River Quartz Monzonite portion of the batholith is described more fully in Part IV.

The quartzites, such as those at Baraboo (Dalziel, et al., 1970) and at McCaslin (Mancuso, 1960) are folded and faulted, as are the underlying rhyolites. If the rocks of the Wolf River Batholith are less deformed as Van Schmus suggests (1976), this would mean that the widespread folding in the quartzites predates the intrusion of the batholith, and the batholith is anorogenic. The important point to note is that, regardless of the minimum age of this folding, the maximum age makes it younger than the Penokean Orogeny.

Upper Precambrian Rocks (1,100-1,000 m.y.)

The younger Precambrian formations are confined to the northwestern parts of Wisconsin and Michigan. The initial opening of the Mid-continent rift (King and Zeitz, 1971) about 1,100 m.y. ago, may have been demarked in Michigan by the outpouring of the "South Range Traps" (Powder Mills Group), of Lower Keweenawan age. This was followed by the outpouring of the Portage Lake Lava Series that was erupted from the general position of the rift, and by the covering of these lavas by in excess of 5 km of sedimentary rocks in Michigan. Hubbard (1972) suggests that significant deformation of the Lower Keweenawan rocks took place shortly before or during Middle Keweenawan time.

Associated with the Keweenawan rocks is the Jacobsville Sandstone (Part III). I consider the sandstone to be Upper Keweenawan, but its precise stratigraphic position is not

established. Its importance lies in the fact that the sandstone lies on a widespread unconformity, and the fluviatile sediments show good evidence for derivation from a deeply weathered source area.

Paleozoic Rocks

The land surface remained almost undisturbed during Paleozoic time. It would seem reasonable to expect that the area was covered by Paleozoic sedimentary rocks and that these have become removed by weathering and erosion. The presence of Ordovician limestone some ten miles west of Keweenaw Bay makes such a possibility reasonable. Part IV contains a brief discussion of the K^{40} radiation in the Franconia Formation of Cambrian age in Wisconsin.

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PART II

MODES OF OCCURRENCE OF URANIUM AND
THORIUM IN THE PRECAMBRIAN ROCKS OF THE
UPPER PENINSULA OF MICHIGAN

Carol Johnson

ABSTRACT

Three types of radioactive occurrences are recognized in Michigan: primary concentrations in igneous rocks, a single syngenetic concentration of monazite in the Goodrich Quartzite, and supergene concentrations in Middle Precambrian metasedimentary rocks, granitic rocks, metadiabase, and Keweenawan felsites. The supergene concentration in Middle Precambrian metasedimentary rocks is the most prevalent and appears to have the most potential.

The writer proposes a model for "the Lake Superior type uranium occurrence". It originates through the leaching of uranium from carbonaceous slates of the upper Marquette Range Supergroup and reconcentrates it in various rock types. The process which formed these occurrences is thought to be related in time and in mechanism to the formation of soft iron ores of the Lake Superior region and the deposition of the Jacobsville Sandstone.

Supergene concentrations formed by the leaching of uranium from granitic and rhyolitic rocks and its redeposition within fractures of the same rocks are believed to have a similar origin. These occurrences are less widespread, but may have economic potential.

INTRODUCTION

This work represents one portion of the ERDA contract AT(05-1) - 1651 to J. Kalliokoski, retitled "Evaluation of the Uranium Potential of the Precambrian Rocks of Northern Wisconsin and Michigan". It deals with only Michigan, and consists to a great degree of the collection and synthesis of all known literature and data pertaining to the occurrence of uranium and thorium in Precambrian rocks in Michigan. I supplemented this information by analysing 54 typical bedrock samples for uranium and thorium by neutron activation. I was given another 31 analyses of granitic rocks by Mr. D. Sutherland of D. S. Robertson and Associates, Ltd. These had been analysed by the fluorometric method.

I started this work in the summer of 1975, as part of a M.S. thesis, but because I was not able to complete all of my analytical work during the one year duration of the contract, I am submitting this report prior to completing my thesis in the Fall of 1976.

CHAPTER 1

CHARACTERISTICS OF RELEVANT TYPES OF
PRECAMBRIAN URANIUM DEPOSITS

A useful way to evaluate the uranium potential of an area is to compare the types of known occurrences with economic counterparts elsewhere, and to examine the geology for those kinds of settings that have been found to be favorable elsewhere. To this end I am including here a series of descriptions of what I consider to be important counterparts of the Michigan occurrences. In Chapter 3 I will describe the actual Michigan occurrences. This approach may help to emphasize important points of similarity.

TABLE 1-1

Important Deposits and Michigan Counterparts

<u>Type and Examples</u>	<u>Michigan Counterparts</u>
Uraniferous Precambrian Quartz Pebble Conglomerates: Elliot Lake, Ontario; Witwatersrand, South Africa; Jacobina, Brazil	Monazite-bearing Goodrich Quartzite, a conglomerate containing well worn pebbles of vein quartz and chert with angular fragments of iron form- ation in a quartzite matrix. Radio- active mineral is monazite.
Uranium in Granites and Pegmatites: Rossing, Southwest Africa; Massif Central, France; Spokane, Washington, USA.	Greens Creek Pegmatite, an irregular pegmatite probably of metamorphic origin, containing primary grains of radioactive minerals. Republic Migmatite, radioactive leucosome within a migmatite.
Uranium in Syenites and Nepheline Syenite: Ilimaussaq, Greenland	Radioactive syenite dike near Mar- quette.

Type and Examples	Michigan Counterparts
Vein Deposits of Possible Supergene Origin in Precambrian Gneisses: Beaverlodge and Rabbit Lake areas, Saskatchewan	Radioactive fissures at Big Eric's Crossing, Huron River; Wiggins Pros- pect; Lavato's Occurrence; the three Leitch and Isham Prospects and the Voelker Prospect.
Vein Deposits of Possible Supergene Origin in Precambrian Metasedimentary and Volcanic Rocks: Rum Jungle-Alligator Rivers Province, Northern Territories, Australia	Radioactive concentrations in frac- tures, breccia zones, faults and lithologic contacts in black slates of the Michigamme Formation, oxidized iron ores of the Bijiki, Greenwood, Riverton and Gwinn Iron Formations and in altered felsites of Keweenawan age.
Uranium Associated with Diabase Dikes: Theano Point area, Ontario	Haggett Dike, Taylor Mine, Graphite Quarry and the M&G Mine.

Precambrian Uraniferous Quartz-Pebble Conglomerates

One of the most important types of uranium deposits in the world are the Precambrian quartz-pebble conglomerate deposits. The largest of these are the Witwatersrand, South Africa (Minter, 1976; Pretorius, 1974, 1975); Elliot Lake, Ontario (D. S. Robertson, 1970, 1974; J. A. Robertson, 1969; and Roscoe, 1969, 1973); and Jacobina, Brazil (Bate-man, 1958; Gross, 1968; Cox, 1967; and White, 1956). All represent a resistate assemblage of quartz pebbles, pyrite and uranium in a sericitized and variously recrystallized quartz matrix. The major ore minerals are uraninite, thucolite, brannerite and uranothorite. Pyrite can average as much as 3 percent by weight of the total rock.

These conglomerates were derived from granitic source areas containing metavolcanics and some metasediments. They moved through a fluvial system, and the sediments exhibit a typical braided stream pattern with the appropriate structures such as scours and foreset and festoon crossbedding. The grain size of the pyrite and uranium minerals becomes much finer at the proximal end of the fan (Pretorius, 1974; Minter, 1976). The fluvial fan system of the Klerksdorp Goldfield in the Witwatersrand Basin is shown in Figure 1-1. Six such fluvial fan systems have been identified in the Witwatersrand basin. The Elliot Lake deposits occur in two troughs or channels separated by a basement high.

Figure 1-1 - Fluvial fans in the Klerksdorp Goldfield, Witwatersrand Basin. The apices of successive fans move from the basin-edge towards the depositional axis. 1 = Dominion Reef; 2 = Government Reefs; 3 = Jeepstown Reefs; 4 = Main Reef; 5 = Livingston Reef; 6 = Bird Reef; 7 = Kimberley Reefs.

The prevailing idea on the origin of the Witwatersrand deposits are that the uranium and gold were transported as detrital particles, the gold settled in the mid-lobe section of the fan and the uranium moved somewhat downstream. Concentration took place physically through gravity settling and subsequent winnowing by wave and current action. The role of biochemical processes in the depositional cycle is under debate (Pretorius, 1975).

From the time-distribution of the deposits, Roscoe (1973) postulates that the placer type deposits are limited to Precambrian fluvial-deltaic strata older than 2.2 b.y., prior to the development of an atmosphere with free oxygen.

Uranium-bearing Precambrian conglomerates also occur in Western Australia. Some of them are less well sorted polymictic conglomerates composed of a pyritic-arkosic matrix and a "weak assemblage" of heavy minerals and thucolite (Robertson, 1974).

Important conditions for the formation of higher grade deposits such as at Elliot Lake (Robertson and Douglas, 1970) appear to be the existence of a granitic source area with abundant uranium-bearing accessory minerals, a large and persistent drainage system providing sorting, winnowing and utmost concentration of the uranium bearing heavies, and their subsequent preservation from erosion. Weathering and transportation conditions were such that it prevented the oxidation of the uranium into more soluble forms, possibly representing conditions of formation prior

to 2.2 b.y. Of course, there is an inherent danger in prescribing strenuously to the 2.2 b.y. lower age limit for uranium in quartz-pebble conglomerates. The critical oxygen concentration may have been achieved at a slightly later time, and perhaps the discovery of younger uraniferous quartz-pebble conglomerates will help define the absolute age boundary for these deposits.

With the possible near-term exhaustion of higher grade uranium ores (Leiberman, 1976), the rising uranium prices, and the lower concentration of uranium which can be mined profitably, it might also be worth looking at the less promising polymictic conglomerates of the appropriate age, similar to some of those found in Western Australia.

Uranium in Granites and Pegmatites

Low-grade uranium ore deposits are known from a variety of host rocks such as late magmatic differentiates, alaskite, leucocratic granites, biotite gneisses and biotite quartz monzonite, all of which are intruded by networks of aplite and pegmatite dikes of similar composition. The uranium occurs in uraninite and multiple oxides of uranium and also in ionic and molecular disseminations within other minerals. Possible examples are Rössing, Southwest Africa (Berning, Cooke, Heimstra and Hoffman, 1976); the French Central Massif (Geffroy, 1972); Charlebois Lake, Saskatchewan (Armstrong, 1974); Crocker Well, Australia (Armstrong, 1974; Campana and King, 1958); and the Spokane area, Washington, U.S.A. (Armstrong, 1974; Weissenborn and Moen, 1974).

Of these deposits, the Rössing uranium deposit has created the greatest amount of interest. The deposit is situated in the center of a late Precambrian orogenic belt located in Southwest Africa. The uranium mineralization is associated with a syntectonic alaskite which exhibits textures ranging from aplitic and granitic to pegmatitic. It is composed of quartz, microcline and microcline perthite with some biotite, and ranges from small quartz-feldspar secretion lenses to large intrusive-replacement bodies. Contact metamorphism is most pronounced around marbles. Barren or sparsely mineralized alaskite is found beyond the deposits. The mineralized portion is attributed to higher contents of uranium in the migmatized source rocks.

Uraninite constitutes 55 percent of all radioactive minerals, betafite represents 5 percent and secondary uranium minerals around 40 percent, indicating that the supergene enrichment is an important phase in this type of deposit. The uraninite occurs within the quartz, feldspar and biotite. The secondary minerals occur along joints, cracks, mineral boundaries and between flakes of biotite.

Berning, Cooke, Heimstra and Hoffman (1976) suggest that the alaskite was emplaced by a passive metasomatic process, through the action of granitizing fluids that replaced already migmatized country rocks along shears, fractures, bedding planes, and axial planes of folds. They postulate that the uniform chemistry and mineralogy and K-rich composition of the aplite points to a derivation of the syntaxis of pre-existing quartzites and gneisses.

Vein Deposits of Possible Supergene Origin in
Precambrian Metasedimentary and Volcanic Rocks

The origin of the pitchblende deposits of the Rum Jungle and Alligator Rivers area in Australia is still the basis of considerable debate (Langford, 1974). Some similarities between these deposits and the occurrences of Michigan do exist, however. For that reason, three areas of pitchblende mineralization in the Northern Territories of Australia will be described.

The ore deposits of the Rum Jungle area occur in meta-sedimentary rocks of the Lower Proterozoic Golden Dyke Formation (Spratt, 1965; South, 1972; Dodson, Needham, Wilkes, Page, Smart and Watchman, 1974). Pitchblende occurs in pyritic-graphitic slates, phyllites and chloritic schists within this formation which overlies Archean basement. The mineralization occurs around major structures such as shears or faults, where the ore minerals occur in joints, fractures and cleavage planes. The source of the uranium is thought to be either the black slates or the basement granites.

The pitchblende deposits of the Alligator Rivers area have been found more recently. The deposits occur in the Lower Proterozoic Koolpin Formation, near the granitic Nanambu Complex. Metamorphic grade decreases away from the complex, which is of Archean age, but which was partially remobilized 1700-1800 m.y. ago. The major deposits occur in chloritic metasedimentary rocks that are draped around

the complex. The largest pitchblende deposit of the world--the Jabiluka deposit--was discovered in this area in 1973. Jabiluka 2 is said to lie under the Kombolgie sandstone, just below the unconformity (Langford, 1975).

All of the pitchblende deposits of the Alligator River area occur in chloritic schists, with evidence of sericitization. Uranium-lead ages from the area show four ages, 1880, 1700, 900, and 500 m.y., suggesting that the uranium may have been deposited syngenetically in the sediments 1800 m.y. ago, and concentrated at 1700 m.y. It was then subjected to lead loss at 900 and 500 m.y. (Dodson, et al, 1974).

The third group of deposits are in the South Alligator River area. Of these thirteen deposits, pitchblende occurs at ten of them in cherty shale of the Lower Proterozoic Koolpin Formation and in adjacent Upper Proterozoic sandstone. At one, pitchblende occurs in diorite, at another in tuff, breccia and altered rhyolite, and at one in weathered and altered Upper Proterozoic tuffs and shales. Carbonaceous shale is present at the typical deposit and its local shearing caused folding and fracturing of the adjacent more competent cherty shales, where ore occurs as massive blebs, veins and small lenses to a vertical range of about 100 feet. Secondary ores occur at the surface and are derived from the pitchblende. The ore bodies are believed to be 500-650 m.y. old, that is, younger than the tectonic structure and all known igneous activity in the area (Prichard, 1965; Dodson, et al, 1974).

S. A. South (1972)

Figure 1-2 - Uranium deposits of the Darwin area,
Northern Territories, Australia.

All deposits of the South Alligator region are located at or near the Middle Proterozoic unconformity. Overlying the unconformity are the Edith River Volcanics and the Kombolgie sandstone, which consists of 1730 meters of sediments and minor volcanics. Ayres and Eadington (1975) postulate that the source of the uranium was the Edith River Volcanics. They estimate that on the basis of Th/U ratios as much as 10 ppm of uranium may have been leached from the rhyolite member and emplaced in the underlying metasedimentary rocks by supergene processes.

It should be noted, however, that some ascribe to a different point of view. The spatial distribution has been interpreted by some to indicate a relation between the mineralization and a major igneous phase 1700-1800 m.y. ago. The deposits show a low hydrothermal alteration and the mineralizing solutions are thought to have been "isolated by lithification of the Lower Proterozoic sediments and mobilized during the igneous and contemporaneous tectonic phases" (Dodson, et al, 1974).

Dodson, et al (1974) suggest three steps in the formation of the uranium deposits of the Rum Jungle-Alligator River Province:

1. Syngenetic enrichment of uranium in carbonaceous sediments during Lower Proterozoic time.
2. Concentration of ore-grade deposits of uranium minerals in favorable places from mineralized solutions mobilized during a major igneous/tectonic event.

3. Mobilization of uranium by circulating solutions through leaching and redeposition not far away between 900 and 500 m.y. ago.

Vein Deposits of Possible Supergene Origin in Gneisses

Vein deposits in granitic or gneissic host rocks are widespread in the world (Langford, 1974; Rich, Holland and Petersen, 1975; Matos Dias and Soares de Andrade, 1970). The origin of these types of deposits is a subject of controversy in that many are questioning their assignment to the hydrothermal class.

The nature of the problem can be illustrated by the deposits of the Beaverlodge area. The first deposits found were vein like, and the original theory put forth by Robinson (1955) regarded all of the veins as hydrothermal. This theory, however, was not applicable to new finds, such as at Rabbit Lake. New hypotheses based on a supergene model were proposed by Langford (1974) and Knipping (1974) to explain the spatial and stratigraphic relationships of all of these Saskatchewan deposits.

The area around Beaverlodge is underlain by the Precambrian Tazin Group, characterized by metamorphosed quartzites, amphibolites, granites, gneisses and garnet-bearing rocks, representing the products of a long and complex geologic history. The Tazin Group is unconformably overlain by the Martin formation, a continental redbed sequence of basal conglomerate, arkose, siltstone, basaltic flows and gabbroic sills (Figure 1-3).

F. F. Langford (1975)

Figure 1-3 - Geologic cross section through the Beaverlodge area, Saskatchewan.

It is well known that many of the pegmatites contain anomalously high concentrations of uranium, and many consider this to be a primary feature of those rocks. In addition, uranium occurs as epigenetic pitchblende and more rarely as uranophane in veins, under many kinds of structural settings. Ruzika (1971) characterized the two types of mineralization as follows:

"The syngenetic mineralization is confined to areas with minor faulting and little or no mylonitization of the bedrock; such areas were designated as stable blocks by Beck (1967). The epigenetic mineralization is confined to areas with intense faulting, brecciation, mylonitization and characteristic folding; such as Beck designated as linear belts.

Distribution of epigenetic deposits is structurally controlled; structural control is evident also in the localization and in morphological features of the pitchblende ore bodies."

At Rabbit Lake the uranium deposit occurs in dolomitic and calcareous metasedimentary rocks of Lower Proterozoic age below a major unconformity which is overlain by Middle Proterozoic sandstone. Knipping (1974) says that the deposits at Rabbit Lake were formed 1000 m.y. ago and bear no relationship to the Hudsonian orogeny. He states that alteration and uranium emplacement are related to the surface and do not extend more than 300 to 400 feet below the unconformity.

Those in favor of a hydrothermal origin for the epigenetic deposits at Beaverlodge, suggest that at a late stage in the Hudsonian granitization process syngenetic uranium from older granites was released to solutions and emplaced prior to the deposition of cover rocks (Beck, 1969).

In order to account for the stratigraphic control which he sees to be prevalent in the area, Langford (1975) postulates a supergene origin for all of the uranium deposits. He suggests that prior to the deposition of the Martin formation the area was high, and there were many fault basins. Uranium was weathered from the highlands and became precipitated in such reducing environments as represented by fractures in basement rocks and in cooling cracks within the Martin Lake lavas. Langford suggests that at Rabbit Lake the deposit was formed when the events which produced the Beaverlodge ores were repeated during the deposition of the Athabasca sandstone in Late Helekian time.

Uranium Associated with Diabase Dikes

The Theano Point area, about 70 miles north of Sault Ste. Marie, Ontario is dominated by pre-Huronian granitic intrusions and a few smaller Keweenawan granites, with patches of Keweenawan volcanic rocks along the shore (Nuffield, 1955; Lang, 1952). The area is cut by numerous diabase dikes of Lower Keweenawan age and some of late Keweenawan age.

The area is characterized by two types of occurrences of radioactive minerals, one within the granite or pegmatite, and the other in or near, and structurally related to, diabase dikes. At the discovery point, pitchblende occurs in a brecciated contact zone of a jointed and slickensided diabase dike with the surrounding granite. Pitchblende occurs as stringers, with calcite and hematite, in fractures which are probably tension cracks.

All deposits of pitchblende in the area have been found in structures that are in, and related to, diabase dikes. The dikes are commonly sheared and fractured (Nuffield, 1955; Lang, 1952).

I believe that it is safe to postulate that the uranium was leached from the granitic country rocks and precipitated in favorable structures and traps in and around the diabase dikes. Sulfides in the diabase may have served to reduce the uranium and precipitate it from solution.

Evidence of the uranium mobility in the area has led to the testing of this hypothesis by Moncrieff Uranium Mines (Anon., Northern Miner, 1976).

Uranium in Syenites and Nepheline Syenite

Alkaline granites and late members of calc-alkalic igneous rock series rich in silica and potassium are also enriched in uranium and thorium. Also some saturated and undersaturated syenites and their volcanic equivalents are strongly enriched in uranium and thorium, and the youngest intrusions in an alkaline igneous suite are generally richest in the rare elements (Sorensen, 1970).

Ilimaussaq is the youngest intrusion into the Precambrian alkaline-igneous province in South Greenland. The nepheline syenites were formed during two main stages. First a per-alkaline nepheline syenite magma became enriched in volatile components and in rare elements, and are characterized by concentrations of sodalite and eudialyte. Such end products of highly evolved magmas, rich in residual elements are called agpaitic rocks. During the second state these earlier rocks were intruded by rocks consisting of microcline, albite, nepheline, alkali amphibole, and alkali pyroxene. These rocks are enriched in elements such as Sr, RE, Nb, U, Th, and Zn, and are accompanied by swarms of hydrothermal veins made up of albite, analcime, ussingite and natrolite. All of these rocks are believed to have crystallized from one body of magma which differentiated during crystallization in a fairly closed system (Bohse, Rose-Hanson, Sorensen, Steenfelt, Lovborg and Kunzendorf, 1974).

Whereas the disseminated uranium mineralization in the earlier syenites averages only from 9 to 23 ppm (Bohse, et al, 1974), the youngest melanocratic rocks contain up to 0.1% uranium and 0.5% thorium. The late hydrothermal veins are also rich in radioactive minerals. Thus, the end products of such differentiation series may represent low grade deposits of uranium and thorium.

Peralkaline granitic magmas, the end products of an over-saturated series, will generate a fluid phase that may carry off the uranium along with chlorine and fluorine. If these fluids escape into fractures, a porphyry type deposit may be formed. The Ross-Adams deposits in Alaska may have formed in this manner (Bohse, et al, 1974).

Uranium in Iron Formation

Several radioactive occurrences in Michigan occur within the Precambrian iron formations. For that reason, the uranium-bearing iron ore deposits in the USSR will be discussed, although the processes which formed them may not be the same processes which formed the occurrences in Northern Michigan.

Uranium mineralization occurs within the border facies of the Krivoy Rog iron ore deposit in the USSR (Ruzicka, 1971). The host rocks are migmatized, altered quartzites and other sedimentary rocks containing hematite and magnetite mineralization.

The mineralization occurs in four different associations:

(1) stratiform bodies within albitites, containing uraninite, magnetite, hematite, aegirine, rhodusite, malacon, pitchblende, uranium silicate, aragonite and graphite; (2) lenticular concentrations of magnetite, hematite, carbonate and uraninite; (3) irregular accumulations of albite, dolomite, and uraninite, with minor sulfides and quartz; (4) irregular accumulations of albite, amphibole, aegirine and malacon. Ruzicka (1971) has classified these occurrences as metasomatic in origin.

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CHAPTER 2

THE PRECAMBRIAN GEOLOGY OF MICHIGAN

Introduction

The geology of Michigan's Precambrian has been compiled by Bodwell (1972), and the Marquette Trough area has been summarized by Cannon, Gair, Klasner and Boyum (1975) and by Boyum (1975). Quite recently Van Schmus discussed the dating of Precambrian rocks of Michigan and Wisconsin (1975). Therefore, only those aspects of the geology that the author considers pertinent to uranium resources will be discussed here. Emphasis is placed on those formations known to contain mineralization, those that because of their higher uranium content may serve as a source for supergene uranium, and those that may serve as a host for such uranium. These formations are marked with an asterisk in the Tables of Formations (Tables 2-1, 2-2, 2-3, and 2-4).

Lower Precambrian Granites and GneissesGeneral

The Lower Precambrian rocks throughout most of the western Upper Peninsula are represented by granites, gneisses, basic and felsic volcanic rocks, amphibolites and meta-sediments. Rb-Sr age dating of whole rock granite samples from both the Northern and Southern Complexes yielded ages that vary between 2.5 and 2.8 b.y. (Van Schmus and Woolsey, 1975). However, these authors could not establish a single

isochron from the scattered data. Peterman, Zartman and Sims (1976) note that the gneiss near Watersmeet yields a Pb/Pb age of zircons of 3310 to 3370 m.y. and they suggest a primary age of 3500 m.y. for the gneiss. Sims (pers. comm., 1976) postulates that those gneisses are part of the same 3.8 b.y. gneiss terrain that has been studied in the Minnesota River Valley (Goldich and Hedge, 1974). Furthermore, he identifies an east-northeast contact that separates the greenstone-granite terrain of the Northern Complex and Ironwood area from the gneisses of the Southern Complex and of the Marinesco-Hurley area (Figure 2-1).

Several lines of evidence tend to confirm that the granites of Michigan can be separated into these two broad groups: in the eastern part of the Northern Complex variously metamorphosed basic (Mona Schist) and felsic volcanic (Kitchi Schist) rocks are an important rock type. Such rocks are rare in the Southern Complex (Klasner, 1972; Bodwell, 1972; Cannon and Simmon, 1973). By contrast, in the Felch area are the metasediments of the Dickinson Group, and granites contain rare fragments of schist and quartzite. Such rocks are absent from the Northern Complex. Both areas do contain migmatites and amphibolite masses in granite gneiss terrain.

Gair and Thaden (1968) have shown the radioactivity of the gneisses of the Northern Complex to average .024-.025 mR/Hr., whereas those of the Southern Complex average .035-.045 mR/Hr. They suggest that this difference may denote unrelated bodies of granitic rocks. The real question seems

Figure 2-1 - Map showing distribution of Lower Precambrian greenstone and gneiss terrane.

to be whether the higher radioactivity in the Southern Complex is due to metamorphism and recrystallization of the older gneisses, at which time uranium became concentrated in pegmatites and migmatites, or conversely, whether the more complex thermal metamorphism of the southern gneisses might somehow be related to a higher primary content of radioactive elements.

Heavy mineral studies by Tyler, Marsden, Grout and Thiel (1940) show the presence of both the hyacinth and malacon varieties of zircon in the gneisses of the Southern Complex whereas those of the Northern Complex are characterized by only hyacinth. They believe that the presence of malacon is diagnostic of younger granites -- which to them are more abundant in the Southern Complex. These granites may be late intrusions into an old granitic terrain, or the product of remobilization of pre-existing granites.

From the viewpoint of the availability of source rocks for supergene uranium metalization, it is important to note that the gneisses and granites are exposed in relatively large areas of Northern Michigan, and, from the evidence of provenance in conglomerates, that they have been exposed sporadically both prior to and after the Penokean orogeny, 1900 m.y. ago. Thus, during exposure and possible weathering, these crystalline rocks could have contributed uranium to supergene solutions. Therefore, their possible role in the formation of some of the supergene uranium prospects cannot be overlooked. Granitic country rocks are almost

certainly the source for the supergene uranium occurrences within granites, and they could also have played a greater or lesser role in the mineralization of some (but not all) of the occurrences in Middle Precambrian rocks.

Uranium is a very mobile element and might be reconcentrated within granites during metamorphism and recrystallization. This type of reconcentration may have occurred in the Southern Complex which is known to contain 3.5 b.y. old granite-gneisses, that have been subjected to igneous intrusion at 2.7 b.y., intrusion and metamorphism at 1.8 b.y. and low grade regional metamorphism at 1.65-1.7 b.y. (Peterman, Zartman and Sims, 1976; Van Schmus, 1976).

I have made uranium and thorium analyses by neutron activation on a number of samples from both the Northern and Southern Complex, in an attempt to predict the potential for mineralization in and around the granite bodies and to establish regional geochemical background abundances. The results are discussed in Chapter 4.

The following is a brief review of some of the larger igneous bodies, based mostly on descriptions in the literature. In a general way rocks of the "gneiss terrain" are described first because they are older. However, it is recognized that all gneisses are not necessarily older than all granites. The matter of later metamorphism of these rocks will be discussed in a later section.

Bell Creek Gneiss

The Bell Creek Gneiss occurs in the Southern Complex and is older than the Compeau Creek Gneiss, having been intruded by that found in the Bell Creek Gneiss. The most common rock type is a coarse-grained granite gneiss with large pink megacrysts of microcline microperthite. Finer-grained rocks, mafic gneiss and migmatite also occur, as well as lenses of highly metamorphosed iron formation. The chemical composition of the rock indicates that it is predominantly adamellite with some granodiorite and granite. It is not known to intrude any rocks, yet its chemical composition is suggestive of an igneous origin. Cannon and Simmons (1973) intimate that the gneiss may be a highly metamorphosed metavolcanic rock.

Carney Lake Gneiss

The Carney Lake Gneiss underlies about 50 square miles in the Iron Mountain area (Treeves, 1966). No radioactive prospects are known to occur in the gneiss, but several zones of minor radioactivity (2-5 times background) were noted during the summer. The gneiss is heterogeneous and consists of three varieties: a gray gneiss (accounting for 25 percent of the total rock), a composite gneiss (70 percent), and a red gneiss. The red gneiss is composed of microcline, quartz and albite, and occurs as younger veins, layers and pegmatitic pods which pinch and swell along the foliation of the older enclosing rocks. The rock is strongly jointed (Treeves, 1966).

Granites near Felch

Fault-bounded masses of granite gneiss occur in the area around Norway Lake, north of Felch, and represent the oldest major rock body in the Felch area. All three of the Leitch and Isham prospects occur in these gneisses. These have been mapped and described by James, Clark, Lamey, and Pettijohn (1961) as non-uniform, but generally consisting of a red, foliated medium to coarse-grained granite gneiss that shows abundant evidence of very strong deformation. There is also a reddish porphyritic gneiss with pink perthitic and elliptical microcline phenocrysts and a pink to light orange, fine-grained massive granite.

Gneissic granite forms two large masses south of Felch. It generally consists of massive to foliated pink or gray granite containing microcline and albite. It grades into quartz diorite. The rock contains older deformed pegmatitic veins and layers and numerous amphibolitic inclusions.

Porphyritic red granite is found also along M-95, one and one-half miles north of Randville. It contains augen-like pink feldspars of microcline, surrounded by oligoclase, quartz and biotite (James, et al, 1961).

Margeson Creek Gneiss

The Margeson Creek Gneiss is exposed in the Amasa uplift north of Crystal Falls (Gair and Wier, 1956; Wier, 1967). Two radioactive prospects occur in this gneiss. Gair and Wier (1956) describe two rock types: a banded granodiorite

or tonalite rock, generally gray colored with biotite and hornblende-rich phases, and a more abundant rock type which is a non-banded, but foliated pink or gray granite. They also note a foliated quartz-sericite rock along inferred faults and believe it to be a mylonitized granite. Elsewhere shear seams are filled with fine grained sericite (paragonite?) and quartz. Migmatite is reported to be widely distributed, though not abundant, and biotite and sericite schists are also reported to be minor phases among the layers of the banded gneiss.

Gneisses Near Watersmeet and Marenisco

The Gneiss near Watersmeet (Wolf Lake Granite of Allen and Barrett, 1915) outcrops along U. S. Highway 45. It consists of gray biotitic gneiss, migmatite and pegmatite (Fritts, 1969). It is surrounded by garnet-grade metamorphic rocks which may be related to the reactivation of the gneiss (Sims and Peterman, 1975).

Recent uranium-lead age dating on zircons has shown the gneiss to be at least 3.4 b.y. old (Peterman, Zartman and Sims, 1976), and Sims (pers. Comm., 1976) has postulated that the gneiss is part of the same 3.8 b.y. terrain as the gneisses of the Minnesota River Valley. Mylonitic rocks previously identified as "Strata near Cup Lake" are thought by Sims to denote the general boundary between the gneisses and the granite-greenstone terrain to the north (pers. comm., 1976).

Granites Near Lake Gogebic

The granites around Lake Gogebic were mapped by Fritts in 1969. Several different granite-gneiss bodies have been defined. The "Gneiss near Mt. Kimberley" and "Granite near Nelson Creek" were formerly mapped as the Presque Isle Granite. One radioactive occurrence associated with a calcite vein has been noted in the gneiss. The "Granite near Nelson Creek" is a pinkish gray to light red granite and pegmatite, containing a band of chlorite schist with numerous quartz-carbonate veins west of the south tip of Lake Gogebic. The "Gneiss near Mt. Kimberley" is a banded gneiss of meta-sedimentary and/or metavolcanic origin. It also contains granite to dioritic rocks of igneous origin.

The "Granite near Thayer" includes a granitic to quartz-monzonitic gneiss, injection gneiss, migmatite, granite and pegmatite. It also includes a porphyritic felsite, described as a foliated fine-grained gray rock with phenocrysts of quartz and microcline and surrounded by garnet-grade metamorphic rocks.

Compeau Creek Gneiss

The Compeau Creek Gneiss has been described by Gair and Thaden (1968) from its exposures in the Northern Complex and by Cannon and Simmons (1973) from the Southern Complex. If the major rock types in the two complexes are indeed of differing ages, then possibly the name "Compeau Creek" should not be assigned to both rocks.

The gneiss consists of foliated granodiorite and tonalite with local inclusions of amphibolitic gneiss. According to Puffett (1974), in the Northern Complex this gneiss intrudes the Mona Schist. It consists of greater than 95 percent quartz, microcline, and plagioclase, with some chlorite. Accessory minerals include apatite, sphene, epidote and zircon. Three small radioactive occurrences are found in the Compeau Creek Gneiss in the Southern Complex.

Gneisses Near Herman

Gneisses of the western end of the Northern Complex were studied and mapped by Turner (1973). The two major rock types, neither known to be radioactive, are a gray gneiss and a felsic gneiss. The felsic gneiss, locally migmatitic, is composed essentially of plagioclase (An₃₂₋₃₅) and quartz. It is intruded by a body of trondhjemite, a very light colored rock composed of plagioclase (An₂₈₋₃₃) and quartz with minor chloritized biotite, muscovite, apatite, zircon, hematite and pyrite. The gray gneiss is composed of plagioclase (An₃₄₋₃₆), quartz, biotite, chlorite and hornblende. Both gneisses contain discontinuous layers of amphibolite and also are cut by north-south trending metadiabase of Middle Precambrian age and east-west and north-south trending diabase dikes of Keweenawan age.

On the basis of chemical analyses, indicating similarities to calc-alkaline rocks ranging from andesitic to rhyolitic, Turner speculates that the gneisses may be metamorphosed volcanics or immature sediments derived from an

igneous calc-alkaline provenance. The amphibolites may be metamorphosed flows, sills or tuffs (Turner, 1973).

Dead River Pluton

The Dead River Pluton, located in the Negaunee Quadrangle west of Marquette in the Northern Complex is not known to be radioactive. It is a large syenitic, dioritic and granodioritic body which intrudes the Mona Schist. Puffett (1974) describes it as non-foliated, about three square miles in extent and consisting of three rock types: granodiorite porphyry, hornblende diorite, and a porphyritic syenite that occurs along two fault zones. The syenite has distinctive large perthite crystals in a groundmass of hornblende, biotite, fine-grained feldspar, sphene, and magnetite. The perthitic crystals contain hematite-stained hairline fractures giving them a pink to reddish cast.

Palmer Gneiss

The Palmer Gneiss is named for its occurrence near the village of Palmer. It is not known to be radioactive. Its origin is questionable, and it is included with rocks of the Lower Precambrian only for convenience. Gair (1975) states that the gneiss consists of green, gray and tan schist with some associated light green to tan massive quartz-sericite rocks. The schist contains conformable pods or stringers of granitic rock or feldspar-chlorite gneiss, which may be several feet thick in places. The origin of the gneiss is questionable. However, Gair (1975) suggests that on the

basis of chemical and petrographic evidence the gneiss may have been formed by the alteration of Compeau Creek Gneiss during, or at the close of, Middle Precambrian time. He suggests the following possibilities for the origin of the gneiss:

- 1) Shearing and alteration of Compeau Creek Gneiss during faulting of Middle Precambrian rocks against Lower Precambrian rocks at the close of Middle Precambrian time.
- 2) Passage of aqueous solutions along the contact between Lower and Middle Precambrian rocks.
- 3) Alteration of a regolith, with or without shearing, during folding at the close of Middle Precambrian time (Gair, p. 15, 1975).

Lower Precambrian Sedimentary Rocks

Dickinson Group. The Dickinson Group, the oldest sedimentary unit in Northern Michigan, occurs in the Felch area of Dickinson County. The Group includes the East Branch Arkose, Solberg Schist and Six Mile Lake Amphibolite.

The East Branch Arkose is the oldest formation and is a basal sequence overlying the granites and gneisses of the area (James, Clark, Lamey and Pettijohn, 1961). It is composed of arkose, coarse conglomerate, and volcanic tuffs and felsic flows. The pebbles of the conglomerate have been flattened and sheared, and consist of vitrous quartzite with lesser amounts of granite gneiss, slate or schist, and quartz.

The Solberg Schist represents deposition of fine-grained sediments following the coarser East Branch Arkose sequence. The Six Mile Lake Amphibolite is considered to be the metamorphosed remnant of basaltic flows and tuffs.

Minor radioactivity was noted in outcrops of the East Branch Arkose in Sec. 8, T42N, R28W, and may represent enrichment of uranium along shears and fractures similar to that in granites in the area. However, the Early Precambrian age of the formation cannot be overlooked. Thus, one should consider whether this formation could prove to be similar to the poorly sorted, arkosic, uraniferous conglomerates found in Western Australia (Robertson, 1974).

Metamorphism of Lower Precambrian Rocks

Recent uranium-lead age dating by Peterman, Zartman and Sims (1976) has shown that the gneisses in the Watersmeet area have a minimum age of around 3.4 b.y. and may have a primary zircon age of 3.5 b.y. They were subjected to intrusion and partial recrystallization at 2.7 b.y. as indicated from two samples of leucosome from migmatite. This data thus indicates that some Lower Precambrian rocks were metamorphosed for the first time prior to Middle Precambrian time.

Middle Precambrian Rocks

General Comments

The Middle Precambrian metasedimentary and metavolcanic rocks are separated from the basement rocks by a major unconformity, and have been referred to the Marquette Range Supergroup (Cannon, 1973). They have been divided into four groups and their lithologic variations record episodic vertical movement of basement granites during sedimentation. After the deposition of these rocks, and during a period of

locally high thermal flux, the Lower Precambrian basement rocks were uplifted in huge undeformed fault blocks between which the metasedimentary rocks formed troughs and synclines. Their deformation and high grade regional metamorphism constitute the Penokean Orogeny.

Middle Precambrian rocks in Northern Michigan are believed to be around 1900 to 2000 m.y. old (Van Schmus, 1976), and clearly predate the culmination of the Penokean Orogeny that has been dated as having occurred around 1850-1900 m.y. ago.

Sedimentary Rocks

In the following section, the Middle Precambrian metasedimentary rocks are discussed basin by basin in order to avoid uncertain correlations and to emphasize the various patterns of sedimentation that can be seen in the individual basins. As stated previously, the descriptions center on those formations known to contain uranium mineralization, those which are believed to be potential host rocks, and those which may have been a potential source for supergene uranium.

Marquette Trough. The Marquette Trough is an east-west feature about 50 miles in length, separating the Northern Complex from the Southern Complex. Sims (pers. comm., 1976) suggests that the trough marks the boundary between the older 3.5 b.y. old gneissic terrain (the Southern Complex) and the younger 2.7 b.y. old greenstone terrain (the Northern

Complex). Such a regional fault would help explain the marked deformation of pillow lavas along the south margin of the Northern Complex, north of Ishpeming. Table 2-1 shows the stratigraphic sequence of the Marquette Trough area.

a) Chocolay Group. The oldest conglomerates of the Middle Precambrian section in the Marquette Trough are the Enchantment Lake Formation and the Reany Creek Formation. The Reany Creek Formation is described by Puffett (1969) who divides the formation into three units, a basal conglomerate, a middle sequence of graywacke and slate, and an upper unit of interbedded arkose, quartzite, slaty graywacke and conglomerate. The basal conglomerate contains rounded and angular boulders of granite and greenstone in a poorly sorted coarse-grained arkosic or chloritic matrix. At least part of the formation is believed to be of glacial origin. Taylor (1972) in describing the Kona Dolomite, notes that in the Wewe Hills area south of Goose Lake, a pebble known to have originated from the base of the Reany Creek conglomerate was found in the Middle Quartzite Member of the Kona Dolomite. This, he indicates could mean either that the conglomerate and the quartzite are facies equivalents or that there was a period of erosion between their formation. Since no facies change was noted in the field, he favors the possibility of an erosional period. He speculates that an unconformity developed after deposition of the Reany Creek Formation and before deposition of the

TABLE 2-1

Lithologic Sequence in Marquette
and Baraga Counties, Michigan

		Supergroup, Group, Formation and/or Member		Description		
Precambrian	Upper Precambrian	Keweenaw	Diabase	Nonmetamorphosed diabase dikes and stocks.		
	Middle Precambrian			Pegmatite	Coarse-grained-microcline-quartz-muscovite rocks. Relatively rare but most abundant near Republic.	
				Metadiabase	Amphibolitic rock, much with relict diabasic texture. Mostly as sills in Middle Precambrian rocks and dikes in Lower Precambrian rocks. Much is probably associated with rocks of the Clarksburg Volcanics Member of the Michigamme Formation.	
		Marquette Range Supergroup	Baraga Group	Michigamme Formation	Upper Slate Member	Metapelite and metagraywacke. 1100'
					Bijiki Iron-Formation Member	Mostly cherty silicates iron-formations. Some gruneritic schist. 100-200'
					Lower Slate Member	Metapelite and metagraywacke with some pyritic carbonaceous slate.
					Clarksburg Volcanic Member	Mafic pyroclastic rocks with intercalated meta-argillite and iron-formation.
					Greenwood Iron Formation Member	Cherty silicate iron-formation. 500-1200'
					Goodrich Quartzite	Massive to banded protoquartzite with conglomerate near base. 1500'+
			Menominee Group		Negaunee Iron-Formation	Mostly cherty silicate iron-formation with oxide iron-formation near top. 3500'+
					Siamo Slate	Laminated metapelite. 600-1250'
					Ajibik Quartzite	Banded to massive, light-colored quartzite. 600-1250'
			Chocolay Group		Newe Slate	3000'
					Kona Dolomite	2600'
					Mesnard Quartzite	500'
					Enchantment Lake Formation	500'
					Reany Creek Formation	
	Lower Precambrian			Palmer Gneiss Compeau Creek Gneiss Mona Schist Kitchi Schist Bell Creek Gneiss	13,000-25,000'	

Compiled from: Boyum, 1975; Cannon and Klasner, 1972; Gair 1975; Gair and Thaden, 1968, Puffett, 1974.

Enchantment Lake and overlying Mesnard and Kona Formations. This would place the Reany Creek Formation below the Chocoday Group, and would make it the oldest sedimentary formation in the Marquette Trough.

The Enchantment Lake Formation has been described by Gair and Thaden (1968) and Gair (1975). It is a discontinuous unit of conglomerate, graywacke, arkose and slate. The maximum thickness is around 500 feet north of Enchantment Lake. The conglomerate contains fragments of tonalitic gneiss and greenstone in a chloritic matrix. The arkose is a light colored, moderately well sorted rock in which feldspar makes up 20 to 75 percent of the rock. There is also some subarkose, a feldspathic quartzite that consists of subrounded detrital quartz in a matrix of sericite or of sericite, chlorite and fine grained quartz and feldspar. The slate is thought to be partly of glacial origin.

Overlying the Enchantment Lake Formation are the Mesnard Quartzite, Kona Dolomite and the Wewe Slate, all representing a shallow transgressing sea invading from the north and east onto a stable shelf (Tyler and Twenhofel, 1952; Clark, 1974). These sediments were not deposited in the western part of the Marquette Trough, but the Kona equivalent is found in other basins in the western Upper Peninsula.

No radioactivity has been noted in any member of the Chocoday Group. However, chalcocite mineralization is rather widespread near the base of the Kona Dolomite (Taylor, 1972; Clark, 1974).

b) Menominee Group. Overlying the Chocolay Group is the Menominee Group composed of the Ajibic Quartzite, Siamo Slate and Negaunee Iron Formation. With the exception of very minor radioactivity in the Ajibic Quartzite near Three Lakes (possibly due to K-feldspar fragments in the quartzite), no radioactivity is found in the Menominee Group. These sediments are unconformable over Chocolay Group sediments in the Marquette area and lie unconformably on basement rocks to the north and west. The equivalent to the Negaunee Iron Formation is found in the Gogebic Range and the Felch Trough and Iron Mountain areas. In the Iron River-Crystal Falls area this period is represented by the Hemlock Formation (Prinz, 1976). Tectonic disturbances during this time, reflected in the formation of slaty cleavage in the Siamo Slate may represent the beginning of the Penokean Orogeny.

c) Baraga Group. A period of weathering occurred prior to the deposition of the Baraga Group, as evidenced by the presence of hard iron ore at the top of the Negaunee Iron Formation and pebbles of hard iron formation in the Goodrich Quartzite, the basal sequence of the Baraga Group. The Baraga Group is the youngest sedimentary unit in the Marquette Trough area and includes the Goodrich Quartzite and the Michigamme Formation which were deposited in subsiding basins. To the northwest in the Baraga Basin the group lies unconformably on basement granites, and elsewhere is unconformable over the Menominee Group. To the southwest it is represented by the Michigamme equivalents: the Tyler

and Copps Formation. Rocks of this group are not found in the Felch Trough-Iron Mountain area, either because of non-deposition, or due to later erosion. In either case, this restricted distribution denotes that the area was high.

Seven prospects in the Marquette Trough area occur in members of the Baraga Group. In that the Michigamme Formation is both a source rock for uranium mineralization as well as a host rock, and the Goodrich Quartzite contains syngenetic concentrations of thorium-bearing minerals, these formations will be described in greater detail.

d) Goodrich Quartzite. The Goodrich Quartzite of the Baraga Group contains a coarse basal conglomerate which occurs in lenses 220-300 feet thick, but thins rapidly along the strike, indicating the possibility of considerable relief on the depositional surface. The coarse and poorly sorted clastics denote a high energy environment. Two types of material are present: pebbles and boulders of well worn and rounded vein quartz with minor quantities of granite and schist all of distant derivation, and large angular fragments of the Negaunee Iron Formation, which are of local derivation. Tyler and Twenhofel (1952) suggest that the conglomerates are of deltaic, subareal origin. Nordeng and Spiroff (1962) attribute the origin of at least part of the Goodrich Quartzite to the action of mud flows. The presence of a preponderance of well-rounded quartz pebbles indicates that the Lower Precambrian terrain was undergoing intense chemical weathering at this time.

In places the Goodrich Quartzite also contains detrital grains of monazite along the bedding planes, where the monazite settled out as a heavy black sand. However, the formation contains only trace amounts of uranium. The age of the formation (1900 m.y.) suggests that perhaps atmospheric oxygen was sufficiently high during the deposition of these rocks to preclude the possibility of it containing detrital uraninite, as in the Blind River type deposits.

e) Michigamme Formation. The Michigamme Formation of the Baraga Group contains a varied succession of rocks: the Greenwood Iron-formation Member, the Clarksburg Volcanics Member, the Lower Slate, the Bijiki Iron-formation Member, and the Upper Slate (Cannon and Klasner, 1975).

North of Marquette, near Silver Lake, the Michigamme Formation lies unconformably on basement granite, but elsewhere is conformable over the Goodrich Quartzite or its equivalent.

A grayish to pink-speckled basal quartzite has been noted in the Michigamme Formation along the unconformable contact with the Dead River Pluton in the Negaunee Quadrangle (Puffett, 1974). It is composed of a feldspathic, sericitic and locally conglomeratic quartzite about 200 feet thick. The poorly sorted rock contains clasts of vein quartz, slate and granite up to 1-½ inches in diameter. A chert conglomerate containing clasts of gray non-feruginous chert, and mafic and felsic volcanics occurs higher in the section and is believed by Puffett (1974) to be derived from a landslide or similar disruption of volcanic debris.

The Michigamme Formation becomes finer grained upwards in the sequence. The Michigamme Formation is important in that it contains carbonaceous, pyritic slates with syngenetic uranium contents ranging from 20-40 ppm. Where oxidized it is capable of releasing this uranium to ground waters; where in the reduced state it is also capable of precipitating uranium from solution (Vickers, 1956).

The Greenwood Iron Formation Member is a banded, magnetic silicate iron formation with beds of argillaceous clastics (Boyum, 1975). The Clarksburg Volcanics Member is composed of mafic, metamorphosed pyroclastics. The Bijiki Iron Formation which separates the Upper from the Lower Slate Members, is a cherty, sideritic iron formation similar to the Negaunee Iron Formation and is locally oxidized. The Upper Slate contains graywacke, argillites, quartzites and black carbonaceous pyritic slate with some siltstone (Boyum, 1975).

Amasa-Iron River-Crystal Falls Area. The entire stratigraphic section is exposed in this area, the lower part in the anticlinal Amasa "oval", and the upper part in the complex triangular syncline of the Iron River-Crystal Falls area in southern Iron County. The sedimentary rocks of the Iron River-Crystal Falls area are underlain by the mafic flows of the Hemlock Formation. Basement granites are not known in the immediate area. The rocks (shown in Table 2-2) have been described by Dutton (1958) and James, Dutton, Pettijohn, and Wier (1968).

TABLE 2-2

Lithologic Sequence in Iron
and Dickinson Counties, Michigan

Precambrian	Upper Precambrian	Keweenaw series	Diabase dikes and sills (probable age about 1,100 million years)				
	Middle Precambrian	Animikie series	Intrusive contact				
			Granitic intrusive rocks (probable age at least 1,400 million years)				
			Intrusive contact				
			Metadiabase and metagabbro				
			Intrusive contact				
			Paint River group	Fortune Lake slate 4,000'+			
				Stambaugh formation 100'			
				Hiawatha graywacke 0-500'			
				Riverton iron-formation 10-800'			
				Dunn Creek slate, with Wauveca pyritic member 400-1,500'			
			Baraga group	Badwater greenstone 0-15,000'			
				Michiganne slate 1,000-10,000'+			
				Fence River formation 0-250'		Anasa formation 600-1,800'	
				Hemlock formation, with Mansfield iron-bearing slate member and Bird iron-bearing slate member 2,000-15,000'			
				Goodrich quartzite 0-500'			
			Manominee group	Unconformity			
				Loretto slate member			
				Curry iron-bearing member			
				Brier slate member			
				Traders iron-bearing member			
			Chocoma group	Pelch formation 20-500'			
				Unconformity			
				Randville dolomite 800-2,000'+		Saunders formation 1,000' (?)	
				Sturgeon quartzite 800-1,850'			
				Fern Creek formation 0-70'			
			Lower Precambrian	Unconformity			
				Gneissic granite and other crystalline rocks			
				Dickinson group	Intrusive or replacement contact??		Quinnese formation (posi- tion uncertain)
Six-Mile Lake amphibolite	Hardwood gneiss (posi- tion uncertain)						
Solberg schist, with Skvok Creek member							
East Branch arkose							
Unconformity							
Granite gneiss							
Quartzite and schist (small bodies included in granite gneiss)							

(Modified after: H. L. James, 1958)

a) Chocolay Group. Surrounding the gneisses of the core of the Amasa oval is the Chocolay Group, represented by the Saunders Formation, a cherty dolomite which has been correlated with the Kona Dolomite of the Marquette Trough.

b) Baraga Group. Overlying the Saunders Formation is the Baraga Group, containing the Hemlock(?), Amasa, Michigamme and Badwater Formations. The Hemlock may belong to the Menominee Group, in that Prinz (1976) believes it to be partly correlative with the Negaunee Iron Formation of the Marquette area. The Hemlock and Badwater Formations are composed almost entirely of metabasalt, with some interbedded iron-bearing sedimentary rocks. Johnson (1975) has described the occurrence of a fluvial conglomerate which occurs within the Hemlock Formation.

Conformable over the Hemlock is the Amasa Formation, a cherty iron formation and ferruginous slate about 1800 feet thick. The Michigamme Formation is 6000-7800 feet thick and is conformable over most of the Amasa Formation. However, a conglomerate is noted to occur in some areas. The Michigamme Formation is exposed along the Paint River, where it consists of gray colored graywacke and slate and minor amounts of tuff. The upper part of the formation contains phyllite and graphitic or cherty slate which is separated from the lower portion by a band of greenstone. Also near the top is a magnetic iron formation (James, et al, 1968).

Black coaly material was exposed in a test pit north of Iron River. The anthracitic coal occurs as lenses within the graphitic shale and argillite (Tyler, Barghorn and Barrett, 1957).

c) Paint River Group. The youngest of the Middle Precambrian metasediments is the Paint River Group. Five formations are recognized: the Dunn Creek Slate, Riverton Iron Formation, Hiawatha Graywacke, Stambaugh Formation and Fortune Lakes Slate. The Group is about 6500 feet thick. Radioactive zones occur within oxidized portions of the Riverton Iron Formation.

The Dunn Creek Slate consists of graphitic slate and sericitic slate-siltstone, and occurs in small and scattered outcrops. A thick lower sequence found only around Crystal Falls contains cherty black slate, slaty iron formation, striped slates and interbedded black slate, chert and iron carbonates. The gray sericitic slate is non-graphitic and contains large cubes of pyrite in some beds. It consists of quartz with minor feldspar grains in a sericitic-chlorite matrix with patches of carbonate. Overlying the sericitic slate is the Wauseca Pyritic Member, which is divided into two parts. The base is a slate-breccia containing fragments of graphitic slate in a dense graphitic matrix. It is especially rich in carbon. The upper unit is a laminated slate with layers rich in finely disseminated pyrite. Pyrite forms an average of 39.7 percent by weight of the slate breccia and 38.0 percent of the laminated slate. The finely disseminated pyrite oxidizes readily and has been known to cause spontaneous fires. The Dunn Creek Slates are from 200-1500 feet thick.

Nine radioactive occurrences are found in the Riverton Iron Formation, all at or near stratigraphic contacts between oxidized iron formation and black slate (see Chapter 3). Near the surface most of the iron formation is thoroughly oxidized. Where unoxidized, it is composed of layers of chert and siderite with some argillaceous or carbonaceous seams. Stratigraphically the formation grades upward into a slaty iron formation with increasing amounts of pyrite. This then grades into a pyritic-slate member similar to the Wauseca Pyritic Member of the Dunn Creek Slate. The base of the Riverton is composed of 5-200 feet of graphitic chert-breccia, probably formed by slumping. The oxidized iron formation retains the banded structure, but the carbonate is altered to red and yellow hematite or goethite. It may be hard and massive or earthy, and is usually very porous. In extremely oxidized portions the iron oxides replace the chert layers. Typical thickness for the Riverton ranges from 500-800 feet in the western part of the district to 150-300 feet in the eastern portion (James, et al, 1968).

Overlying the Riverton are the Hiawatha Graywacke, the Stambaugh Formation and Fortune Lake Slates. The Hiawatha Graywacke is a typical clastic graywacke with some slate and siltstone. The lower portion is usually made up of a chert fragment breccia in a graywacke matrix. The typical graywacke is iron-rich and consists of clastic quartz and chert grains in a chlorite matrix containing patches of siderite. In the western part of the district the gray-

wacke becomes arkosic and sericitic. It is from less than 50 feet thick to as much as 500 feet thick.

The Stambaugh is a magnetic slate and chert unit of clastic and chemical origin. Pyrite is present in layers. The formation is around 100 feet thick.

The Fortune Lakes Slate is the youngest unit and underlies a very large area. It is composed of slate and graywacke and siltstone. It is usually gray colored and may be 4000 feet thick. Outcrops are sparse (James, et al, 1968).

James, et al (1968) noted a siliceous breccia along a belt in the southwestern portion of the district. The rock is massive, white to gray, containing fragments of silica in a matrix of yellow and red silica. Small cavities are lined with small quartz crystals. They believe the rock to be a silicified portion of the Saunders dolomite, and they compare it to the silcretes of Australia and South Africa, which are products of chemical weathering under arid conditions.

Baraga Basin. The Baraga Basin is situated north and east of L'Anse between the granitic and gneissic rocks of the Huron Mountains and the Northern Complex. The Middle Precambrian metasedimentary rocks are represented solely by the Baraga Group, which rests unconformably on the granitic basement rocks.

According to Mancuso, Laugheed, Seavoy and Shaw (1975) the section consists of a quartzite in the southwest portion of the basin (outcrops are seen at Pikes Peak and Arvon Hill),

conformably overlain by a maximum of 70 feet of chert-carbonate rock (iron formation and volcanoclastics). They believe these to be correlative with the Greenwood Iron Formation and Clarksburg Volcanics. Overlying these are an estimated 1100 feet or more of black slate of the Michigamme Formation (Mancuso, et al, 1975).

The cherty iron formation is seen in outcrop at Big Eric's Crossing on the Huron River, and in a small area southeast of Pikes Peak. The iron formation consists of chert, calcite, ferroan calcite and ferroan dolomite-ankerite, with minor amounts of chlorite, hematite, pyrite and carbonate-apatite. The volcanoclastic sequence is composed of tuffs, breccias and lapillistones, with layers of black, carbonaceous, pyritic chert (Mancuso, et al, 1975).

Two radioactive occurrences are found in these meta-sediments in the Baraga Basin and two more occur at the extreme southwestern end of the basin where it joins the Marquette Trough.

Gwinn Syncline. The Gwinn Syncline is a downfolded segment of metasediments located 16 miles south of Marquette. It is six miles long and one to two miles wide, trending N45W.

The metasediments include two unconformable series of arkose, iron formation and slate from 800 to 1000 feet thick, belonging to the Baraga and Menominee Groups. It is not known for certain whether the iron formation is Bijiki

(Baraga Group) or Negaunee (Menominee Group); Boyum (1975) has correlated it with the Negaunee (See Table 2-3).

In the northern part of the basin the rocks are complexly folded and faulted. The southern portion is spoon shaped, and steeply dipping on the southwest limb (Allen, 1914).

The basal conglomerate of the Gwinn Series contains pebbles and boulders of quartzite, quartz-slate and siliceous, cherty and slightly dolomitic slate derived from an older sequence which is not present in the Gwinn Syncline. It is from 0 to 60 feet thick and also occurs sporadically outside the syncline. Overlying the conglomerate is the lower slate composed of black, graphitic and gray slates up to 60 feet thick. Overlying this is 50 to 100 feet of iron formation. All known iron ore bodies are on the eastern limb of the syncline, all are soft oxidized ores, and all occur at the base of the formation (Boyum, 1975). Five radioactive occurrences are known in the Gwinn iron formation, and pitchblende was found in drill core from the Francis Mine.

Above the iron formation is another slate unit, 30-100 feet thick, composed of interbedded black slate, gray slate and dark graywacke and quartzite (Allen, 1914).

Unconformably overlying the Gwinn Series is the Princeton Series. The basal conglomerate is over 100 feet thick in places and is composed of pebbles of chert and siliceous black slate, quartz, arkose, and quartzite, with rare frag-

TABLE 2-3

Lithologic Sequence in the Gwinn Syncline

Paleozoic		Ordovician Cambrian	Limestone and sandstone
Precambrian	Late	Keweenawan	Intrusives
	Middle	Baraga Group	Princeton Series Ferruginous slate, cherty quartzite and graywacke conglomerate
		Menominee Group	Gwinn Series Dark gray slate, graywacke Iron-Formation Dark gray to graphitic slate
	Early		Granite, greenstone

ments of iron formation in a dark graywacke and quartzite matrix. The conglomerate is overlain by interbedded slates, ferruginous slates, cherts, quartzites and ferruginous quartzites and graywacke, 400-500 feet thick (Allen, 1914).

Felch Trough and Iron Mountain. In the Iron Mountain area, the Fern Creek Conglomerate is the Middle Precambrian basal unit (Table 2-2). It is believed to be the same age as the Enchantment Lake Formation of the Chocoma Group in the Marquette Trough area. Pettijohn (1943) describes this formation as a "profusion of angular and subangular blocks" of pink granite gneiss, granite and vein quartz, ranging in size from pebbles to boulders. Above the pink basal conglomerate is a graywacke conglomerate which Pettijohn suggests might be a tillite.

Overlying the Fern Creek Conglomerate in the Iron Mountain area is the Sturgeon Quartzite, Randville Dolomite, the Felch Formation and Vulcan Iron Formation (Baley, Dutton and Lamey, 1966). The Fern Creek Conglomerate is not present in the Felch Trough area, either because of non-deposition or later erosion. In either case it indicates that the area was high.

The base of the Sturgeon Quartzite is described by Pettijohn (1943) as a breccia composed of blocks of red granite gneiss overlain by a coarse conglomerate of the same composition. In the vicinity of the Sturgeon River Dam he notes that a shear zone between red arkosite of the Sturgeon and

red granite gneiss is heavily charged with sulfides. Minor radioactivity is noted in this area.

Gogebic Range. In the Gogebic Range area, 40,000 feet of Middle Precambrian metasedimentary rocks belonging to the Menominee Group and Baraga Group are present (Fritts, 1969).

The oldest formation, found in the Ironwood area, is the Palms Formation of the Menominee Group. It is up to 800 feet thick and consists of a basal conglomerate, a laminated siliceous argillite, and an upper vitreous quartzite. The basal conglomerate is usually less than five feet thick and is composed of pebbles and cobbles of white vein quartz, chert, granite, and green schist in a sandy matrix.

Overlying the Palms Formation in the Ironwood area are the Ironwood Iron Formation and the Tyler Slate. Unconformably above these to the east is the Copps Formation, and four overlying sequences of graywacke, metavolcanics, slate and arkosic graywacke including the rocks near Cup Lake, graywacke near Banner Lake, rocks near Blair Lake and graywacke near Paulding. The Ironwood Iron Formation has been correlated with the Negaunee Iron Formation.

With the exception of minor radioactivity associated with the pyritic, black slates of the Tyler Formation, no radioactivity has been noted in these metasedimentary rocks.

Origin of Soft Iron Ores

A review of the origin of soft iron ores is important to our understanding of the geological history of the area, and the origin of supergene uranium deposits.

Three theories have been put forth concerning the origin of the soft iron ores, and are discussed by James, et al (1968) and by Boyum (1975). The theories are 1) formation by meteoric waters -- deep weathering during an arid period, 2) hydrothermal alteration by waters of magmatic origin, and 3) modified hydrothermal, where waters of meteoric origin dominated, and were supplemented and activated by magmatic waters.

In this section the writer will dwell briefly on only the first theory in that it is the most widely accepted. There are two reasons for considering soft iron ores in connection with the study of uranium deposits: 1) several of the known radioactive occurrences are found within oxidized iron formation. There are no radioactive occurrences within hard oxidized ores, or within the banded non-oxidized iron formation. 2) The origin of the soft oxidized ores through deep weathering suggests that supergene processes have been active in the region.

The meteoric theory proposed by Van Hise and Leith (1911) is consistent with the mineral assemblage, the occurrence of ores in upward facing structures, and the decrease in oxidized iron formation with depth. Three major problems associated with this theory, noted by James, et al (1968)

and Gair (1975), include the large scale removal of silica, the very deep extent of the ores (in excess of 6000 feet in some places), and the extensive argillization of the mafic dikes within the oxidized zones.

Soft ores of the Bijiki, Negaunee, Riverton and Gwinn Iron Formations were formed by the oxidation of original siderite and the replacement of all or part of the chert by mobile iron oxides. The ores are characteristically very porous mixtures of earthy hematite and yellow earth goethite. The ores are restricted to zones of low-grade regional metamorphism (chlorite zone) and extend to depths exceeding 6,000 feet in some places (James, et al, 1968). The mineral assemblage includes goethite, hematite, illite, kaolinite, gypsum and apatite (?) (James, et al, 1968). Oxidized iron formation is more abundant near the surface and decreases with depth. Its distribution is irregular, and oxidized iron ore extending to great depths may be found adjacent to non-oxidized banded iron formation. Many of the large soft iron ore bodies reach their maximum size at depths of 500 to 1500 feet below the surface.

The ore bodies were formed in their present structural positions. Extensively folded and contorted relict bedding is often present, but it is impossible for these very soft and porous ores to have been so deformed after oxidation. Minor folding, faulting and intrusion (Boyum, 1975) may have occurred since formation of the ores. Those ore bodies which have a recognizable structure, occur in upward facing, open structures, usually synclines. Some are bounded by

faults and diabase dikes. The footwall is always a less permeable rock type, and is typically pyritic slates or metadiabase sills. In parts of the Bijiki Iron Formation, the footwall is a silicate iron formation (James, et al, 1968; Boyum, 1975).

The formation of the oxidized ores postdates the Penokean (1900 m.y.) deformation and metamorphism. Gair (1975) notes the presence of an extensively altered Keweenawan dike in soft iron ore in the Tracy Mine near Negaunee. This leads him to conclude that most of the alteration of the iron formation took place after the intrusion of the Keweenawan diabase or post-1000 m.y. The younger age limit (450-650 m.y.) for the origin of soft iron ores is given by a set of discordant U/Pb and Pb/Pb ages from pitchblende in a vein in soft iron ore found at the Sherwood Mine in Iron River (Vickers, 1956).

The deep extent of the ores is explained by their formation during a prolonged period involving a deep artesian circulation system. If Gair's observation is correct, that the weathering is of post-Keweenawan age, then the arid period may be coincident with the time of formation of the Jacobsville Sandstone found to the north and west. These redbeds show evidence of extensive chemical weathering in the source area. West of Lake Gogebic they are seen to contain abundant pebbles of well rounded chert, quartz and iron formation, and rarer angular fragments of feldspar. A period of pre-Jacobsville weathering is indicated by the paleo-regolith at Presque Isle near Marquette (Kalliokoski,

1975). The Jacobsville is believed to be Cambrian in age by Hamblin (1958), Lower to Middle Keweenawan in age by Babcock (1975, 1976) and Hamblin (1975), and Upper Keweenawan by DeGraff (1976). It is interesting to note that the altered dolomite breccia (silcrete) of the Saunders Formation is also believed to have been formed during an extensive arid period (James, et al, 1968).

Similar present-day weathering conditions in Australia (noted by James, 1968) has resulted in artesian circulation to depths of 4000 feet. Gair (1975) notes in the Marquette area, that gypsum shows a broad, but irregular distribution in a flat zone occurring between sea level and a few hundred feet above sea level. Its occurrence suggests that it formed parallel to a water table, and its formation could be due to the same process which formed the soft iron ores. The flat lying early Keweenawan sandstones to the north and west document an erosional surface that could not have undergone much tilting in Paleozoic or Recent times.

Structure of Middle Precambrian Rocks

Middle Precambrian sedimentation began with stable shelf deposits (Chocolay Group). After mild uplift, sedimentation continued in a mildly active miogeosynclinal environment (Menominee Group) and fault uplift of the basement rocks at this time represents the beginning of the Penokean Orogeny. After uplift, erosion and local deformation, the area was submerged and the Baraga Group and Paint River Group were deposited in an environment in which abundant volcanic flows

were also deposited. Intrusion of diabase dikes and sills may have occurred at this time. The deposition of the Paint River Group was followed by major Penokean uplift and deformation (Cannon, 1973; Van Schmus, 1975). The Middle Precambrian metasediments have been preserved as tightly infolded synclines, broad synclinorial basins and monoclines.

The structure of Middle Precambrian rocks is important when considering supergene processes. In the Crystal Falls-Iron River area the tight folds in Middle Precambrian meta-sedimentary rocks appears to have controlled the oxidation of the iron formation and also provided controls for the solutions that formed the pitchblende occurrences at the Sherwood Mine. In the Marquette Trough and Baraga Basin, mineralization is seen to be associated with faults and breccia zones in at least two places. Faults, fractures and shears in Lower Precambrian granites and gneisses have also been mineralized by supergene solutions. The structural deformation of these rocks is one of the most important factors in defining potential host rocks for mineralization.

The major structural features are interpreted by Cannon (1973) and by Klasner (1972) to be of two types. There are an earlier set of structures trending east-west and ranging in size from very small folds to folds with wavelengths of several miles. This folding has produced considerable horizontal shortening of the Middle Precambrian rocks, which does not extend into the Lower Precambrian basement. For this reason this deformation has been attributed to

gravity sliding along a regional slope trending east-west, perhaps formed by a very early stage of crustal movement. It is not known whether sliding was confined to the contact between Lower and Middle Precambrian rocks, or whether it also occurred along one or more horizons within the Middle Precambrian sequence.

The second, or later stage of movement is represented by vertical tectonics, whereby blocks of Lower Precambrian rocks were uplifted, passively deforming previously folded Middle Precambrian sedimentary and volcanic rocks into structural basins between the uplifts.

Middle Precambrian metasedimentary rocks were again intruded during early Keweenawan time by east-west trending diabase dikes and later were faulted along north-south faults (Klasner, 1972). The north-south and north-east faults are prominent features and are easily detected as stream lineaments and as patterns on aeromagnetic maps. A major feature in the Marquette Trough area is the north-east trending Michigamme fault, which cuts across Lake Michigamme (Klasner, 1972).

Metamorphism of Middle Precambrian Rocks

Regional metamorphism began during Penokean deformation and reached its peak after the end of the tectonic activity, 1850-1900 m.y. ago (Klasner, 1972; Van Schmus, 1976). Four nodes of metamorphism are related to this thermal period (Figure 2-2). The largest node is centered around Republic and contains five concentric metamorphic zones (chlorite, biotite, garnet, staurolite and similanite). The smaller

Figure 2-2 - Zones and nodes of Penokean Regional Metamorphism, modified from James (1955), Cannon (1973), Boyum (1975).

Peavy node in the Felch area is similar, and is centered on the gabbroic synorogenic Peavy Pond Complex. The Watersmeet and Florence nodes are not as well exposed, but apparently contain only the first three zones (James, 1955). James speculates that the Republic node was formed by a sub-jacent pluton, intruded to within one mile of the present surface. However, it should be emphasized that no evidence of an igneous body of this age has been found to date, other than the several small pegmatitic bodies that have been dated at 1650 m.y. by Van Schmus (1976).

The metamorphism is seen best in fine grained sediments and in iron formation, and is of low pressure type with stable minerals including sillimanite and andalusite. No tilting or major deformation has occurred since the metamorphism (Cannon, 1973).

Keweenawan Rocks

General Comments

Keweenawan rocks in Michigan are separated from the older rocks by a major unconformity formed subsequent to the Penokean Orogeny. The series consists of a thick sequence of mafic flows and continental sedimentary rocks, and is dated around 1200-1100 m.y. (Table 2-4). They are the products of volcanic activity and sedimentation in a rift environment (Chase and Gilmar, 1973; Van Schmus, 1975).

Two radioactive occurrences are noted in felsites of the Middle Keweenawan Portage Lake Volcanics. The felsites

TABLE 2-4

Stratigraphy in Ontonagon Counties

Period	Series or Supergroup		Group	Formation	Thickness (feet)	Predominant Rock Types
Quaternary	Pleistocene			Unconformity		
Upper Precambrian (Precambrian Y)	Rocks of Keweenaw Age	Upper Keweenaw	Oreata Group	Freda Formation	12,000+	Red lithic sandstone.
				Nonesuch Formation	450-550	Gray lithic sandstone and siltstone
		Middle Keweenaw		Copper Harbor Conglomerate	1,600-6,000	Red lithic conglomerate and sandstone.
				Unnamed Formation	0-9,000	Mafic to felsic volcanic rocks; very minor sedimentary rocks.
		Lower Keweenaw	Powder Mill Group	Portage Lake Volcanics	8,000-13,000	Mafic volcanic rocks and minor sedimentary rocks; felsic volcanic rocks rare.
				Unconformity(?)		
				Unnamed nonmagnetic rocks	about 6,000	Probably sedimentary rocks.
				Unconformity		Unconformity
Middle Precambrian (Precambrian X)	Marquette Range Supergroup		Beraga Group (?)	Kallander Creek Formation	15,000(?)	Intermediate volcanic rocks; subordinate mafic volcanic rocks.
				Diorite	25	Diorite
				Unconformity(?)		
				Siemens Creek Formation	4,400	Mafic volcanic rocks.
Lower Precambrian (Precambrian W)			Menominee Group	Bessemer Quartzite		Quartzite
				Unconformity		
				Tyler Formation		Argillite and siltstone.
			Menominee Group	Ironwood Iron-Formation		Iron-formation.
				Palma Formation		Argillite and quartzite.
				Unconformity		
						Metasedimentary metavolcanic, and intrusive complex.

Hubbard (1975)

represent the end product of the differentiation of basaltic magmas (Cornwall, 1951) and thus may be enriched in uranium and thorium relative to the more basic rocks. These felsites may be potential source rocks for supergene mineralizing processes.

Lower Keweenawan Rocks

The oldest Keweenawan rocks in Michigan are the Powder Mill Group (Hubbard, 1975-b) composed of the Siemen's Creek Formation, a 4400 foot unit of basalt and andesite and the overlying Kallander Creek Formation. The Kallander Creek Formation is composed of basalt, andesite and quartz-bearing felsites, of which 4000 feet are exposed in Ontonagon and Gogebic Counties in Michigan. The rocks differ from overlying volcanics by their location and structural attitude as well as rock type, metamorphic grade and residual magnetic polarity.

Middle Keweenawan Rocks

Unconformably overlying these volcanics are the Middle Keweenawan Portage Lake Volcanics, the Unnamed Formation and the Copper Harbor Conglomerate. Also included in the group is the Western Sandstone or "Sediments near Jackson Creek" (Hamblin, 1975-b) which may be the western extension of the Jacobsville Sandstone, or possibly, an older sedimentary unit.

The Portage Lake Volcanics are subareal lava flows which form the southeast limb of the Lake Superior Syncline.

They range from olivine basalt to sodic andesite and dacite in composition and are 13,000 to 15,000 feet thick (Cornwall, 1951; Leonardson, 1966).

The Unnamed Formation either interfingers with or is overlain by the Copper Harbor Conglomerate, a 4500 foot thick sequence of poorly stratified conglomerate and sandstone interbedded with lava flows. The conglomerate contains well-rounded to subrounded pebbles and boulders of rhyolite, rhyolite porphyry and minor amounts of lava flow fragments.

The sediments near Jackson Creek are poorly indurated sandstone and conglomerate composed of pebbles and sand-sized grains of quartz with some clasts of iron formation and dolomite (Hubbard, 1975b). Hubbard believes that the sediments are Middle Keweenaw in age and may be an extension of the Jacobsville Sandstone.

Felsites

Keweenaw felsites are numerous, but make up a very small percentage of the total rock volume. The felsites occur in two groups (Browne and Haynes, 1956; Leonardson, 1966). Most of them (at least 10 felsites) occur near or below the Bohemia Conglomerate lower in the Portage Lake Volcanic sequence, near the Keweenaw Fault. They are both intrusive and extrusive in origin, are lenticular in shape, up to 300-400 feet thick, but rarely exceed two miles in length. This group includes the Mt. Houghton Felsite (Fritts, 1952), the Montreal River, Bare Hill, West Pond, and Fish Cove Felsites (Papadakis and Raza, 1954), the Mt.

Gratiot Felsite (Browne and Haynes, 1956), the Copper City Rhyolite (Davidson, et al, 1955) the felsite at the Indiana Copper Mine (Butler and Burbank, 1929), the Bergland Rhyolite (Leonardson, 1966) and probably the felsite at the Bergland radioactive prospect along Trestle Creek. The Bergland Rhyolite is intrusive into an intraformational sandstone unit. It has been dated by the whole rock Rb-Sr method at 1250 ± 26 m.y. (Chadhuri, 1966). The Copper City Rhyolite is dated at 1040 m.y. and the Mt. Houghton Felsite is 1038 m.y. both by the Rb-Sr method (Chadhuri, 1975).

The second group of felsites occurs in and above the upper Portage Lake Volcanics and includes at least five felsite bodies, among which are the Porcupine Mountain Felsite (Hubbard, 1975a), the Chippewa Felsite (Thaden, 1950; Leonardson, 1966) the Firetower Porphyry (Leonardson, 1966), and the Bear Lake Felsite (Broman, 1953) which is intrusive into the Freda Sandstone. Rb-Sr whole rock age dating on the Firetower Rhyolite yields 905 ± 53 m.y. and the overlying Chippewa Felsite is 1100 ± 30 m.y. (Chadhuri, 1966). The Bear Lake Felsite, which is intrusive into the Freda Sandstone yields a Rb-Sr whole rock age date of 1007 ± 25 m.y. (Chadhuri, 1975). The largest felsic body, the Porcupine Mountain Felsite, consists of several flows of a vesicular and massive nature. The felsite contains sparse quartz phenocrysts in a devitrified cryptocrystalline matrix, with abundant secondary quartz (Hubbard, 1975a).

Upper Keweenawan Rocks

The Nonesuch Shale of Upper Keweenawan age is a sequence consisting of gray siltstone, sandstone, and shale, up to 700 feet thick. The bedding tends to be massive and uniform, with individual units showing lateral persistence, and suggesting deposition in a quiet water environment, at least partly deltaic. The lower twenty-five feet of the Nonesuch Shale is mineralized with copper sulfides over a wide area, but in economic concentrations only near White Pine. No radioactive zones have been noted (White and Wright, 1950).

The Freda Sandstone is a conformably overlying sequence of cross-bedded red sandstone and siltstone with some conglomerate and red shale. Its maximum thickness is 12,000 feet. It is composed of fragments of metamorphic, plutonic, intermediate and felsic volcanic rocks of Lower and Pre-Keweenawan age (Hubbard, 1975a). The sediments were apparently deposited by braided streams flowing from the south (Hamblin, 1961).

Jacobsville Sandstone

The Jacobsville Sandstone is discussed in another part of this report. It is a very thick red bed sequence, on the order of 10,000 feet and consists of sandstone with some conglomerate and siltstone. The sandstone formation is significant in that it represents a period of subareal erosion and intense chemical weathering in the source area. It shows lithologic similarities to the Athabasca Sandstone

and the Martin Formation in Saskatchewan. In its fluviatile character, it has some resemblance to the Tertiary Sandstone of Wyoming and the Triassic Sandstones of the Colorado Plateau.

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CHAPTER 3

THE URANIUM AND THORIUM OCCURRENCES
IN MICHIGAN'S PRECAMBRIAN ROCKSIntroduction

This report on the radioactive occurrences of northern Michigan represents a compilation of previously existing data most of which was written by U. S. Atomic Energy Commission personnel during the 1950's. Information on numerous newer showings is also included. Much of the earlier work was done by R. C. Vickers who presented his findings as a Ph.D. thesis to the University of Wisconsin, and made them available in a USGS Open File Report in 1956 (Vickers, 1956-a). Vickers attributed the formation of the numerous small uranium prospects to supergene processes. He was obviously ahead of his time, in that the importance of supergene processes in the formation of vein-type uranium occurrences is just beginning to be realized (c.f. Langford, 1974).

Thirty-eight occurrences are discussed here as well as a few lesser occurrences of radioactivity in bedrock and float. Most of these showings are quite small and the radioactivity quite localized. Over the years, the size of the showings has decreased further as samples have been carried away for study. Almost nowhere do samples of the reported higher grade material remain, and none of the occurrences appear to have economic potential at this time. Keeping this in mind, the important aspect of this study is to describe the various occurrences in the hope that these may disclose character-

istics and patterns that in turn will lead to similar but larger areas of mineralization.

The prospects are listed in Table 3-1 and their location is plotted on Figure 3-1 and on Plate 1 (in pocket). Road logs and county road maps are in the Appendix. In the following discussion all AEC assays quoted are those performed during the work on the 1950's, unless otherwise stated. I have supplied additional analyses for this work that were done by the neutron activation method at the Ford Nuclear Reactor, Ann Arbor, Michigan (see Chapter 4).

I have classified the occurrences into three categories based on my interpretation of the origin of the mineralization: primary, syngenetic, and supergene. Primary mineralization as used in this report denotes radioactive accessory minerals within the granites and gneisses, which formed at the time that the magma cooled. Primary minerals recognized in one of the prospects include zircon, uraninite, monazite, and thorianite. Primary mineralization appears to be the main cause of the radioactivity at three showings. However, primary uranium-bearing minerals have been noted at other places, but the measured radioactivity has been enhanced by the more abundant supergene uranium minerals.

In this report the term syngenetic is restricted to the sedimentary process in which the formation of the host rock and the concentration of ore minerals took place simultaneously and by the same mechanism. A single syngenetic

Figure 3-1 - Location of radioactive occurrences in Michigan

TABLE 3-1

List of Radioactive Occurrences in Northern Michigan

Radioactive Occurrences Reported by Vickers, 1956	Additional Occurrences in This Report
Gogebic County	Ontonagon County
1. Erikson Prospect	23. Bergland Prospect
Iron County	24. Indiana Copper Mine
2. Cardiff Mine	Iron County
3. Wauseca Mine	25. Lavato's Occurrences
4. James Mine	26. Float
5. Sherwood Mine	Marquette County
6. Zimmerman Mine	27. Sargent Prospect
7. Buck Mine	28. Republic Migmatite
8. Book Mine	29. Syenite Dike
9. S. Mastadon Mine	30. Voelker Prospect
10. Tobin Mine	31. Greens Creek Granite Prospect
11. Anderson-Wiggins Prospect	32. Goodrich Conglomerate
Baraga County	33. Goodrich Boulder
12. Graphite Quarry	34. Goodrich Float
13. Huron River	35. Smith Mine
14. Portland Mine	Dickinson County
Marquette County	36. Leitch & Isham Sec. 13
15. Taxpayer Sample	37. Leitch & Isham Sec. 12
16. M & G Mine	Baraga County
17. Float	38. Joe Forsythe Prospect
18. Greens Creek Slate Trench	39. Haggett Dike
19. Princeton Mine	40. Big Eric's Crossing
20. Stephenson Mine	41. Taylor Mine
21. Francis Mine	
Dickinson County	
22. Isham Prospect	

occurrence is noted in the Goodrich conglomerate, consisting of detrital grains of monazite.

The majority of the showings in Michigan are interpreted to be of supergene origin. That is, they were formed by downward percolating ground waters which leached uranium from the surrounding rocks and reprecipitated it in traps and zones of reduction. These vein occurrences are not believed to have a hydrothermal origin for two reasons: 1) an obvious stratigraphic control is noted, and 2) most of the veins lack a typical hydrothermal vein assemblage (quartz, sulfides, calcite, etc.), wall rock alteration patterns and sharply defined contacts. Quartz veins and sulfide assemblages have been noted at some occurrences, but close study by Vickers (1956-a) indicated that more than one stage of mineralization was represented. It is his view that the quartz veins are much earlier than the pitchblende, and may represent a plumbing system for downward percolating surface waters. The main criterion for assigning to these radioactive occurrences a supergene origin is their relationship to lithologic feature: their association with oxidized host rocks, their spatial relationship to graphitic-pyritic slates, and their occurrence in fractured (more brittle) host rocks.

Primary Occurrences

Primary uranium and thorium-bearing accessory minerals account for the observed radioactivity at three places in northern Michigan. They include a syenite dike, a migmatite and a pegmatite.

Syenite Dike - NE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 7, T48N, R25W

A radioactive syenite dike (No. 29) is described briefly by Gair and Thaden (1968) from an area about three and one-half miles northwest of Marquette. The dike is a red brick color and is composed of plagioclase, K-feldspar, and hornblende, with minor sericite, chlorite, carbonate, quartz, sphene, rutile, and lucoxene (Gair and Thaden, 1968). The dike strikes N20W (Figure 3-2) and on the weathered surface is nearly indistinguishable from the Compeau Creek Gneiss. The boundary between the two rock types was based on the difference in their radioactivity. The radioactivity of the dike is 6-9 times that of the adjoining granite, is evenly distributed, and is thought to be primary. The radioactive mineral has not been identified. Neutron activation analysis of a sample of this material showed 18 ppm U, and 150 ppm Th.

Migmatite Near Republic - NW $\frac{1}{4}$ Sec. 6, T46N, R29W

The radioactive outcrop of migmatite (No. 28), a favorite stop for petrologists, is located immediately northwest of the northernmost of the two bridges over the Michigamme River along M-95. Radioactivity, about 5 to 8 times the average for the surrounding rocks is localized in the north

Figure 3-2 - Radioactive syenite dike near Marquette

end of the outcrop, occurs in patches and appears to be related to the leucocratic portions of the migmatite. The outcrop was not sampled or analyzed, and therefore, the source of the radioactivity, whether potassium, thorium or uranium is not known for certain. Based on AEC assays from the surrounding area, it would appear that the radioactivity is caused by primary minerals rich in thorium. Malan and Sterling (1969) report a gamma ray spectrographic assay for a bulk sample of granite from an unidentified area near Republic, which contained 102.4 ppm $eThO_2$, 14.7 ppm eU_3O_8 and 5.22% eK.

Greens Creek Pegmatite - SW $\frac{1}{4}$, Sec. 35, T46N, R26W

A previously unreported prospect (No. 31), shown to me during the summer, occurs along M-35 south of Palmer, where a ten-foot cut was blasted some years ago in a granite outcrop. Here, most of the radioactivity appears to be associated with a pegmatitic zone in the granite, but there is also some radioactivity along a fracture cutting the outcrop. The pegmatite contains augen like masses of albite and quartz, up to two inches in length, in a groundmass of magnetite and biotite. I have prepared autoradiographs of the rock and these show the presence of primary radioactive accessory minerals within the biotite and magnetite. They have been identified as zircon, monazite, and minor uraninite and thorianite (Bingham, pers. comm., 1976). The large blue-gray albite crystals are characterized by cross-cutting hematite-stained hairline fractures that in some cases are

numerous enough to color the rock red or pink. The host rock is a pink, coarse grained granite gneiss with $\frac{1}{4}$ - $\frac{1}{2}$ inch long feldspar augen.

Syngenetic Occurrences

Goodrich Quartzite - Secs. 27,28,29,30,31,32, T47N, R26W

Radioactivity in the Goodrich Quartzite was discovered by State Geologist Robert Reed in 1951 while working for the AEC. The formation was studied by Vickers (1956-b) and was found to contain detrital grains of monazite along the bedding. Here the rock is a conglomerate and it contains well worn quartz pebbles mixed with angular fragments of iron formation of local derivation, in a quartzite matrix. The base of the formation (No. 32) at the old Isabella mine in Palmer contains large angular block of Negaunee Iron Formation and is only weakly radioactive (.022 mR/Hr., corresponding to .0045% Th). Radioactivity reaches its maximum at points above 300 feet from the base (1.3 mR/Hr., corresponding to .052% Th; Gair, 1975).

According to Vickers (1956-b), the thorium content ranges from 2.9 lbs/ton in the lower 200-300 feet to as high as 110 lbs/ton (0.37%) in glacial erratics. Vickers notes that the Goodrich Quartzite is a potential low grade resource for thorium. Gair (1975) estimates that the Goodrich contains 169,500 tons of thorium, although not all is recoverable.

Some years ago, Bob Reed located a large boulder, which is much higher in radioactivity than any seen in outcrop,

about one-quarter mile southwest of the village of Palmer in the old Volunteer mine area (No. 33). He believes the boulder to have come from old underground mine workings.

I was shown a similar highly radioactive block, a glacial erratic on a hilltop north of the Sweitzer Reservoir area, west of Palmer (No. 34).

Ajibic Quartzite - Sec. 24, T48N, R31W

Abnormal radioactivity in the basal conglomerate of the Ajibic Quartzite was reported by Klasner and Cannon (1975) in the USGS Open File Maps of the South Half Three Lakes Quadrangle and the South Half Michigamme Quadrangle. The very high readings were later attributed to instrument error. Additional field checking has disclosed that the radioactivity is only slightly above that for the nearby granites, so that sampling and assaying does not seem warranted. Gamma ray spectrographic analyses reported in Malan and Sterling (1969) on Ajibic Quartzite near Negaunee showed 15.5 ppm $eThO_2$, 12.4 ppm eU_3O_8 , and 3.6% eK, and an assay of Mesnard Quartzite from the Palmer area contained 2.4 ppm $eThO_2$, 10.7 ppm eU_3O_8 and 0.28% eK.

Supergene Occurrences

General

The vast majority of radioactive occurrences in northern Michigan are caused by pitchblende and/or secondary uranium minerals, such as metatorbernite or meta-autunite, in Middle Precambrian metasediments, diabase dikes of uncertain age, and

Keweenawan felsites. As noted earlier, I have classified these occurrences as supergene for two reasons: an apparent association of these radioactive showings with lithologic contacts, and a lack of evidence for hydrothermal activity associated with these occurrences. At such localities as the Huron River, Sherwood Mine, and the Francis Mine where the uranium minerals are associated with quartz veins and sulfide minerals, Vickers (1956-a) has shown that there was more than one stage of mineralization and that the veins may have provided channelways for downward percolating supergene solutions.

One might propose that all of the veins are hydrothermal, and formed during some single period of thermal activity. In this connection it should be pointed out that Michigan's Precambrian terrain has been subjected to high grade regional metamorphism at 1800-1900 m.y. and a less intense thermal event at 1625 m.y. (James, 1955; Van Schmus, 1976). However, the deposition of radioactive matter in the Keweenawan felsites obviously postdates these periods of high grade metamorphism. Also, Pb-Pb and U-Pb age dating of a pitchblende sample from the Sherwood Mine yielded a range of post-metamorphic ages of approximately 350-650 m.y. (Vickers, 1956-a). As noted on earlier pages, these ages are thought to correspond to the time of formation of the soft iron ores within which several of the prospects occur.

Granitic Host Rocks

General

Radioactive occurrences thought to represent supergene deposits in granites are widely distributed. Locations include granite at Big Eric's Crossing on the Huron River, the Sargent Prospect near Republic, the Voelker Prospect near Palmer, the three Leith and Isham Prospects near Felch, the Wiggins Prospect and Lavato's Occurrences of the Amasa uplift area, and the Erikson Prospect in the Marenisco area.

Big Eric's Crossing - NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec. 35, T52N, R30W

A radioactive fissure was located during the course of this work about 300 feet north of the bridge at Big Eric's Crossing on the Huron River, a site dear to the hearts of fisherman (No. 40). The fracture cuts Lower Precambrian basement granite which is exposed in the river bed during the summer period of low water (Figure 3-3). The fracture also cuts supergene veins and layers of chert and carbonate, which formed during Middle Precambrian weathering of the granite, but could not be traced into the paleo-regolith that underlies Middle Precambrian cherty iron formation (possibly Greenwood, Mancuso, et al, 1975) which dips gently outward from the granite. The fissure was not seen in the iron formation. Jacobsville Sandstone outcrops less than 100 feet north of the occurrence.

The fracture can be followed for about 35 feet and forms a narrow crack on the outcrops. Hematite has stained the granite walls along the fissure a deep brick red along a

Figure 3-3 - Outcrop map showing radioactive fissure at Big Eric's Crossing, Huron River, Baraga County.

distance of 14 feet and for a width of 6 to 8 inches on either side of the crack. Radioactivity is confined to the fracture, and the highest radioactivity -- about 30 times background -- is restricted to a zone about 18 inches in length, which also exhibits the deepest hematite staining of the walls. This zone is located about 20 feet from the unconformity.

The occurrence, although small and non-economic, is very similar to those described from the Beaverlodge area of Saskatchewan. There pitchblende occurs in faults in the basement gneisses unconformably below a redbed sequence (the Martin Formation) that resembles our Jacobsville Sandstone in lithology, though possibly not in age. The occurrence documents that, at least on a very small scale, the process that formed the Saskatchewan deposits also has been in operation in Michigan.

Sargent Prospect - W $\frac{1}{2}$ NW $\frac{1}{4}$ Sec. 32, T47N, R29W

The Sargent Prospect (No. 27) is a twelve foot deep prospect pit on the side of a granite ridge south of Bruce's Creek, about two miles north of Republic on M-95. The bottom of the pit is filled with water, even after a dry summer.

The granite host rock (Bell Creek Gneiss) is a coarse grained white gneiss that is jointed into large blocks. Radioactivity was reported by Vickers and Freedman (1952) to occur in a shear zone, and in the pit one can see a wedge-shaped crushed (shear?) zone that widens downward toward the bottom. The area is anomalously radioactive (0.05 mR/Hr.),

but the high radioactivity in the pit itself (0.1. mR/Hr.) is at least partly due to geometric effects. The visible portion of the crushed zone did not appear to be higher in radioactivity. No samples above background radioactivity were found on the dump near the pit. Either the higher grade samples have been carried off or some of the radioactive minerals have become leached. Vickers and Freedman (1952) report the following assays:

0.008% eU_3O_8 radiometric and 0.003% U_3O_8 chemical

0.006% eU_3O_8 radiometric and 0.002% U_3O_8 chemical

Anderson-Wiggins Prospect - SE $\frac{1}{4}$ Sec. 35, T45N, R32W

The Anderson-Wiggins Prospect (No. 11) is located in a fractured granite outcrop in the Margeson Creek Gneiss in the Amasa oval. Radioactivity occurs in a mafic segregation of the gneiss and along a fracture extending approximately 15 feet along the outcrop. Some hematite staining of the feldspars has colored the granite pink. James and King (1950) describe the prospect as occurring in a medium to coarse grained foliated pink granite with xenolithic layers and masses of amphibolite and irregular stringers of coarse pegmatitic granite. The field occurrence suggests to these workers that there has been leaching of uranium from surrounding granite. Uranophane has been identified in microcrystalline fracture coatings (Vickers, 1956-a), and a single assay reported by Vickers showed .008% eU and .002% U.

Lavato's Occurrences - N½Sec. 12, T44N, R31W

Two radioactive zones in the Margeson Creek Gneiss (No. 25), and a large radioactive boulder (No. 26) all located two miles west of the Anderson-Wiggins Occurrence were shown to me during the fall of 1975. The first is located in an outcrop about 4 feet high and 50 feet long of light pink granite gneiss. Radioactivity is associated with a light green colored sericitized shear zone striking N40E and cutting the northwest end of the outcrop. The radioactive shear zone is about six inches wide and is exposed for approximately two feet. Radioactivity in the shear zone is about ten times that of the surrounding granite. A selected sample of the light green-colored sheared material assayed 418 ppm U and 23 ppm Th (neutron activation analysis).

The second occurrence is in a low outcrop about 300 feet north of the sericitized shear. The host rock is similar to that of the first occurrence, and contains irregular quartz stringers and masses of amphibolite. Radioactivity occurs in small patchy and irregular weathered sericitic zones, and averages four times the background radioactivity. No samples were taken.

A large radioactive boulder of purple-red gneiss occurs on the logging road near these occurrences. The boulder is an erratic in that it is glacially rounded, and is of a different lithology from any seen in the outcrops of the area. The highest radioactivity in the boulder is about 18 times background.

Figure 3-4 - Outcrop map, Leitch and Isham Prospect,
Sec. 13, T42N, R29W.

Figure 3-5 - Outcrop map, Leitch and Isham Prospect,
Sec. 12, T42N, R29W.

Voelker Prospect - SW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec. 11, T46N, R26W

The Voelker Prospect (No. 30) is located in a fine-grained pink granite gneiss, about 5 miles south of the village of Palmer. The radioactivity is seen in a small prospect pit about three feet deep located in a shear zone between two large granite bluffs striking N60W. The radioactive material is a fine-grained biotite-chlorite schist containing small lath-like crystals of red-colored plagioclase. Vickers (1952) describes it as a chloritic shear zone, which he says extends 20 feet along the granite nob. The area is covered with rubble and I was unable to trace the radioactivity beyond the exposures in the pit. The highest radioactivity noted is about seven times background.

Leitch and Isham Prospects - Sec. 12,13 T42N, R29W and
Sec. 7, T42N, R28W

Anomalous radioactivity is noted in three prospects in the Felch area (Nos. 22, 36 and 37), all discovered many years ago by Mr. T. D. Isham of Owosso, Michigan.

The southernmost of the three prospects (No. 36) (N $\frac{1}{2}$ NW $\frac{1}{4}$, Sec. 13, T42N, R29W) consists of a ten-foot wide band of biotite schist included in pink granite gneiss, situated at the base of a blasted granite scarp, about 30 feet long and 20 feet high (Figure 3-4). Radioactivity occurs along a 30-foot fracture trending N10°W and dipping 80°SW, cutting the biotite schist. Small stringers of granite cut the schist. Assays performed by the AEC ranged from .002% to .030% U₃O₈ (chemical). Table 3-2 lists the assay results reported by Everhart (1952).

TABLE 3-2

<u>Sample No.</u>	<u>Collector</u>	<u>%U₃O₈e (radiometric)</u>	<u>%U₃O₈ (chemical)</u>	<u>Remarks</u>
1361-I	H.V. Lee (1950)	-	0.03	
1361-J	H.V. Lee (1950)	0.02	-	
-	L.P. Barrett (1951)	0.01	0.003	
-	L.P. Barrett (1951)	0.029	0.002	
4582-B	D.L. Everhart (1952)	0.009	0.002	
4582-C	D.L. Everhart (1952)	0.02	0.008	Collected from freshly blasted rock in the most radioactive spot in the prospect

Radioactivity in the second prospect (No. 37; Sec. 12, T42N, R29W) occurs near the Section Line between Sections 12 and 13, about 1200 feet N35E from the first occurrence (Figure 3-5). Radioactivity is associated with a shear zone cutting granite outcrop at N80°W and dipping 75°SW. A radioactive specimen of a biotite-quartz portion of the granite gneiss showed eight times background radioactivity.

Uraninite has been identified at both of these prospects, although the majority of the radioactivity is due to thorium (Everhart, 1952). Assays reported by Everhart (1952) are listed in Table 3-3.

TABLE 3-3

<u>Sample No.</u>	<u>Collector</u>	<u>%U₃O₈e (radiometric)</u>	<u>%U₃O₈ (chemical)</u>
1361-K	H. V. Lee (1950)	-	0.01
4592-D	D. L. Everhart (1952)	0.02	0.002

At the northernmost prospect (No. 22; NW $\frac{1}{4}$ Sec. 7, T42N, R28W), located about five miles north and west of Felch, radioactivity occurs in granite in a ten-foot section of a fracture zone that contains parallel vertical fractures trending N15-20E, near the contact with diabase. The fractures are coated with specular hematite. Vickers (1956-a) reports that highest radioactivity is associated with marcasite, hydrous iron oxide, and calcite, and contained 0.3% eU and 0.11% U.

The prospect occurs just southeast of a newly created dam and wildlife refuge. Anomalously radioactive granite is also seen along an E-W trending ridge, west of the dam. The granite exhibits a very strong gneissic texture and in places is stained with hematite to a very deep brick-red color.

Assays reported in Everhart (1952) are in Table 3-4.

TABLE 3-4

<u>Sample No.</u>	<u>Collector</u>	<u>%U₃O₈ (radiometric)</u>	<u>%U₃O₈ (chemical)</u>
1361-C	F. Pardee (1950)	-	0.031
1361-H	H. V. Lee (1950)	-	0.07
-	L. P. Barrett (1951)	0.013	0.001
-	L. P. Barrett (1951)	0.009	0.001
-	L. P. Barrett (1951)	0.065	0.024
4582-A	D. L. Everhart (1952)	0.06	0.014

Erikson Prospect - SE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 10, T46N, R43W

Uranophane has been identified by Vickers from a calcite-bearing vein cutting granite of the Presque Isle Gneiss (No. 1), about four miles northeast of Marenisco (1956-a). A single assay reported in Vickers showed 0.004% eU and 0.004% U. I was unable to locate the prospect. Neutron activation analysis on a grab sample from the same Section shows 12 ppm U and 30.8 ppm Th.

Metasedimentary Host RocksGeneral

Most, although not all of the prospects in Middle Precambrian metasedimentary rocks are associated in some way with pyritic-carbonaceous slates. Some occur within the black slates, and some are within oxidized iron formation near stratigraphic contacts with black slate.

Huron River Occurrence - NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec. 1, T51N, R30W

Pitchblende was discovered by geologists of the Jones and Laughlin Ore Company in 1949 along the banks of the East Branch of the Huron River (No. 13). Pitchblende base metal calcite mineralization is associated with a brecciated quartz vein marking the plane of a thrust fault cutting the carbonaceous slates of the Michigamme formation (Figure 3-6). The vein strikes N36°W and dips 10°SW, and ranges from 10 to 30 feet thick. The slates have a regional dip of eight degrees to the south. The pitchblende and secondary uranium minerals (metatyuyamunite and volborthite) occur as small

Figure 3-6 - Cross section of Huron
River uranium occurrence.

discontinuous stringers and pods in quartz and calcite that cement the breccia.

Forty-one drill holes by the Jones and Laughlin Ore Co. and Ford Motor Co. show that the radioactive minerals are restricted to secondary shear zones and fractures near the thrust fault, and also are restricted to the top 40 feet of the bedrock along a length of about 600 feet. The subsidiary shear zones occur in the upper block of the slates, are parallel to the main breccia zone, and dip 25-75°SW (Vickers, 1955-a).

Altered greenish gray slates near the prospect are believed to be oxidized portions of the carbonaceous black slates, and most of these green slates occur within twenty feet of the bedrock surface. Vickers (1956-a) postulated that the uranium was derived from the oxidized portions of the slate by downward percolating surface waters and reprecipitated as pitchblende in reduced areas of the slate which also contain pyrite.

Joe Forsythe Prospect - NW $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 13, T51N, R32W

The Joe Forsythe Prospect (No. 38) was mapped by Kiril Spiroff in 1958 (Figures 3-7 and 3-8), soon after the prospect had been bulldozed and the overburden scraped off in a shallow, U-shaped trench. Radioactivity is associated with a brecciated cherty Middle Precambrian iron formation exposed in very low outcrops within the trench. Also exposed in the trench is a dark feldspathic quartzite. Within one half

Figure 3-7 - Geology of the area surrounding the Joe Forsythe prospect.

Figure 3-8 - The Joe Forsythe prospect trench showing radioactivity and drill hole data.

mile of the trench are outcrops of granite and Jacobsville Sandstone. One small outcrop of gray slate was seen about 1500 feet southwest of the prospect.

The radioactivity in the trench is quite irregular and up to ten times background.

Graphite Quarry - Section Line: Sec. 9 and 16, T49N, R33W

Radioactivity (No. 12) occurs in and along a metadiabase dike cutting graphitic slates of the Michigamme Formation (Figures 3-9 and 3-10), in an old abandoned graphite quarry on Ford Motor Co. lands (Vickers, 1955-b). The dike is about four feet wide, strikes N60W, and dips 65°SW (approximately parallel to the cleavage) where it is exposed in the north quarry wall. The dike splits and appears as two dikes on the east quarry wall.

The dike is extensively altered to kaolinite, perhaps due to the supergene oxidation of pyrite in the wall rocks, and ranges from dark red to almost white in color. The red material consists of kaolinized feldspar grains and iron oxides after altered ferromagnesian minerals. The white material consists of kaolinite and relatively unaltered grains of magnetite. Minute crystals of metatorbernite and pyrite were noted by Vickers along slickensided surfaces in the kaolinized dike near the hanging wall (1955-b).

Vickers considered the altered dike to be Middle Precambrian in age and possibly related in time to the folding of the metasediments. However, he interprets the secondary

uranium minerals to have been formed during the recent weathering cycle by the oxidation of pitchblende. Select samples of the dike contained more than 0.1% U (Locality 'A' in Figure 3-9), and the radioactivity appeared to increase with depth (Vickers, 1953).

The slate in the quarry was chip-sampled at 50-foot intervals and showed a uniform uranium content of 0.003 to 0.004%. The slate also contains 30 percent carbon and 3 to 7 percent iron (Vickers, 1955-b).

A narrow quartz vein 3 to 4 inches wide exposed in the west quarry wall is also radioactive (Locality 'B' in Figure 3-9). The vein strikes N70W and dips 35°N. Pyrite and iron oxides were visible in the vein (Vickers, 1955-b).

Assays reported by Vickers (1955-b) are shown in Table 3-5.

Taylor Mine - E½NW¼Sec. 9, T49N, R33W

At the old Taylor Iron Mine (No. 41), about one mile north of the old graphite quarry, and located along the same old logging road, radioactivity has been discovered recently by geologists of D. S. Robertson and Associates, Ltd. The initial discovery was made within an area inside the fenced off Taylor Mine property, where a fallen tree had uprooted several radioactive pieces of brecciated slate. Radioactivity in the area has been traced to several pitchblende showings in fault-related breccia zones within brittle rocks below the pyritic-carbonaceous slates and also along lithologic contacts (D. Sutherland, pers. comm., 1975).

Figure 3-9 - Radioactive zones at the graphite quarry,
Baraga County.

Figure 3-10 - Geology of the graphite quarry, showing radio-activity.

Figure 3-11 - Geologic cross section of the Taylor Mine area, Baraga County.

TABLE 3-5

Uranium Analyses of Samples From the Graphite Quarry, Baraga County, Michigan

<u>Sample No.</u>	<u>eU</u>	<u>U</u>	
MB-70-53	0.052	0.068	Selected sample of altered dike containing visible metatorbenite at Locality A.
MB-71-53	0.023	0.019	4-ft. channel sample across dike at Locality A.
MB-72-53	0.014	0.019	4-ft. channel across dike.
MB-73-53	0.015	0.010	1-ft. channel across north split.
MB-74-53	0.009	0.010	3-ft. channel sample south dike.
MB-75-53	0.014	0.009	6-inch channel of hanging-wall slate, Locality A.
MB-76-53	0.033	0.037	2-ft. channel sample across most radioactive part of dike at Locality A.
MB-78-53	0.012	0.097	1.2-ft. channel of south dike taken 5 ft. above quarry floor.
MB-79-53	0.009	0.006	1.4-ft. channel sample of dike, taken 5 ft. above quarry floor.
MB-80-53	0.009	0.006	018-ft. channel of north dike taken 8 ft. above quarry floor.
MB-81-53	0.007	0.005	4-ft. channel sample of dike taken 7 ft. above quarry floor.
MB-84-53	0.028	01007	Selected sample of radioactive vein quartz, Locality B.
MB-85-53	0.006	0.004	13-ft. chip sample of black slate, west end of quarry.
MB-86-53	0.007	0.004	20-ft. chip sample of black slate, west end of quarry.
MB-87-53	0.008	0.003	6-ft. chip sample of black slate, northwestern part of quarry.
MB-88-53	0.005	0.003	2.5-ft. chip sample of black slate, adjacent to dike on hanging wall, northwestern part of quarry.
MB-89-53	0.005	0.003	13-ft. channel sample of black slate, adjacent to dike on footwall, northern part of the quarry.
MB-90-53	0.008	0.008	2-ft. channel sample of dike, east end of quarry.

(Vickers, 1956)

The area has been mapped by Klasner (1972) (Figure 3-11). The entire sequence consists of Lower Precambrian granite overlain by phyllite, slate, iron formation, hematitic wacke and hematitic phyllite of the Baraga Group of Middle Precambrian age. The rocks are folded into slightly overturned folds, and are offset by numerous north-trending transverse faults. The metasediments are cut by west-trending Keweenawan diabase dikes.

M & G Iron Mine - Sec. 29, T48N, R29W

The old M & G Iron Mine is located about one mile north of Champion (No. 16). Drilling by the A.E.C. showed the iron formation to be oxidized to a depth of about 80 feet, and meta-autunite has been identified in oxidized iron formation from the dump of the old mine. Four small radioactive occurrences were found by the A.E.C. (Figure 3-12). One is a six-inch quartz vein in black slate, and contains 0.019% eU and 0.018% U. Two small concentrations were found in oxidized iron formation near the contact with the immediately underlying layer of black slate. The fourth occurrence, in oxidized iron formation at the contact with a metadiabase dike, is the most radioactive (0.035% eU). The abnormal radioactive occurrences in oxidized iron formation were associated with relatively high calcium and phosphorous contents (Vickers, 1956-a).

The average uranium content of the material as shown in Vickers (1956-a) is as follows:

Figure 3-12 - Drill hole information showing radioactivity at the M & G Mine, Marquette County.

Unoxidized iron formation - 0.000 - 0.002% eU_3O_8
 Oxidized iron formation - 0.001 - 0.034%, ave. 0.003%
 Black slate - 0.005% eU_3O_8

"Old Mine" - Sec. 30, T48N, R29W

About one mile to the west of the M & G Mine is another old iron mine referred to in Vickers (1956-a) simply as "Old Mine" (No. 15). Oxidized iron formation from the dump assayed 0.011% eU_3O_8 (Barrett, 1953).

Portland Mine - Sec. 26, T48N, R31W

Radioactivity was reported from dump material from the old Portland Mine, in Bijiki Iron Formation west of Lake Michigamme (No. 14). I noted a radioactive specimen of pyritic slate (four times background) on a dump and also located an abnormally radioactive boulder of iron formation in the abandoned open pit. The iron formation is of the oxidized cherty variety and is somewhat vuggy and brecciated. Barrett (1953) reported a high assay of 0.017% eU_3O_8 for iron formation from a dump at this mine.

Gwinn Syncline

Radioactivity occurs at five old iron mines within the Gwinn Syncline. They are as listed below:

- (No. 21) Francis Mine - Sec. 27, T45N, R26W, pitchblende
- (No. 20) Dump Stevenson Mine - Sec. 20,29, T45N, R26W, up to 0.012% eU_3O_8
- (No. 19) Princeton Mine Dump - Sec. 19,20, T45N, R26W, up to 0.1% eU_3O_8
- (No. 19) Princeton Open Pit - Sec. 18, T45N, R26W, up to 0.1% eU_3O_8
- (No. 35) Dump Smith Mine - Sec. 18, T45N, R26W, up to 0.018% eU_3O_8

Two three-inch specimens of radioactive iron ore from the old Francis Mine were discovered while scanning drill core (Vickers, 1956-a). The drill core is of oxidized iron formation and unoxidized black slate, and shows concentrations of uranium, copper and lead. Vickers (1954) indicates that in a small sample, perhaps not particularly representative, assays showed 0.24% and 0.068% eU and 0.12% and 0.08% U respectively.

Greens Creek Slate Trench - NE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 24, T46N, R27W

Radioactivity in a slate and quartzite inlier within the Compeau Creek Gneiss along Greens Creek had been noted by State Geologist Robert Reed in the 1950's. In 1969 Kerr McGee dug a trench 220 feet long and about 6 to 10 feet deep (No. 18), exposing light gray quartzite, black carbonaceous slate, minor thin beds of iron formation, and Lower Precambrian granite. The granite is believed to be in fault contact with the slates at the south end of the trench where the granite shows some alteration. An aeromagnetic anomaly indicates the possible presence of a reversely polarized diabase dike a few hundred feet north of the trench (Hatfield, 1969).

The highest radioactivity was associated with small nodules of carbon within the slate, estimated on the basis of radioactivity to contain as much as 1% uranium (Vickers, 1955-c). The largest radioactive area in the prospect, however, was in the quartzite layers where metatorbernite and bassetite were identified along with the clay mineral

dickite (kaolinite, according to Hatfield). Pyrite and malachite were also identified. Channel samples assayed by the A.E.C. were from 0.004 to 0.036% uranium. A select sample assayed 0.68% uranium (chemical). Three one-foot samples across the radioactive quartzite assayed by the Kerr McGee Corporation were as follows: 0.046%, 0.033% and 0.100% U_3O_8 . Two high grade samples reported by Hatfield (1969) were 0.87% and 0.265% U_3O_8 . The A.E.C. assays reported by Vickers, 1955-c are listed in Table 3-6.

Crystal Falls-Iron River District

Several similar occurrences of radioactivity are described here from nine mines in the Iron River-Crystal Falls area (Barrett, 1953; Vickers, 1956-a). The specific occurrences are:

Mineral Hills District-Iron River

- (No. 5) Sherwood Mine - Sec. 23, T43N, R35W, pitchblende
- (No. 2) Dump, Cardiff Mine - Sec. 22, T43N, R35W, up to .041% eU_3O_8
- (No. 3) 8th Level Wauseca Mine - Sec. 23, T43N, R35W, up to 0.015% eU_3O_8
- (No. 4) 7th Level James Mine - Sec. 23, T43N, R35W, up to 0.02% eU_3O_8

Caspian-South of Iron River

- (No. 6) 6th Level Zimmerman Mine - Sec. 7, T42N, R35W, up to 0.014% eU_3O_8
- (No. 7) Buck Mine - T42N, R35W, pitchblende

Crystal Falls

- (No. 10) 14th Level, Tobin Mine, Sec. 30, T43N, R32W, up to 0.014% eU_3O_8

Alpha

- (No. 8) 2nd Level Book Mine, Sec. 12, T42N, R32W, up to 0.01% eU_3O_8
- (No. 9) Dump South Mastadon Mine, Sec. 13, T42N, R33W, up to 0.01% eU_3O_8

TABLE 3-6
 Uranium Analyses of Samples from the Greens Creek
 Slate Trench, Marquette County, Michigan

<u>Sample No.</u>	<u>eU (percent)</u>	<u>U (percent)</u>	<u>Length (feet)</u>	<u>Description</u>
Surface samples taken in 1953				
4-53	0.78	-0.05		Selected sample of slate containing radioactive carbonaceous pellets.
5-53	.041	.001		Slate float
142-53	.046	.006		Slate float
143-53	.002	.002		Slate outcrop, 150 feet southeast of trench.
Analyses by S. Furman, R. DuFour, and J. Wahlberg, U. S. Geological Survey				
1	0.61	0.68		Selected sample of metatorbomite-bearing slate from trench.
3	.005	.007	8	Samples numbered 3-9 are channel samples of the slate taken from the trench in consecutive order from the northeast to southwest.
4	.004	.004	7	
5	.036	.036	4	
6	.010	.009	4	
7	.005	.006	5	
8	.008	.008	4	
9	.004	.004	6	

Analyses by Roosevelt Moore and Percy Moore, U. S. Geological Survey

Vickers (1955)

Pitchblende was identified in oxidized iron formation of the still operating Sherwood iron mine, located in the Mineral Hills district one mile north of Iron River. Radioactivity was noted on two levels and in a drill core. Traces of pitchblende along with base metal sulfides were found in narrow pods and lenses within oxidized iron formation, and near the structural contact with black slate (Barrett, 1953; Vickers, 1956-a).

The minerals present in the mineralized iron formation of the Sherwood Mine are uraninite, pyrite, chalcopyrite, galena and sphalerite. The host rocks for the radioactive material at the sample localities were (Figure 3-13):

Locality A: Banded red jasper and hematite with seams of black slate.

Locality B: Layers of yellow ocherous limonite with seams of black slate.

Locality C, D, and E: Soft reddish hematite with seams of black slate.

The highest value obtained in the mineralized area was 0.513% eU_3O_8 (James, et al, 1968).

Pitchblende was also identified at the Buck Mine in Caspian, just south of Iron River. Vickers (1956-a) states that the mineralization is localized along a small shear zone within the footwall black slate, and is overlain by oxidized iron formation.

Figure 3-13 - Geologic cross section of the Sherwood Mine, showing location of radioactive occurrences.

Minor Radioactive Occurrences

Ferruginous slate float (No. 17), containing 0.3% eU_3O_8 and 0.17% U_3O_8 was found by L. P. Barrett in Sec. 1, T47N, R29W (Vickers, 1956-a).

Minor radioactivity occurs in outcrops of pyritic slates of the Michigan Formation in Sec. 30, T48N, R29W, near the eastern end of Lake Michigamme.

Minor radioactivity was noted in pyritic black slates of the Tyler Formation, in outcrops along the south side of U. S. Highway 2 at the bridge over the Black River. The slates contain abundant spherical-colloform structures of pyrite, and radioactivity was noted to be about three times background.

Radioactivity Associated with Diabase Dikes

Radioactivity occurs along and within diabase dikes at four localities, Haggett Dike (No. 39), the Graphite Quarry (No. 12), Taylor Mine (No. 41) and the M & G Mine (No. 16). The diabase dikes at the latter three occurrences cut Middle Precambrian metasedimentary rocks and were described in that section. Haggett Dike cuts granitic rocks.

Haggett Dike - NE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 13, T51N, R32W

Exposed in the same section and believed to be a part of the old Joe Forsythe Prospect is a radioactive, slightly altered diabase dike (No. 39) shown to me during the fall of 1975. The dike is dark gray on the fresh surface and weathers to an orange-red color. It occurs in a pink

Figure 3-14 - Outcrop map of radioactive Haggett diabase dike, in granite, Baraga County.

granite gneiss, strikes N25W and locally is sheared at the margins for a few tens of inches (Figure 3-14). Radioactivity occurs along fractured portions of the dike margin in a patchy and irregular manner for a length of about 40 feet. The highest radioactivity measured was about 20 times background. The pink granite gneiss in the area is also slightly anomalous, and appears to be nearly twice the normal radioactivity for granites of the Northern Complex. Gray gneiss is also exposed in this area and is less radioactive than the pink gneiss.

Radioactivity in Keweenawan Felsites

Radioactivity has been reported from two Keweenawan felsites of the Portage Lake Series. The felsites occur near Bergland north of Lake Gogebic, and at the old Indiana Copper Mine near Mass.

Bergland Occurrence - NW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec. 35, T49N, R24W

Uraninite and uranophane were reported from the Bergland occurrence (No. 23) by Beroni and Patterson (1956). I field checked the showing and found that the radioactivity is associated with an altered and bleached felsite, rather than sandstone, as originally reported. The highest radioactivity is found in fractures within the felsite at the contact with the underlying basalt. The radioactive zone strikes N55E and I traced it along an intermittent series of outcrops for about 200 feet.

Thin section studies of the altered felsite show deeply embayed phenocrysts of quartz rimmed with secondary quartz overgrowths, in a ground mass of fine grained quartz, sericite and clay (possibly devitrified volcanic glass). In the groundmass are also masses of carbonate, a few spherulites of devitrified glass and minor chlorite. No feldspar was detected in an X-ray diffraction pattern. The quartz peak was most prominent, followed by calcite, mica and clay.

Indiana Copper Mine - NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec. 27, T51N, R37W

The old Indiana Copper Mine (No. 24) is reported to have contained felsites with up to 200 ppm uranium (Holen, pers. comm., 1975). I was unable to find any radioactivity in that range. Figure 3-15 taken from USGS Professional Paper 144 (Butler and Burbank, 1929) gives an indication of the complex geologic setting of the Indiana Copper Mine. In dump samples the felsite is brecciated and veined with copper minerals. Most of the felsite is brown, but other dump samples show a white bleached color, and are veined with fluorite. In addition basalt and Jacobsville Sandstone also occur on the dump.

Radioactivity of the Nonesuch Shale

A radiometric study of the Nonesuch Shale was carried out at the White Pine Mine by White and Wright (1950). The rock units checked were the Upper Shale, First Sandstone, and Parting Shale members of the Nonesuch Shale and the

Figure 3-15 - Geologic cross section at the Indiana Copper Mine, Ontonagon County.

upper 3 to 6 feet of the Copper Harbor Conglomerate, all exposed in the 2500 feet of workings which were accessible at the time around the inclined shaft (Bill Schacht shaft).

The Nonesuch Shale was found to be slightly less radioactive than most black shales. On the basis of the radioactivity it was estimated to contain .001-.003% eU. The sandstone above and below the Parting Shale contains less than .001% eU. The workers also concluded that there was no correlation between radioactivity and the amount of copper in the shale.

Jacobsville Sandstone - Sec. 10, T52N, R30W

Larry Babcock reported that uranium was observed in an X-ray fluorescence pattern of vein material from a copper-bearing calcite vein cutting Jacobsville Sandstone (pers. comm., 1975). The vein is exposed in a small adit along the Lake Superior shore northeast of Huron Bay, accessible by boat.

D. Sutherland visited the adit and reported that the radioactivity (twice background) inside the adit was due to geometric effects (pers. comm., 1976). Analyses for uranium and thorium in the vein material are being performed at Phoenix Memorial Laboratory at the time of this writing.

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CHAPTER 4

URANIUM AND THORIUM CONTENT IN IGNEOUS ROCKS

General Comments

Neutron activation analyses for uranium and thorium in granites and gneisses were made by Mr. Tom Myers, technician in charge of irradiation studies at the Ford Nuclear Reactor at the University of Michigan, Ann Arbor. This analytical work was made possible because of a grant to the Ford Nuclear Reactor from ERDA that permits this type of cooperation.

Additional fluorometric analyses for uranium in whole rock samples of granites and gneisses were obtained from D. S. Robertson and Associates, Ltd. These analyses were made by X-ray Assay Laboratories in Toronto.

The analyses are presented in a preliminary form here because of their possible value as background data for uranium exploration. I will be making a considerable additional number of neutron activation analyses on rocks for my thesis. At that time I will discuss the data more fully.

Neutron Activation Analyses

Twenty-six granite gneiss samples were collected from the Watersmeet-Marenisco area (Figure 4-1), and analyzed for uranium and thorium (Table 4-1). The rock samples were crushed to a fine powder, and a 50-100 mg aliquot was

Figure 4-1 - Location of samples, Watersmeet, Marenisco and Bergland areas.

weighed out and sealed in Supersil glass tubing. This was taken or mailed to the Ford Nuclear Reactor. For standards Tom Myers used one that he had prepared for this purpose, and the USGS Rock Standard G-2. The samples and standards were irradiated at 6 to 12 inches from the south face of the reactor core at a flux of 10^{13} thermal neutrons/cm²/sec for ten hours. The samples were allowed to decay for eight days, and were counted for ten minutes each.

Under these experimental conditions the limit of detection for uranium and for thorium was approximately 2 ppm. Because the uranium content of the USGS Standard G-2 is also 2 ppm, it was not possible to determine the accuracy and precision of the analyses. We found the standard deviation of thorium in USGS Standard G-2 to be 13.2 percent (compared to 6.8 percent for published values).

Fluorometric Analyses

Fluorometric analyses for uranium were performed by X-ray Laboratories in Toronto on whole rock samples gathered by geologists of D. S. Robertson and Associates, Ltd. (Figure 4-2). The precision of the method is 1 ppm in the range reported. The author is grateful to D. S. Robertson and Associates for providing these data (Table 4-2).

Figure 4-2 - Location of samples analyzed by fluorometric method.

Preliminary Interpretation of Data

I noted in Chapter 5 that one may assume an average initial Th:U ratio for acid igneous rocks to be about 3:1. A large increase in the ratio may be indicative of uranium loss from the rock. I have indicated in Table 4-1 those analyses that show such high ratios.

TABLE 4-1
Neutron Activation Analyses

<u>Gneiss Near Watersmeet (Wolf Lake Granite)</u>		U (ppm)	Th (ppm)	Th/U
123	NE $\frac{1}{4}$ Sec. 4, T45N, R39W	13	65	5
124		< 2	32	16+
125	NW $\frac{1}{4}$ SW $\frac{1}{4}$ Sec. 4, T45N, R39W	3	9	
126		< 2	9	
127		< 2	24	12+
<u>Granite Near Thayer</u>				
136	NW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 8, T46N, R41W	< 2	8	
137	SW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 8, T46N, R41W	11	54	
138		2	8	
140		< 2	< 2	
141		13	28	
142	NW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 23, T46N, R42W	< 3	8	
144		< 4	7	
146	NW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 28, T46N, R41W	< 2	< 3	
147		< 2	3	
148		< 2	< 3	
<u>Gneiss Near Mt. Kimberley</u>				
150	NE $\frac{1}{4}$ Sec. 33, T47N, R42W	< 2	18	9+
152		< 2	5	
154	NW $\frac{1}{4}$ Sec. 4, T46N, R42W	2	2	
156		6	70	11
158		3	39	13
<u>Granite Near Nelson Creek</u>				
133	SE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 12, T46N, R43W	3	12	
145	NE $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 10, T46N, R43W	12	31	
163	NE $\frac{1}{4}$ SW $\frac{1}{4}$ Sec. 3, T46N, R44W	3	22	7
165	SW $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 11, T46N, R44W	< 2	12	6
166	NE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 13, T46N, R44W	2	21	10
167	NE $\frac{1}{4}$ Sec. 33, T47N, R43W	6	39	6

TABLE 4-2
Fluorometric Analyses

<u>Northern Complex</u>		<u>U(ppm)</u>
S-1	SE $\frac{1}{2}$ NW $\frac{1}{4}$ Sec. 36, T52N, R30W	17
S-2	NE $\frac{1}{4}$ SW $\frac{1}{4}$ Sec. 36, T52N, R30W	7
S-3	SE $\frac{1}{4}$ SE $\frac{1}{2}$ Sec. 36, T52N, R30W	1
<u>Southern Complex - Palmer - Gwinn Area</u>		
S-4	NW $\frac{1}{4}$ Sec. 31, T47N, R26W	4
S-5	NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec. 2, T46N, R27W	8
S-6		2
S-7	NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec. 9, T46N, R26W	31
S-8	SE $\frac{1}{2}$ NW $\frac{1}{4}$ Sec. 9, T46N, R26W	8
S-9	S $\frac{1}{2}$ NE $\frac{1}{4}$ Sec. 8, T46N, R26W	19
S-10	S $\frac{1}{2}$ NW $\frac{1}{4}$ Sec. 18, T46N, R26W	4
S-11	W $\frac{1}{2}$ SE $\frac{1}{2}$ Sec. 18, T46N, R26W	7
S-12	S $\frac{1}{2}$ NW $\frac{1}{4}$ Sec. 30, T46N, R26W	5
S-13	NW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 29, T46N, R26W	6
S-14	NW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 28, T46N, R26W	2
S-15	W $\frac{1}{2}$ Center Section Line, Sec. 12, T45N, R26W	1
S-16		6
S-17		6
S-18	SW $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 20, T46N, R25W	14
S-19	NW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 9, T45N, R25W	1
S-20		1
<u>Amasa Oval</u>		
S-21	NW $\frac{1}{4}$ SE $\frac{1}{4}$ Sec. 34, T46N, R32W	3
S-22		2
S-23	NE $\frac{1}{4}$ NE $\frac{1}{4}$ Sec. 17, T44N, R31W	24
S-24		5
S-25	NE $\frac{1}{2}$ NW $\frac{1}{4}$ Sec. 20, T44N, R31W	8
<u>Felch Area</u>		
S-26	NE $\frac{1}{2}$ Sec. 12, T42N, R29W	1
S-27	NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec. 7, T42N, R28W	7
S-28		
S-29	NE $\frac{1}{2}$ NW $\frac{1}{4}$ Sec. 7, T42N, R28W	10
S-30	NW $\frac{1}{4}$ NW $\frac{1}{4}$ Sec. 4, T41N, R28W	2
S-31		1

CHAPTER 5

DEPOSITIONAL MODELS AND AREAS FAVORABLE TO MINERALIZATION

Introduction

As discussed earlier, uranium and thorium mineralization in northern Michigan occurs in three ways: a) primary concentrations in the form of radioactive accessory minerals within granites and gneisses, b) a single syngenetic occurrence, noted in a quartz-pebble conglomerate, and c) supergene concentrations in Lower Precambrian granites, gneisses, Middle Precambrian metasedimentary rocks, Upper Precambrian rhyolites, and diabase dikes of uncertain age. These three types of occurrences are schematically represented in Figure 5-1. The most prevalent type of occurrence, and the type which I feel has the most economic potential is the supergene occurrence. In this chapter, each of the three types of mineralization will be discussed and evaluated and in conclusion I will present my concept of and model for the Lake Superior type uranium deposit.

Primary Concentrations

Primary mineralization accounts for the radioactivity observed in three places in northern Michigan. Although none of the three prospects have economic potential, the process which formed them could easily occur on a larger scale. In addition, this process, combined with supergene enrichment, could also form economic concentrations.

Figure 5-1 - Schematic representation of uranium concentrations, A = primary concentrations in pegmatites; B = syngenetic concentrations in quartz pebble conglomerates; C = supergene occurrences along unconformities, modified after R. G. Darnely, 1975.

The syenite dike near Marquette represents the concentration of uranium and thorium by magmatic differentiation similar to but on a much smaller scale than the Ilimausaq complex in Greenland. If the same process which formed the syenite dike had been operative during the emplacement of something the size of the Dead River pluton, the results might be an economic deposit of both uranium and rare earth elements. This type of occurrence, however, does not appear to be present on a large scale in Michigan.

The Greens Creek pegmatite and the migmatite near Republic are interpreted to represent the reconcentration of uranium and thorium by metamorphism and recrystallization of an older rock (A, in Figure 5-1) has demonstrated the mobility of uranium in granitic rocks under metamorphic conditions. Peterman, Zartman and Sims (1976) have presented evidence for such a period of intense metamorphism and recrystallization for the gneisses of the Watersmeet-Marenisco area, which they believe to have a primary age of 3.5 b.y. The concentration of the U- and Th-bearing minerals may have occurred during the metamorphism and recrystallization of the Michigan gneisses either 2.7 or 2.8 b.y. ago, or during the less intense later metamorphic period 1.7 b.y. ago. Although such reactivation of uranium, later subjected to supergene process could be a very important type of occurrence in northern Michigan, I do not find the evidence to be overwhelming. This process might involve one or more periods of intense deformation and recrystallization, and

might be characterized by the presence of migmatitic zones, and pods and stringers of quartz, and possibly pegmatitic zones. Enrichment or depletion by supergene solutions is visualized as occurring during a relatively recent period in the geologic history, most probably at the time of deposition of the Jacobsville Sandstone. Numerous well rounded chert and quartz pebbles, seen in drill core of the "western" sandstone indicates that the source area was undergoing intense chemical weathering. Uranium in granitic rocks at this time would have been leached and redeposited in favorable regions within the granite or nearby meta-sedimentary rocks, or near diabase dikes. This process is believed to have been responsible for the mineralization at the three prospects in the Felch area and is also believed to be responsible for the regionally high radioactive background in that area. Abnormally high radioactive backgrounds also are noted in the granites around Republic and to the east around Palmer and Gwinn.

A similar, but not yet documented type of occurrence might involve the intrusion of a highly evolved granitic magma into the older gneiss terrain. Uranium, thorium and other volatile elements, if trapped in the border zone of the intrusion, could form an economic concentration. In their study of the gneisses of the Watersmeet-Marenisco area, Peterman, Sims and Zartman (1976) present evidence for intrusive igneous activity occurring along with the deformation of basement rocks 2.7 to 2.8 b.y. ago. James (1955)

believes that the metamorphic node of the Republic area was formed by a pluton intruded to within one mile of the present surface during the Penokean Orogeny 1.9 b.y. ago. A small synorogenic gabbroic body, the Peavy Pond Complex is associated with the Peavy node in the Felch area. However, no major igneous bodies of that age have yet been recognized in northern Michigan.

Syngenetic Occurrences

No syngenetic concentrations of uranium (B in Figure 5-1) have been noted in Michigan. The Goodrich conglomerate (1.9 b.y.) contains detrital grains of monazite, but only trace amount of uranium. Only one conglomerate, the East Branch Arkose of Dickinson County is known to be of Lower Precambrian age, and thus, according to the criteria of Robertson and Douglas (1970), might be of the appropriate age for hosting detrital uranium.

All of the conglomerates of Michigan are relatively unsorted, polymictic conglomerates. If a clean, well sorted, quartz pebble conglomerate does exist, it remains to be found from under younger sediments or the glacial cover. Although no glacial erratics of such a conglomerate have been found, one should keep in mind the possibility, however slight, of a completely covered occurrence of this type, when exploring by, say, the geochemical method.

Supergene Occurrences

The supergene occurrence is the most prevalent type of uranium concentration in northern Michigan and is the type that I believe to have the most economic potential. This type of occurrence is schematically shown as 'C' in Figure 5-1. In order to evaluate the favorability for supergene uranium mineralization, I have created a depositional model based on my observations of the occurrences and on Vickers (1956) laboratory experiments. I will discuss first the characteristics of the source rocks, then the nature of the host rocks, the time and mode of the mineralizing process and finally, based on our understanding of the geology, the feasibility of the process occurring on a large scale.

Source Rocks

Three types of potential source rocks for supergene occurrences are found in northern Michigan. They are: pyritic black slates, granite gneisses, and rhyolites, all of which contain relatively high concentrations of syngenetic or primary uranium.

Carbonaceous pyritic slates occur in the Michigamme Formation, the Gwinn Series, the Riverton Iron Formation, the Tyler Slate and the Dunn Creek Slate. These slates are characteristic of the upper Marquette Range Supergene which alternates between the sulfide-bearing carbonaceous slates and the chemically precipitated iron formations. The pyritic black slates of the Michigamme Formation contain

20-40 ppm uranium (Vickers, 1955-1956). Vickers (1956) used laboratory experiments to show that up to 42 percent of the uranium in crushed samples of Michigamme Slate from the Iron River district was easily oxidized and leached by ordinary surface waters. The acidity of the leachate and the uranium content in that leachate showed a strong correlation, indicating that the oxidation of the pyrite in the slates, which caused the release of large quantities of sulfuric acid may serve to dissolve the uranium. Vickers suggests that the metamorphism of the slates transformed the carbon into a "fixed" state, and as a result the uranium in the black slates was perhaps not as tightly held as by the original organic material.

Granites are also potential source rocks. Vickers found that in some areas of the Southern Complex they contain an average of 40 ppm uranium (1956; Malan and Sterling, 1969). I have analysed numerous additional samples, as noted in Chapter 4, in an attempt to determine a regional geochemical background for uranium, and to define those granitic bodies that might be source rocks for supergene uranium. I have interpreted the data assuming that the average initial Th/U ratio for acid igneous rocks is about 3 to 1. A large increase in the ratio may be indicative of uranium loss from the rock. A decrease may mean that uranium has been added to the acid igneous rock.

In a more sophisticated study of uranium mobility in the Granite Mountains area, Wyoming, based on isotopic analyses, Rosholt, Zartman and Nkomo (1973) showed that an average of 75 percent of the uranium necessary to have produced the observed radiogenic lead had been removed from the granitic rocks. The loss of uranium as seen in drill core, extended to at least 165 feet below the surface, and represents 20 grams of uranium per 1000 kg of rock. No net loss of thorium was observed. They believed that these granites may have been the source rocks which provided the uranium now concentrated in roll front ore bodies in the nearby Gass Hills district and Crooks Gap district.

Siliceous volcanic rocks are also enriched in uranium and thorium relative to the more basic volcanic rocks, and thus form potential source rocks. A study carried out by Rosholt, Prinjana, and Noble (1971) on glassy and crystallized volcanic rocks of identical composition showed an apparent depletion of uranium in the crystallized rocks on the order of 20 to 70 percent. The loss of uranium was thought to have occurred in one of two ways: 1) as a volatile fluoride during cooling and crystallization, or 2) by groundwater leaching after crystallization. The thorium content remained the same. Volcanic glasses showed no depletion in uranium until the glass was devitrified. They estimated that with an average initial uranium content of 7 ppm uranium in glassy volcanic rocks, about 5 ppm or 5 grams of uranium per 1000 kg of rock would be lost to ground

water leaching upon devitrification and conversion of the volcanic glass to clay minerals and zeolites. This compares with the 20 grams per 1000 kg of rock leached from granitic rocks in the Granite Mountains, Wyoming area.

Host Rocks

Potential host rocks for supergene mineralization could theoretically include most rock types in the area. The important factor then in considering a host rock is its proximity to the source rocks, its permeability and porosity (favorability to the passage of supergene solutions) and a reduced chemical environment required to fix uranium.

Uranium will be leaching from overlying or adjacent source rocks under acid and/or oxidizing conditions, and will be precipitated in the first fractured or porous rocks of a reducing or non-oxidizing nature (Garrels and Christ, 1965, Figure 11-8). Such suitable host rocks include fractured and brecciated black slate; porous oxidized soft iron ore; vuggy, pyritic quartzite; diabase dikes, and shear zones and fractures in granites and gneisses. Unsuitable rock types include those at a distance from potential source rocks, as well as dense, poorly fractured and generally impermeable rocks such as most of the quartzites, gray-wackes and hard iron ores.

Time and Mode of the Mineralizing Process

The mineralizing process requires a period of tectonic activity which produces openings in brittle rocks, followed

by a period of intense chemical weathering. Two periods of tectonic activity are recognized (Klasner, 1972; Cannon, 1973; Van Schmus, 1976) in Michigan. The most intense of these is the Penokean Orogeny dated at 1.9 b.y. It included soft sediment deformation, the formation of slaty cleavage, block faulting of basement rocks, and fracturing of brittle sedimentary rocks. This period resulted in the formation of troughs and synclines within which the Middle Precambrian metasedimentary rocks are now preserved. The second period of deformation occurred during Keweenaw time (post-Freda?, Robertson, 1976), and includes fault movement along new and pre-existing lineations, and the intrusion of diabase dikes. Tectonic activity of this period resulted in the formation of the mid-continent rift, and later of the Lake Superior syncline, the Porcupine Mountains anticline and movement along the Keweenaw Fault.

Periods of weathering are indicated by the presence of conglomerates: quartz pebble conglomerates are interpreted to denote periods of intense chemical weathering, while polymictic conglomerates are thought to indicate less intense weathering conditions. Several polymictic conglomerates occur in the Lower Middle Precambrian section, and include the Reany Creek Formation, the Enchantment Lake Formation, the Fern Creek and the Palms Formations. Extensive quartz pebble conglomerates occur in the Goodrich Quartzite. No supergene radioactive occurrences have been associated with any of these periods of weathering, perhaps because suitable porous host rocks were lacking.

A poorly indurated quartz pebble conglomerate-sandstone occurs west of Lake Gobeic. It is believed by Hamblin (1975) to be of Middle Keweenawan age and may be a western extension of the Jacobsville Sandstone. The Jacobsville is a very thick sequence, in excess of 10,000 feet, of fluvial red-bed sandstones and siltstones. It represents the products of a long and extensive period of weathering. It is interesting to note that the vein deposits of the Beaverlodge, Saskatchewan area are found in Lower Precambrian gneisses and are overlain by the 1600-1800 m.y. old Martin Formation. In the Northern Territories of Australia, uranium occurs in metasedimentary rocks of Lower Proterozoic age, and are near or beneath the Middle Proterozoic sandstone.

The unconformity below the Jacobsville Sandstone, then may be of considerable importance. Hamblin (1961) has shown that for a very large area, the source of the Jacobsville Sandstone was an area underlain by Lower Precambrian gneisses and Middle Precambrian black slates which have relatively high background concentrations of uranium (Figure 5-2). Uranium carried in solution with the Jacobsville sands may have been deposited in and around faults, fractures and reduced zones beneath and within the Jacobsville Sandstone.

The age of the Jacobsville is still debated. If the sandstone is Cambrian in age, then the Middle Precambrian metasedimentary rocks could have been exposed to erosional processes for a maximum of 1400 m.y. If the conglomerate is Upper Precambrian, then the period is still in excess of

Figure 5-2 - Current directions of the Jacobsville Sandstone, modified from Hamblin, 1961.

600 m.y. This extensive period of erosion may have exposed and eroded supergene deposits which formed earlier in the erosional cycle.

More important in this consideration, is the very deep artesian system that could have been operative at this time and that may have formed the oxidized soft iron ores at this time. This circulation system is thought to have extended to a depth of 6000 feet.

"The Lake Superior Type Uranium Deposit"

The model "Lake Superior type uranium deposit" is a supergene concentration of uranium. Its occurrence is related to Middle Precambrian metasediments because of the ease with which uranium in black slates can be leached and reconcentrated. Thus the deposits may occur within the black slates or within the stratigraphically underlying oxidized iron formation. Less commonly, they may occur in other rock types spatially related to the black slates. These are thought to have formed during the extensive weathering period associated with the deposition of the Jacobsville Sandstone.

The model is termed the Lake Superior type in that its occurrence is related to the formation of the soft, oxidized, direct shipping iron ores of the Lake Superior region. Its occurrence, like that of the soft oxidized iron ores is restricted to zones of low regional metamorphism. It is believed that the higher metamorphism of the sediments resulted in an increase in grain size of all of the minerals

in the sediments, resulting in a decrease in permeability and a decrease in surface to volume ratio of the constituent grains.

Supergene concentrations of uranium are also found within granites and felsites. The source rocks in this case are the acid igneous rocks themselves. This type of occurrence is less prevalent in Michigan, perhaps due to the lower permeability of these rock types. However, the Felch area is of particular interest, in that three supergene concentrations of uranium are reported from one area known to have a regionally high background concentration of uranium. Perhaps the period of exposure and weathering in this area was longer, as indicated by the periods of non-deposition in Middle Precambrian time and the obvious faulting and shearing in the area may have served to increase the permeability of the granite gneisses. Another indication of uranium mobility in granitic terrain is the presence of anomalous concentrations of uranium in a peat bog in Marquette County. The uranium is thought to have been leached from the surrounding granites (Kinneman and Illsley, 1962).

Conclusions

In conclusion, the areas thought to have the highest potential for mineralization are those underlain by the black, pyritic slates of the upper Marquette Range Supergroup. Also important, but less widespread are the supergene occurrences in fractured granites and felsites. Future work should in-

clude a study of those graphitic, pyritic slates not yet known to contain concentrations of uranium. Middle Precambrian metasedimentary rocks surrounding the Lower Precambrian gneisses should also be investigated as possible hosts to supergene uranium leached from the granitic rocks, such as the occurrence at Rabbit Lake, Saskatchewan. In this case, fault zones and breccia zones would be of particular interest. The area underlain by the Jacobsville Sandstone is of utmost importance. Again, faulted and brecciated zones would be most favorable to possible uranium mineralization.

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PART III

SELECTED STRATIGRAPHIC RELATIONSHIPS,
PRECAMBRIAN ROCKS OF MICHIGAN

J. Kalliokoski

Keweenawan Sedimentary Rocks, MichiganGeneral

An interesting regional lithologic association is represented by the Copper Harbor Conglomerate, the Nonesuch Formation, and the Freda Formation, oldest to youngest (Plate 1).

The Copper Harbor Conglomerate (100-2,000 m thick) consists chiefly of red to brown arkosic conglomerate and sandstone, cemented with calcite and laumontite; most of its pebbles are of rhyolite, a few are of mafic lava, and other types are rare. Locally it contains interbedded groups of mafic and rhyolitic lava flows, and a very little red shale and volcanic ash (White and Wright, 1960). Near White Pine the conglomerate is predominantly a sandstone and siltstone (Hubbard, 1975). See this report, Part II, Table 2-4.

Above the conglomerate is the Nonesuch Formation (200 m thick). The contact is considered to demarkate the boundary between the Middle and Upper Keweenawan rocks (White, 1972). Near White Pine the Nonesuch is composed of thinly laminated siltstone and very fine to fine-grained sandstone. The rocks are moderate to dark gray, dark greenish gray, grayish red, and reddish brown. The finest rocks are the darkest and grayest (Hubbard, 1975). The Nonesuch Formation has been described from drill core by White and Wright (1966). The "lower parting shale" was found to contain remarkably well preserved organic matter, including spore-like bodies in various stages of degradation, and other micro-organisms

that resemble morphologically bacteria, actinomycetes, or fungi (Moore, Moore, and Spinner, 1969).

The third formation of interest is the Freda Formation (3,660 m thick) described as crossbedded, moderately well sorted sandstone and coarse siltstone interbedded with massive to laminated siltstone. In the west nearly half of the Freda is siltstone and very fine to fine-grained sandstone. Near White Pine an extensive layer of sandy conglomerate occurs about 500 to 800 feet above the base of the Freda Formation (Hubbard, 1975).

Mineralization

As noted by White and Wright (1966), the lower part of the Nonesuch Formation contains a few percent of sulfides, either as copper sulfides, or as pyrite. The work of both White (1972) and Brown (1972) favor the hypothesis that the copper mineralization in the basal Nonesuch could have been accomplished by the introduction of copper-bearing connate waters from the underlying Copper Harbor Conglomerate soon after deposition of the Nonesuch Formation.

White and Wright (1950) estimate the uranium content of the Nonesuch Formation to be 0.001-0.003 eU₃O₈. In a reconnaissance study of typical samples of Keweenawan rocks and minerals, White found no anomalous radioactivity (1950).

These are the only studies made on the uranium content of these rocks. Despite the discouraging results, it seems to me that a more thorough study of these three formations should be made: the two sandstones have sufficient perme-

ability to have permitted the movement of uraniferous solutions in late Keweenawan time, and the Nonesuch Formation contains sufficient sulfide and organic matter to have precipitated such uranium from solution. Quite possibly the rocks near the upper and lower contacts of the Nonesuch Formation were not checked systematically for uranium during copper explorations. In that these formations are regional in extent, a regional evaluation of these rocks would seem to be warranted.

In a paper given at the 1974 IAEA uranium symposium, Adler classified sandstone-type deposits on the basis of whether the reductant responsible for uranium precipitation was inherently incorporated in the sandstone during sedimentation as plant debris (Colorado Plateau and Wyoming) or was later introduced from an external source in the form of humic acid or hydrogen sulfide (Grants). This introduced organic matter is thought to have been derived from decaying vegetation in bogs and swamps overlying near-surface projection of uranium host rocks (Adler, 1975).

It is not at all certain that the hydrologic conditions in Upper Keweenawan time were such as to permit the production and downward percolation of humic acids into the Copper Harbor Conglomerate. Thus for uranium precipitation I would propose the model utilizing the inherent reductants in the Nonesuch Formation.

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Jacobsville Sandstone

General

This formation is named for its exposures near Jacobsville on Keweenaw Bay, where it was quarried for many years as a building stone. It underlies a very large area between Ironwood on the west and Huron Bay on the east, and extends even farther east as a narrow strip along the Lake Superior shoreline (Figure III-1). Its total areal extent on land is in excess of 1000 square miles. As noted also by Carol Johnson in her section of this report, this sandstone is intriguing because it is a red-bed continental sediment, and particularly, because it bears some resemblance to the Lake Athabasca Sandstone of northern Saskatchewan, below which occur some important uranium deposits.

Stratigraphic Positions and Age

Stratigraphic relationships establish that the Jacobsville Sandstone is younger than the South Range traps (Powder Mills Group of Hubbard, 1975), that is, post-Lower Keweenawan. No one has found any dikes cutting the sandstone anywhere. From more regional considerations many workers assign this formation to the Upper Keweenawan Bayfield Group (for example, White, 1966, p. 28). I favor such a point of view. However, others such as Dorr and Eschman (1973) assign the sandstone to the Cambrian, mainly on lithologic grounds, as does Hamblin who did the most comprehensive study

Figure III-1 - Map, showing thickness in feet of Jacobsville Sandstone, from geophysical estimates and drill holes; location of diamond drill holes.

of it (1958, 1961). Hubbard (1968) noted that the stratigraphy allows for more complex interpretations of age relationships, as does Babcock (1975, 1976).

Some outcrops in the eastern part of its extent show the sandstone to rest on an irregular erosion surface on which there has developed a paleosol (Hamblin, 1958; Kalliokoski, 1975). This means that the deposition of the Jacobsville Sandstone was preceded by a period during which the land surface had been sufficiently elevated to allow the development on granite of a 27-foot soil profile, prior to compaction (Kalliokoski, 1975). Such deep weathering must have been accompanied by the introduction of large quantities of elements into the water table. Ancient soil profiles are encountered also in some drill core from near Lake Gogebic.

The Jacobsville Sandstone forms a wedge that dips and thickens northwest (Figure III-2), with the basal unconformity exposed on the southern and eastern side. Geophysical studies suggest that near Ironwood the basal contact dips about 18 degrees northerly (Hubbard, 1975, p. 536). Regionally the northwestern limit coincides with the Keweenaw Fault. DeGraff has indicated that near Lac LaBelle, not too far from Keweenaw Bay, the structural relationships are quite complex (1976).

Thickness

The Jacobsville Sandstone is exposed best near Keweenaw Bay where it forms a series of low outcrops and cliffs.

Figure III-2 - North-south geological section of
Jacobsville Sandstone, T47N, R43W.

However, because of the flat dips, these outcrops probably represent a total thickness of only a few hundred feet of strata. At Victoria Falls, on the northwest side of the basin, 692 feet have been measured (Hamblin, 1958, p. 42). By contrast, the thickness of the sandstone is known to be in excess of 2,800 feet from a drill hole in T47N, R43W, and of 3,600 feet in T55N, R32W. Bacon has noted (1966) that geophysical data can be interpreted to show the presence of 10,000 feet of sandstone some $2\frac{1}{2}$ miles from the Keweenaw Fault, and Aho has confirmed the data (1969). Recent geophysical work by King (1975) suggests the presence of 7,000-8,000 feet of nonmagnetic rock south of the Keweenaw Fault near Ironwood. All of this data is plotted in Figure III-1.

Description of Facies

Five facies can be recognized in the Jacobsville Sandstone. Four were identified previously by Hamblin (1958): conglomerate, lenticular sandstone, massive sandstone, and red siltstone.

The conglomerate is basal, commonly thickest in channels in the floor. Thicknesses of 15 feet are exceptional, except where it is interbedded with sandstone, when the total thickness can exceed 100 feet. Hamblin (1958, p. 31) records about 500 feet of vertically dipping interbedded sequence of sandstone and conglomerate in the Wall Ravine near Laurium. Regionally the remainder of the pebbles con-

sist of material from locally occurring older rocks such as quartzite, iron formation, dolomite, felsite, and granite. Another conglomerate facies is described in a later section.

The lenticular sandstone facies is dominant in the Jacobsville formation west of Huron Bay, both from the standpoint of lateral distribution and vertical extent. This facies is a red to reddish-brown, medium-grained fluvial sandstone, characterized by lenticular bedding, and a conspicuous white or creamy mottling (Hamblin, 1955).

The spots are from round to oval in shape, and up to 10 cm in diameter. In many places they are accompanied by a similar bleaching of the red color along bedding surfaces, across thicknesses of several tens of centimeters and lengths of several meters. According to L. L. Babcock of the Institute of Mineral Research (pers. comm.) these spots contain slightly higher concentrations of any or each of iron, manganese, vanadium, and chromium. Each bleached spot is centered on a dark speck that Babcock says contains roscoelite, a vanadium mica. He suggests that the mobile metal elements may have been derived from accessory magnetite in the sandstone. Obviously the iron has undergone a change in oxidation state during this alteration.

The term "massive sandstone facies" is applied to the part of the Jacobsville formation that is distinguished by massive and relatively persistent bedding, such as at Jacobsville and at Victoria Falls. The individual beds may

average 5 feet in thickness. The color of the rock is light shades of red, reddish-brown, pink or white. The facies is perhaps lacustrine, and also perhaps stratigraphically above the lenticular sandstone facies (Hamblin, 1955).

Red siltstone facies is exposed in cliffs east of Marquette (Hamblin, 1955). Similar siltstone-shale beds are interbedded with the "lenticular sandstone facies".

A fifth facies, also a conglomerate, can be recognized. Because its distinctive characteristics and possibly restricted distribution are not generally known, this facies will be described in the next section.

Western Conglomerate Facies

A distinctive sequence of reddish-brown to brownish-gray or light gray quartz pebble conglomerate and quartz rich sandstones comprise the entire Jacobsville Sandstone sequence in the area west of Lake Gogebic, and has also been intersected in one drill hole near Alston, about 15 miles east of Lake Gogebic (AE1, Figure III-1). Hubbard (1975) notes that this sandstone outcrops on Jackson Creek in the southern part of the Thomaston 15-minute quadrangle, where it also shows evidence of folding. The best information regarding the thickness of this unit comes from

drill core that is stored at the U. S. Bureau of Mines Twin Cities Storage Library. This core is available for public inspection.¹

Trent (1973) has presented a brief but accurate description of the conglomerate that was provided to him by W. S. White. The rock intersected in drill core is a "reddish-brown to brown quartz pebble conglomerate with interbeds of medium to coarse grained quartz pebble sandstone; sub-angular to well rounded quartz pebbles predominate, and average 1/4 to 2 inches (5-30 mm) in diameter; local zones of abundant quartz pebbles 30-40 mm in diameter; pebbles of iron formation, dolomite, and other pre-Keweenaw rocks common....."

In places the sandstone, instead of being quartzose, is feldspar-rich, with about 20 percent 1 to 4 mm, sparkling, pink feldspar grains, along with flakes of almost black chlorite and biotite. There are also sporadic interbeds of red shale and siltstone, one foot to four feet thick, and in core TT6 there is a nine-foot thickness of reddish-brown sandstone at 1200 feet, similar to the more typical Jacobsville Sandstone.

¹ Hole	Sec.	Twp.	Rg.	Depth Ft.	Owner
TT 1	5	47N	43W	1303	Keweenaw Land Association
TT 2	5	47N	43W		Keweenaw Land Association
TT 3	5	47N	43W	484	Keweenaw Land Association
TT 4	9	47N	43W	478	Keweenaw Land Association
TT 5	9	47N	43W	460	Keweenaw Land Association
TT 6	33	48N	43W	2845	Keweenaw Land Association
TT 7	27	48N	46W	567	Keweenaw Land Association
AE 1	35	48N	40W	2467	Bear Creek Mining Company

The western facies probably underlies the more normal Jacobsville Sandstone. In the drill hole near Alston (AE 1), the top 2190 feet is the typical red Jacobsville Sandstone, as noted by Johnson and White (1969). This is underlain by about 100 feet of very poorly cemented brownish quartz and quartzite pebble conglomerate, quite similar to that intersected in holes farther to the west. The base of the conglomerate is poorly defined in that it rests on weathered basalt, and some of the weathered material has become incorporated in the conglomerate, perhaps during interstratal solution.

Quite possibly the "western conglomerate facies" is a correlative of Hamblin's "conglomerate facies"; both have an abundance of locally derived pebbles, many of which are of vein quartz, or quartzite, denoting derivation from a weathered source area. The main difference is one of thickness. Perhaps this denotes that at the time of the deposition of the conglomerate the western portion of the Jacobsville basin was depressed at a more rapid rate than the eastern.

Mineralization and Alteration

I logged all of the core from hole TT 6, and parts of the other cores, and checked all cores for radioactivity, but could not detect any unusual radioactivity.

The only positive information on the occurrence of uranium in the Jacobsville Sandstone comes from the work of

Kinneman and Illsley (1962) who found anomalous concentrations of uranium in well water at Buckroe, Michigan. This data is discussed in another section of this report (Part V).

There is some information on other kinds of epigenetic mineralization in the Jacobsville Sandstone. In drill core TT 7, I found green copper staining on the surface of two quartz pebbles, one at 388 feet and the other at 392 feet. Babcock (pers. comm.) has noted the occurrence of barite concretions and of barite veinlets in widely separated localities at Point Abbay, and south of there traces of chalcocite have been reported from a narrow fissure along which has been driven a short adit.

The predominant red color of sandstones and conglomerates denotes the existence of a high oxidation state in the rocks, and an absence of alteration. The cream-colored spots and alteration zones along bedding denote the possible loss of the hematite during local reduction.

The basal "western conglomerate facies" is distinctive because of its gray color and the local weak cementation of its pebble. Both the color and the condition of cementation may be the result of alteration.

There is no record anywhere, in what little information we have, of the occurrence of pyrite, nor of pseudomorphs or molds after pyrite.

One could expect organic matter to occur in rocks of this age in that at the White Pine Mine the Nonesuch Shale has been found to contain an abundance of spores and filamentous

organic forms (Moore, et al, 1969), clear evidence of the existence of plant life in Keweenawan time. Thus, even if the Jacobsville Sandstone were Keweenawan, and not Cambrian, some beds in it could be expected to contain organic matter if the beds had been formed under appropriate geological conditions.

Conclusions

What limited data there is on the subject, none of it shows the Jacobsville Sandstone to contain reducants capable of precipitating uranium. However, the scarcity of data warrants emphasis.

By contrast, Middle Precambrian carbonaceous and pyritic sedimentary rocks underlie parts of the sandstone. These rocks would be capable of providing the chemical environment necessary for uranium deposition.

Lower Keweenawan lavas are much more extensive below the Jacobsville Sandstone than are the Middle Precambrian sedimentary rocks. Where pyritic, these lavas may also provide a favorable depositional environment.

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PART IV

MODE OF OCCURRENCE OF URANIUM AND THORIUM
IN PRECAMBRIAN ROCKS OF WISCONSIN

J. Kalliokoski

Chapter 1

FEATURES OF THE GEOLOGY OF PRECAMBRIAN ROCKS OF WISCONSIN

Middle Member, Waupee Formation (1,850-1,950 m.y.)

As noted in Part I, sedimentary rocks of this general age are rare in Wisconsin. In order to assess one such sedimentary rock sequence for its uranium potential, I visited several outcrops of the middle member of the Waupee Formation, along a line extending a thousand feet north from the NE Cor. Sec. 12, T31N, R16E, near Mountain, Wisconsin.

Lahr (1972) describes the Waupee Formation to consist of three members: 1) the basal member, mainly basalt, now metamorphosed to amphibolite, but with some felsic metasedimentary layers, 2) the middle member, composed primarily of metamorphosed feldspathic and quartzose sedimentary rocks, with subordinate amounts of volcanic flows and volcanoclastic sedimentary rocks, and 3) the upper member, characterized by a distinctive sequence of thinly laminated metamorphosed tuffaceous rocks.

The outcrops of the middle member that I visited consist entirely of felsic to intermediate metavolcanic rocks (Figure IV-1). The most northern outcrop is of flow-banded felsic lava, cut by a series of northwest-trending metabasite dikes ranging in thickness from about 50 cm to 2 meters. As Lahr's description intimates, the Waupee Formation is essentially volcanogenic.

Middle Precambrian Quartzites (1,800(?) - 1,500(?) m.y.)

Areas of flat-lying to steeply-folded quartzites and quartz-pebble conglomerates with minor shale and limestone are widespread in the north-central states (Figure IV-2) (Dott and Dalziel, 1972). In Wisconsin the occurrences in

Figure IV-2 - Distribution of possible 1,800-1,500 m.y. quartzites and quartz-pebble conglomerates near Lake Superior.

question include the Baraboo, Waterloo, and Barron Quartzites and the McCaslin Formation, in the Michigan-Wisconsin border the "Lower Keweenaw" or Bessemer Quartzite, in Minnesota the Sioux Quartzites, and in Minnesota-Ontario Border the

Figure IV-1 - Interlayered, flowbanded felsic (left) and intermediate volcanic rocks (center and right), Middle Member, Waupee Formation, about 500 feet north of NE Cor. Sec. 12, T31N, R16E.

Sibley-Puckqunge Quartzite. Everywhere these rocks appear to rest on a mature erosion surface, whether of local or of regional extent, and the Barron Quartzite is said to overlie paleosols at many localities.

Other than their predominant mature quartzite lithology, and their sedimentary facies that denotes original accumulation on a subsiding shallow-water continental shelf, there is no strong evidence to warrant correlating some or all of these occurrences. As to their chronostratigraphic age, Hubbard (1972) assigns the Bessemer Quartzite, and Craddock (1972; Figure IV-2) assigns several of the other formations to the Lower Keweenawan. They may be correct; certainly these rocks indicate a change in paleogeologic conditions from those represented by the older, less mature sedimentary rocks.

The older age limit to these quartzites is based on the fact that the Baraboo Quartzite rests on 1,800 m.y. rhyolite and the younger limit is derived from the age of a pegmatite that cuts the Waterloo Quartzite and from the Hager Quartz porphyry body of the 1,500 m.y. old Wolf River Batholith that intrudes the McCaslin Formation (Van Schmus, et al., 1975b).

It is worth repeating here that at, for example, Baraboo (Dalziel et al., 1970) and at McCaslin Mountain (Mancuso, 1960) the quartzites are folded and faulted, denoting an orogeny at least as young as post-1,800 m.y., distinctly younger than the Penokean Orogeny, and involving shelf sediments rather than more geosynclinal sedimentary and volcanic rocks.

The McCaslin Formation has attracted considerable interest as a potential source for uranium because of the reported discovery of uraniferous conglomerate on McCaslin Mountain. The reader is referred to the following chapter of this report for a fuller discussion of this formation.

Middle Precambrian Plutonic Rocks (1,500 m.y.)

Of particular interest to this study are the Wolf River Batholith and the Wausau Syenite Complex described recently by Medaris and others (1975), Van Schmus and others (1975), and by Myers (1973a,b), and dated at 1,500 m.y. (Maps 2,3). The batholith is a large anorogenic plutonic complex, similar lithologically to the rapakivi massifs of Finland. The most abundant rock type is quartz monzonite, separable into three major lithologic bodies. Other types include syenite, granite, quartz and feldspar porphyries, monzonite, and anorthosite.

The Red River Porphyritic Quartz Monzonite phase occurs as a northeast trending body about 15 km wide and more than 50 km long. Except for one, all of the significant, verified uranium occurrences known from Wisconsin, occur within this body, clustered along the northwest and southeast margins (Map 2). Malan and Sterling refer to parts of this granite in their observations that: "the uranium content in sparse sampling of a quartz monzonite....is much greater than in any Precambrian plutonic rocks that have been sampled in the southwestern United States....or similar rocks that have been sampled in the west-central and northwestern United

States (1969). It is not known how the uranium content of the Red River Quartz Monzonite compares with the uranium abundances in the other units of the Wolf River Batholith.

The Red River Porphyritic Quartz Monzonite contains fewer phenocrysts in porportion to matrix, and angular, rather than ovoidal, alkali feldspar phenocrysts, in comparison to the two other quartz monzonite units; phenocrysts: matrix ratio of 20:80; planar fabric due to alignment of phenocrysts. Feldspar phenocrysts occur (0.5 to 2.0 cm) in medium grained matrix of idiomorphic to anhedral quartz, feldspar (plagioclase predominant), and biotite, with amphibole locally present. Rapakivi texture is present but not conspicuous (Maderis, et al., 1973; Van Schmus, et al., 1975a).

In the vicinity of the radioactive localities, on both the northwest and southeast margins of the body, several features are common. Most localities show small areas, probably inclusion, of fine to medium grained white to light gray quartz-feldspar gneiss or of amphibolite, or biotite-rich granite. Small pegmatite lenses, centimeters in width and meters in length, with either sharp or gradational contacts are common. Some of these pegmatites occur along or near the contact of the light colored quartz-feldspar gneiss inclusions. Perhaps the inclusions released water to the magma, and hence the granitic intrusion crystallized to pegmatite. Quartz veinlets are rare, and no evidence was seen of hydrothermal alteration nor of greisenization.

Residual Soil

One important geological feature of central Wisconsin geology, bearing on uranium occurrences, is the occurrence of residual soil. Vickers (1955) mentions these from west of Wausau as containing nodules of thorogummite.

A granite rubble has been quarried near Wausau for gravel, and I have seen similar material undoubtedly of post-glacial age, developed on the Red River Quartz Monzonite at several places (Figure IV-3). In some respects the presence of such rubble is not surprising, because these rocks do show rapakivi affinities, and one is reminded that the name "rapakivi" (meaning "weathered rock") was assigned in Finland to a variety of granite that shows conspicuous evidence for post-glacial weathering.

From the view point of uranium metallogeny, such regoliths could have developed at any time since the unroofing of the granite, and because of their high permeability, would have lost uranium to surface water quite readily (Figure IV-4). This may be a contributing factor for the occurrence of numerous small supergene uranium showings in this particular granite body.

Figure IV-3 - Red River quartz monzonite disaggregating to a rubble regolith (above the pencil) near the Sec. 15 radioactive locality, Tigerton Dells.

Figure IV-4 - Schematic diagram of uranium weathering in a uraniferous granite.

Mylonite Zones

The dominant structural features in Marathon County are shear zones (LaBerge and Myers, 1973). The major zones comprise a wide variety of sheared rocks, including gneisses, schists, and mylonites. A conspicuous mylonite zone is the N30°E Eau Claire River zone which parallels, and in places coincides with the west margin of the Wolf River Batholith, specifically in contact with the Wolf River Granite and Quartz Monzonite body (Maps 2,3).

The mylonite zones are interesting when one considers them in the light of the major geological features of the Beaverlodge area of Saskatchewan. According to the hydrothermal point of view these features include a major struc-

ture (Saint Louis fault) from which the ore-bearing minor faults arise, a complex of uranium-rich metamorphic and granitic rocks, and younger granites from which hydrothermal solutions may have arisen. The supergene point of view seems to consider the fault zones as conduits for downward percolating waters, and some pitchblende ore bodies appear to be situated near the major fault for stratigraphic rather than structural reasons. The problem remains unresolved.

Two of the above regional components can be recognized in Wisconsin: the major fault and uraniferous granite. However, we do not know whether the Wolf River Granite, the body that adjoins the mylonite zone, shows the same high uranium content as does the Red River Quartz Monzonite.

Chapter 2

URANIUM AND THORIUM OCCURRENCES IN WISCONSIN

Introduction

As in Michigan, all of the showings for which records exist are small, consisting of natural exposures or of small pits. These localities are plotted on the accompanying maps (Maps 2,3) and are described in the following pages. Each was visited and described by Hare in 1956 (open file reports). I visited these localities in 1975-76.

Occurrences in Archean(?) Gneiss

Only one uranium occurrence is presently known from possible Archean gneisses in Wisconsin.

Black River

E. H. Hare, Jr. records in 1956 that Edward and Bruno Pawlowicz found a radioactive occurrence on the south bank of the Black River, NE Cor. NW $\frac{1}{4}$, Sec. 32, T29N, R2W, just west of Withie, in Clark County.

The older group of rocks along the shore are a steeply dipping sequence of biotite and hornblende quartz-plagioclase gneiss, biotite granite gneiss, fine-grained amphibolite, and fine-grained, foliated, uniform, pinkish aplite (Figure IV-5).

Figure IV-5 - Outcrops of Precambrian gneiss overlain by sandstone on Black River, near Withie, Clark County.

These are overlain unconformably by flat-lying Cambrian(?) sedimentary rocks. A crossbedded sandstone outcrops about 10 feet higher on the river bluff in the mapped area.

I found the radioactivity to be very low throughout the outcrops, nowhere exceeding 0.02 mR/hr. Hare describes the uranium mineralization to be concentrated in a biotite-rich, quartzofeldspathic segregation in gneiss at a point where the bedrock had been followed into the riverbank silts, by digging. A sample of this mineralization, analyzed by the U.S.G.S., showed 0.111 percent U_3O_8 . I could not find this precise locality.

Occurrences in the Red River Quartz Monzonite

Fred Anklaam Farm

The occurrence is situated on a granite ridge, in NE $\frac{1}{4}$, Sec. 26, T25N, R12E (No. W-1). Access is through the farm-yard of Mr. Fred Anklaam, and the showings are on land owned by a Mr. Hoigard who enjoys his privacy. The original work was done by G. Friedrich and G. Koskowski (Hare, 1956).

The granitic rocks in this area are important in that Malan and Sterling (1969) report that a composite sample of granitic country rocks (away from prospect pits) in the vicinity of the Anklaam Farm gives the following analyses:

Sp. No.	eThO ₂	eU ₃ O ₈	eK
295	61.4	26.7	4.87
295A	93.1	104.7	5.83

They conclude that "the uranium content in sparse sampling of a quartz monzonite....is much greater than in any Precambrian plutonic rocks that have been sampled in the southwestern United States....or similar rocks that have been sampled in the west central and northwestern United States".

An earlier report by King (1960) indicates nothing suggestive of economic value on the property itself.

At this uranium locality the country rocks consist of several varieties of granite (Figure IV-6). Along the

Figure IV-6 - Outcrop maps of Fred Anklam farm occurrence, near Big Falls (Loc. W-1).

explored zones, and to the north, the rock is a coarse-grained pink biotite granite, with pink feldspar phenocrysts ranging from 1 to 10 cm, and 10-15 percent biotite (Figure IV-7). Locally along the explored zone the granite is pegmatitic across a few inches (Figure IV-8). About 50 feet north of the zone it is medium to coarse grained but not porphyritic.

E. H. Hare, Jr. reports there to be a fine-grained gray granite with up to 2 percent purple fluorite along the explored zone. I did not recognize this variety here, but did note trace quantities of fluorite in pegmatite.

Figure IV-7 - Porphyritic Red River
quartz monzonite, northeast of pits,
Fred Anklam farm.

Figure IV-8 - Medium-grained and pegmatitic Red River quartz monzonite, west of explored zone, Fred Anklam farm.

The general background radiation is about 0.035 mR/hr, with no consistent difference between the granitic and aplitic phases. However, pegmatitic zones are more radioactive, 0.04 to 0.04 mR/hr.

Highest bedrock radioactivity is associated with a discontinuous set of fractures or joints, apparent also from the shape of the pits. The highest readings in bedrock (0.07 mR/hr) are from the central part of Pit 2 where an east-west contact between pegmatite and fine-grained granite is offset about 10 cm along two northeast-trending fractures (Figure IV-9). In the westernmost rock pile the most radioactive blocks (0.2 mR/hr) are fine grained granite pegmatite and show very fine lines of cataclasis, with a dark silicate mineral, possibly biotite, along the fractures (Figure IV-9b).

Radies Shaft

This occurrence (No. W-12) is situated about 1200 feet due east of the school at Big Falls, in the north-central part of Sec. 26, T25N, R12E (Map 2), on the Radies farm. The original discovery was made in 1956.

The host rocks consist of fine-grained gray biotite granite gneiss, red biotite granite, and granite pegmatite (Figure IV-10a). The fine-grained gray gneiss is probably the original country rock. Some blocks of it in the dump shows hairline black veinlets along which the gneiss has become reddened for up to one cm.

Figure IV-10 - Outcrop maps of uranium showings on Radies farm near Big Falls; a Radies Shaft (Loc. W-12); B, "Radies farm" (Loc. W-4).

Figure IV-9 - Contact between pegmatite (below pencil point) and fine-grained granite (above pencil point) offset along fractures (parallel to pencil). Fred Anklam farm.

Figure IV-9b - Fractures containing a dark mineral, in radioactive granite, Fred Anklam farm. Scale in cm.

The pit is 15 feet deep, but flooded, so that only about 4 feet of the walls are exposed. There are conspicuous close-spaced, vertical joints in the northwest corner of the pit. The general background radiation is 0.05 to 0.06 mR/hr., with the highest readings of 0.09 mR/hr recorded in the fractured zone. No radioactive minerals could be identified.

I was shown a small sample, 2-3 inches in greatest dimension, of the mineralized material by Mr. T. R. Steinbach. The material consists of a dark substance, possibly finely matted fine-grained biotite, in which are set 1 mm grains of quartz. This sample recorded 0.13 mR/hr.

In a report E. H. Hare, Jr. quotes Mr. Radies that "the greatest concentrations of uranium are associated with the rich black (biotite) pockets within the red granite itself. There is no definite pattern of occurrences of these pockets within the granite. The size of these rich pockets are usually less than one foot in diameter. Mr. Radies has thus far found only a few of the highly radioactive black rock samples....". One such sample showed 0.25 percent U_3O_8 and 0.24 percent eU_3O_8 , according to an A.E.C. chemical analysis. The radioactive disseminated mineral has been identified by x-ray analysis as uraninite (Barrett, 1955, open file report).

Radies Farm

This locality (No. W-4) occurs in southeast part of Sec. 28, T25N, R12E, about 400 feet north of Radies barn.

The host rock is a uniform, coarse-grained pink hornblende granite, with 2 cm feldspar phenocrysts (Figure IV-10b). The granite is cut by small aplite dikes. Radioactivity ranges between 0.05 and 0.1 mR/hr. Hare records radioactivity up to four times background in the southeast corner of the pit, and also that some core drilling, prior to September, 1956, disclosed nothing significant.

"F and K Claims"

Some pits have been blasted into an east-west ridge of granite that crosses County Highway 5 about 1/10 mile north of a small creek (No. W-3). The pits are in SW $\frac{1}{4}$, Sec. 17, and NE $\frac{1}{4}$ Sec. 20, T25N, R13E (Map 2). In 1956-57 the property had been leased to George Friedrich and Henry Kaskowski.

To the east of the road the rock is a coarse grained hornblende granite, containing locally xenoliths of amphibolite that range up to 15 feet in length (Figure IV-11a). As noted by E. H. Hare the abundance of accessory hornblende in the granite is due probably to the assimilation of the amphibolite masses by granite. The south-central part of the outcrop has a small pegmatite, and the northeastern part is cut by a narrow shear zone. There are two sets of joints: northwest in the eastern pit and northeast in the western. The pit on the north side of the outcrop, similar

Figure IV-11 - Outcrop maps of uranium occurrences on "F and K Claims" (Loc. W-3); a, east of road; b, west of road.

to some others in this vicinity, is of much older vintage, perhaps excavated near the turn of the century for road metal.

The general level of radioactivity is 0.05 mR/hr in the western part of the outcrop, where the rocks are fresh and it decreases to 0.025 mR/hr to the east of the mapped portion where the granite has weathered to a gravelly rubble. The pegmatite pod shows 0.035 mR/hr.

The highest readings occur at the contact of hornblende granite with amphibolite. A folded schieren, the size of a horse shoe, shows 0.07 mR/hr (Figure IV-12). It seems to me that the main control for radioactivity has been the intersection of such amphibolite/granite contacts by vertical joints. The uranium mineralization is probably supergene.

The outcrops on the west side of the road shows a greater variety of rocks (Figure IV-11b). The oldest is a white, fine-grained hornblende granite gneiss that has been intruded by pink, non-foliated coarse grained hornblende granite. The white gneiss contains a few quartz veins, that are unusual for their rareness. In places the coarse grained facies is porphyritic, with up to 5 cm phenocrysts, some mantled, and elsewhere it shows pegmatitic zones. At the south edge of the outcrop it is cut by a pegmatite dike that grades from graphic granite in the east to typical pegmatite to the west. The granite is cut also by a set of northwest joints.

Figure IV-12 - Somewhat radioactive, curved amphibolite schlieren, "F and K Claims".

The general level of radioactivity is 0.02 mR/hr for the white phase, and a maximum of 0.07 mR/hr for hornblende granite on the west wall of the pit. Hare reports chemical analyses up to 0.25% U_3O_8 on material from the pit.

The pit has followed the northwest joints. Along one of these joints is a yellowish brown alteration zone, a few cm in width, perhaps caused by the oxidation of pyrite.

According to Hare's 1957 report, radioactivity is confined to a 14-16 inch zone characterized by large hornblende crystals, and associated with a pod of perthite-quartz pegmatite. The zone extends to within a foot of the surface, and the alteration zone noted above forms the upper boundary of the hornblende zone. Hare also noted in the pit bottom, now flooded, a chalcedonic vein that weathers red to yellow, and that shows altered hornblende along the walls over a width of a foot. Perhaps also this alteration was due to the oxidation of pyrite. Uranium would be mobile in the presence of such oxidizing pyrite. Thus, some of the higher-grade material may have been formed by the accumulation of such mobile uranium in chloritized hornblende.

Marion Baseball Park

A small pit (No. W-5) was blasted on a long outcrop of coarse grained pink granite on the north edge of the Marion baseball park (Sec. 2, T25N, R13E) by Wes Mattes in 1956 (Map 2). The general level of radioactivity everywhere on this outcrop is 0.03 mR/hr.

Hare described and presented a sketch map of a second uranium occurrence from near Marion "about 1.6 miles east of the junction of U.S. Hwy. 45 and Co. Hwy. G; in the town of Marion. Turn north off of U.S. Hwy. 45 onto a dirt road that is a couple of hundred feet east of a large gravel pit (also on the north side of the road). Follow the dirt trail northward over the large hill to a stream. The area investigated is where the stream makes a sudden right angle turn from flowing southwest to flowing eastward" (open file report). I could not find the locality, nor could Mr. Wes Mattes of Marion help me on this. Contrary to Hare's report, someone other than Mattes must have worked at this showing.

Tigerton Dells - Sec. 10/15

A prospect pit (W-7) occurs about 1/4 mile east of the Tigerton Dells Tavern, and 500 feet north of Co. Hwy. M, within a few feet of the Section Line between Sec. 10/15, T26N, R12E, near the SE corner of Sec. 10, Shewano County (Map 2). The showing was discovered in 1955 by Wes Mattes of Marion who leased it to Claude and James Pearson of Wisconsin Rapids.

The main rock types (Figure IV-13) are a white, fine-grained biotite granite, intruded by granite pegmatite (Figure IV-14) and probably by coarse-grained red biotite granite, the main rock type (Figure IV-15). On the north

Figure IV-13 - Outcrop map of uranothorite locality, Sec. 10/15, Tigerton Dells (Loc. W-7).

side of the pit the reddish and grayish granite varieties are interlayered indistinctly. The pegmatitic zone trends slightly north of west, and along it the granite contains up to 20 percent biotite. The pegmatite consists of quartz, muscovite, and plagioclase, with accessory hornblende altered to varying degrees to chlorite, and minor fluorite.

The general background radioactivity is 0.04 mR/hr, with the highest readings on a block in the dump of 0.07 mR/hr. A letter from L. P. Barrett to Wesley Mattes, 9-27-55, states that the A.E.C. found a sample from here to contain 1.00 percent eU_3O_8 and 0.094 percent U_3O_8 , and hence that the radioactive mineral may be uranothorite.

The main control for radioactivity may have been the intersection of the pegmatite and biotite granite contact

by northwest trending close space joints. However, because of the presence of uranothorite the locality is shown on Map 2 to have a preimary magmatic rather than a supergene mode of origin.

Tigerton Dells - Sec. 15

Two pits (No. W-2) occur in NE Sec. 15, T26N, R12E in Shewano County. They can be reached by a dirt road that turns south about 300 feet west of Tigerton Dells Tavern, on Co. Hwy. M (Map 2). Wesley Mattes says that he discovered both localities.

The first pit is about 900 feet south of Co. Hwy. M (Figure IV-16a). The rocks consist of fine-grained gray biotite granodiorite, intruded and bounded by coarse-grained pink biotite granite. Along the contact in the west end of the pit is a granite pegmatite, 30 cm thick and perhaps 3 meters in length. The highest radioactivity in the pit is 0.06 mR/hr.

The conspicuous geological features are a few widely spaced northwesterly joints that intersect the pegmatite/gray gneiss contact, and a slight reddening of the gray gneiss along tiny fractures.

The second pit is about 700 feet east-southeast from the first (Figure IV-16b). The geology is similar. A one-meter band of fine-grained white rock, interpreted to be country rock (but possibly white aplite) is bounded on one side by coarse-grained biotite granite and on the other

Figure IV-14 - Granite pegmatite in contact with fine-grained white biotite granites (upper left of photograph) uranothorite locality, Sec. 10/15, Tigerton Dells.

Figure IV-15 - Coarse-grained granite with pegmatite showing gradational contacts, near uran-othorite locality, Sec. 10/15, Tigerton Dells.

Figure 16 - Outcrop maps of radioactive localities, Sec. 15, Tigerton Dells. Locality B is about 700 feet east-southeast of A (Loc. W-2).

by a curved pegmatite. A few joints cut the contact. The general background radioactivity is 0.04 mR/hr, with 0.12 mR/hr on a point of rock protruding into the pit on the west side.

Thorium in the Wausau Syenite Complex

Many attempts have been made to exploit the zircon-bearing pegmatites reported in the NW¼ Sec. 22, T29N, R6E, about six miles west of Wausau (Map 2). The rocks in the area are syenite and nepheline syenite that have intruded an older Precambrian terrain. About 3,100 pounds of float containing about 25 percent zircon was obtained from rock piles during the 1920's. During World War II interest was revived and about 7 tons of zircon-bearing rock was mined from shallow open pits and shipped to Philadelphia for beneficiation tests and chemical analysis.

During 1946 a magnetic and resistivity study, together with diamond drilling, trenching, and soil sampling, was conducted by the U. S. Bureau of Mines in the areas of zircon-bearing pegmatites in the NW¼ Sec. 22. No zircon-bearing rock of grade comparable to that present as float in the area was found.

In 1953 both airborne and ground reconnaissance was done in Secs. 9-11, 14-16, 21-23, 26-28, and 12 radioactive mineral localities were found. Thorium-bearing zircon¹

¹Cyrtolite, less than 0.05 percent U_2O_3 , less than 0.05 percent ThO_2 .

pegmatite float was found within the area of syenite and nepheline syenite, at four localities. The radioactive mineral at four localities outside of the area of syenites was identified as thorogummite, that occurs as nodular masses in residual soil, derived by weathering of narrow veins and pegmatites.

The occurrences might warrant additional exploration should there be a sufficient demand for thorium (Vickers, 1956).

K⁴⁰ Radiation in the Franconia Formation

Many workers have noted that the Franconia Formation near Tomah in Monroe County shows above average radioactivity. Analyses of these rocks were reported in 1960 by Hans K. Adler ("ED" series) and in 1968 by Roger C. Malan ("AAC" series). They appear below (open file reports).

It appears that most of the slightly anomalous radioactivity in the Franconia Formation is caused by the K⁴⁰ isotope of potassium in glauconite.

TABLE IV-1

Analyses of Franconia Formation

Sp. No.	%eU ₃ O ₈	%U ₃ O ₈	%eK	%chem K ₂ O	eTh ppm
ED-257-1	.0023	.0006		4.4	
2	.0013	.0003		8.2	
4	.0010	.0002			
5	.0040	.0003		8.2	
6	.0026	.0002			
A	.0035	.0001			
B	.0028	.0002			
C	.0017	.0002			
D	.0019	.0002			
E	.0010	.0001		1.2	
F	.0014	.0002			
AAC 294	.00015	.0002	7.6		5.3

Analyses of Syenitic Country Rocks near Wausau

AAC 296	2.5		4.22		4.5
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McCaslin Formation

Introduction

Much interest has centered on the uranium potential of the McCaslin Formation, particularly because of the reported discovery of uraniferous conglomerate on McCaslin Mountain.

The McCaslin Mountain specimens were discovered about three-quarters of a mile east of the fire tower by Mr. Harry Gusick, 628 Elm Street, Antigo, Wisconsin. On September 20, 1955, Mr. George Hanson of the Wisconsin Geological Survey (open file report) describes these to be specimens of quartz pebble conglomerates. Pebbles are subrounded and about $1\frac{1}{2}$ inches maximum in samples. Matrix contains fine quartz and rather fine-grained pyrite with greenish tinge. Quartz pebbles are milky white to smokey, and one is rather pinkish. Radiometric assay gave 0.17 percent eU_3O_8 . On November 8, 1955, Mr. Hanson notes (open file report) that the sample contains 0.115 percent U_3O_8 by chemical analysis. On July 11, 1956, Mr. Hanson notes (open file report) that he had visited the McCaslin Mountain area but could find no evidence of a conglomerate phase, nor of conglomerate in the float rock of the glacial till. He suggests that this may mean merely that the conglomerate is not exposed.

On March 20, 1972, Mr. Gusick submitted to the Wisconsin Survey another specimen that he stated to be similar to the specimen analysed by Hanson some years ago (open file report). This specimen was found to contain 0.33 percent U_3O_8 (open file report).

I saw the conglomerate specimen in June, 1976 at the office of the Wisconsin Geological and Natural History Survey. Surfaces have been polished on it, so that it no longer retains its shape as received. I did note that the abundant matrix pyrite exhibited no megascopic evidence of oxidation.

Previous Work

The only study of the McCaslin Formation is by Mancuso (1960). He considers the formation to consist of a basal conglomerate overlain by a thicker quartzite, the total thickness being in excess of 5000 feet (1700m). Near the base gray and red quartzite and white quartz make up 50 to 70 percent of the banded hematite iron formation, and red jasper. Quartzite and quartz pebbles are the predominant type in the finer conglomerates higher in the section. In the western portion of the formation pebbles attain a maximum size of 7 inches, and in general become smaller stratigraphically upward everywhere.

The quartzite, forming the great bulk of the McCaslin Formation, is a hard, brittle, vitreous quartzite, generally white in color, but in places showing shades of gray, pink, purplish-red, or brick red. Bedding is apparent in many exposures because of slight changes in grain size, color, or hematite staining. Cross bedding is common, and ripple marks have been noted. Silty or clayey beds are absent, but gray to red arkose is interbedded with conglomerates.

Figure IV-17 - Metaquartzite, McCaslin Formation, near site of Carter fire tower. Scale in cm.

Figure IV-18 - Quartz-pebble conglomerate, McCaslin Formation; loose block, Carter fire tower. Dark pebbles are hematite quartzite (recrystallized iron formation). Scale in cm.

Age

The precise age of the McCaslin Formation is unknown. Mancuso considers it to be post-Waupee in age on the basis of his having identified pebbles of Waupee-like lithologies. It also contains pebbles of iron formation. Thus, it may be younger than 1,850-1,950 m.y. as are the other quartzites described earlier. Certainly, sufficient time had elapsed from the preceding volcanic episodes for the development of a depositional environment in which predominantly quartzose sediments were deposited.

Present Work

The only outcrops that I visited are at the site of the former Carter fire tower, and along U.S. 32. At the fire tower a low scarp exposes about 8 meters of conglomerate and quartzite, strike S60E, dip 15 degrees southwest. The pebbles in the underlying conglomerate are mainly quartz, from .5 cm to 5 cm in diameter. Recrystallization of the matrix has tended to make some pebbles indistinct. In places there is very finely disseminated hematite in the matrix. The overlying quartzite, about 7 meters in thickness, is massively bedded, with local suggestion of crossbedding. Bedding is enhanced by a slight reddening due to very finely disseminated hematite. The quartzite also is recrystallized with many quartz grains exceeding 3 mm in diameter (Figure IV-17).

Near the fire tower are loose blocks of conglomerate, some of which show pebbles of black quartz (smokey quartz?), foliated hematite-quartzite, and yellowish quartz (Fig. IV-18-21).

One block has a tiny void, 5 mm long, 3 mm wide, and perhaps 8 mm deep, lined with very fine-grained pyrite. The void appears to have been a solid sulfide body, now almost completely oxidized. In view of the number of hand samples that I looked at in the field and in the laboratory, I estimate the maximum abundance of pyrite to be in the 1/10 percent range. I wish to emphasize that I saw no other voids or discoloration that I could interpret as denoting oxidized pyrite. In several of the conglomerates iron oxide occurs as .1 to 1 mm octahedra of magnetite, now oxidized to hematite. In addition several of the blocks show distinct flakes of specular hematite.

The general radioactivity of the quartzite is 0.011 mR/hr, and of the conglomerate, up to 0.03 mR/hr.

Some samples contain a few rare, irregular areas, up to 5 mm in diameter of a soft mineral identified by X-ray diffraction as pyrophyllite (B.M. Hamil, pers. comm.).

Comparison with Huronian Conglomerates at Elliot Lake, Ontario

There are some similarities:

- 1) The pebbles and matrix consist of resistant lithologic varieties.
- 2) The associated sandstones are crossbedded and ripple marked.

The differences between this conglomerate and that at Elliot Lake are also distinct:

- 1) The McCaslin Formation may be as old as 1850-1950 m.y. The uraniferous Huronian

Figure IV-19 - a(left) Black quartzite pebble in conglomerate, McCaslin Formation; loose block, Carter fire tower. Scale in cm. b(right) Small pyrite-lined cavity in conglomerate, Carter fire tower. Same scale as in a.

Figure IV-20 - Quartz-pebble conglomerate, McCaslin Formation; loose block, Carter fire tower. Dark pebbles are of hematite quartzite (recrystallized iron formation). Scale in cm.

Figure IV-21 - Quartz-pebble conglomerate, McCaslin Formation; same block as in Fig. IV-20. Matrix contains much specular hematite. Scale in cm.

conglomerates were deposited between 2150 and 2400 m.y. (Van Schmus, 1976a).

2) The McCaslin Formation has undergone substantial recrystallization and metamorphism everywhere (Mancuso, 1960). By comparison the Huronian conglomerates are not strongly recrystallized.

3) The main accessory minerals in the McCaslin conglomerate are hematite, and hematite after magnetite. As noted above, pyrite is not an abundant constituent. The uraniferous conglomerates at Elliot Lake are, of course, quite pyritic, and low in iron oxides. The Witwatersrand conglomerates lack the iron oxide suite completely.

Conclusions

1) As in Michigan (Part II), the Wisconsin uranium occurrences show characteristics of their supergene origin: the deposits occur in granitic host rocks, of which the main variety is known to have a high uranium content; the highest radioactivity attributed to uranium occurs along fractures that show no hydrothermal alteration or introduced vein minerals; some fractures do show a faint reddening, or a bleaching due possibly to oxidized pyrite.

The age of the supergene mineralization is not known. I am of the opinion that if these occurrences have been formed in post-glacial time, in all likelihood they will be

small and uneconomic. If they represent the products of processes that took place over a longer period of time, during the Cretaceous, Paleozoic, or Precambrian, there is a much greater possibility for the process to have formed a larger concentration somewhere.

2) Although experience has shown that uraniferous quartz pebble conglomerates are about 2,000 m.y. old, or older, and that there is a singular dearth of paleoplacer-type ore bodies in younger conglomerates, one should keep in mind that new discoveries could alter our experience.

In my opinion one should keep an open mind on the uranium potential of the McCaslin and other Middle Precambrian formations. They might be considered as host for, for example, a non-placer type of uranium concentration. Perhaps their paleogeology might have permitted the formation of supergene-type deposits near their lower contact.

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PART V

BACKGROUND DATA FOR GEOCHEMICAL EXPLORATION

J. Kalliokoski

BACKGROUND DATA FOR GEOCHEMICAL EXPLORATION

Moraines in Northern Michigan and WisconsinIntroduction to the Moraine Map

For anyone contemplating exploring for uranium or other metals in Precambrian rocks through sampling or prospecting the glacial overburden, it is useful to be aware of some of the principal distribution patterns of the glacial deposits.¹ It is with this purpose in mind that a moraine map (Map 4) and these pages have been prepared.

Most of our knowledge of the broad aspects of glacial geology of northernmost Wisconsin and the Upper Peninsula of Michigan arises from the work of Leverett (1929) in Michigan and Thwaites (1943, 1956) in Wisconsin. Thus, the terminal moraine map leans heavily on their work, but also includes additional information from other published sources, and some additional observations by the writer from the study of air photograph index lay-down mosaics (Abrams, 1939; Aero Service Corp., 1954). The map shows the limits of the various glacial lobes as determined by the moraines, and the direction of movement of the lobes from drumlin orientations and surface fluting.

¹Wisconsin Geological and Natural History Survey, Madison, will be publishing a glacial geology map of Wisconsin, in color, at a scale of 1:500,000, in late 1976.

Age of Moraines

The region of the Upper Peninsula of Michigan and northern Wisconsin was overridden during a Glacial Period that lasted some half million years by several ice sheets that left their record in a series of deposits in the Mid-central States. Thus, in the area of this report each advancing sheet overrode and carried off the deposits laid down by the recessional phase of the preceding ice sheet. Consequently the first deposits to be preserved in northernmost Wisconsin are those related to the two youngest ice advances, the Woodfordian or Cary (older, beginning about 20,000 years Before Present), and Valderan (younger, about 10,000 years B.P.), both substages of the Wisconsinian Stage of glaciation (Leverett, 1929, Plate 1; Frey, Willman, and Black, 1965, Figure 1). They are identified on the basis of their moraines, and in that these extend across the border from Wisconsin into Michigan, they provide a basis for regional correlation.

Moraines of the Cary (Woodford) Substage

Moraines of what are now termed Cary age, extend across northern Wisconsin, and loop south, west of Green Bay. Associated with these moraines are drumlin fields, one of which occurs in south-central Iron County, Michigan.

These moraines and the drumlins, portray quite graphically the later stages of movement and stagnation of the Cary ice sheet.

Moraines of the Valderan Glacial Substage

During the last stages of glaciation, most of the western Upper Peninsula of Michigan and northernmost Wisconsin was overridden by the Superior ice lobe, centered somewhere to the north. The main feature of this sheet is the "outer morainic system" of Leverett (1929) that extends from along the Wisconsin-Michigan border on the west, through Gogebic, Iron, and Dickinson Counties on the east, and continues into the system that extends north from the west side of Green Bay. This north-south trend denotes the effect of the contemporaneous Lake Michigan lobe.

The physiographic prominence of these Valderan moraines in the western part of the Upper Peninsula of Michigan show up well on the land slope map prepared by the Western Upper Peninsula Development District (1974). On that map the northern limit of the morainal belt in Michigan is clearly defined as far east as the latitude of Keweenaw Bay. Also it is possible to identify on that map the morainal embayment in Iron County with its southwest trending drumlins.

The Superior lobe extended as a broad sheet from 35 miles southwest of Superior, Wisconsin to southern Baraga County. The lobe developed at least two sublobes, one at the southwest end of Lake Superior, west of Bayfield Peninsula, and the other east of that peninsula (Leverett, 1929). Also, to the east of the Porcupine Mountains the general southerly flow of the ice was refracted southwest and west by the east flank of the mountains (Hack, 1965, Figure 3).

The easternmost evidence for the Superior lobe is a drumlin field that I have noted on air photographs to cover a large part of south-central and southwestern Baraga County, south of the Keweenaw lobe. The drumlins are aligned northwest-southeast, parallel to the surface fluting near Ontonagon.

Black makes a different suggestion regarding the age and extent of some glacial deposits in Michigan. He proposes that Woodfordian (or Cary) surface deposits extend northeast all the way from Iron County to the base of the Huron Mountains, and gives this feature the name "Iron River lobe" (Black, 1969, Figure 1). He reached this conclusion on the basis of limited field work and the study of air photographs. Although his hypothesis may be correct, in my view one of its weaknesses lies in the fact that northeast of Iron County the proposed lobe area does not contain a unifying set of glacial features such as an elongate, northeast trending drumlin field. Instead the proposed lobe is crossed by segments of the regional Valderan moraines as mapped by Leverett (1929), and indicated also on the land slope map referred to above.

At a somewhat later time, a much more pronounced glacial lobe became centered in Keweenaw Bay during the waning stages of glaciation. The ice from this lobe moved west, and slightly north of west, across the Keweenaw Peninsula, and southwesterly down the axis of Keweenaw Bay, across a terrain previously glaciated by the Superior lobe.

On the east the extent of the Green Bay lobe (Frye, et al, 1965, Figure 4) can be determined from various kinds of

evidence. Thwaites (1943) was able to map it in Wisconsin from the distribution of red drift, and suggested that the absence of terminal moraines associated with the Green Bay lobe may signify that it had stagnated at the position of its farthest advance. Perhaps the main features associated with this lobe in Michigan are the outstanding drumlin fields of the Menominee drumlin district (Leverett, 1929, p. 39-42), described originally by Russell (1904, 1906). The drumlins are quite distinct on airphoto indexes, as are their rather abrupt western termination. The drumlins show that along the axis of the Green Bay lobe the ice moved southwest, but on its northwest side the ice spread westerly and even northwesterly. This pattern suggests that the ice front was not in contact with another lobe, and hence was free to spread, and that the Green Bay lobe moved southwest from the eastern part of the Lake Superior basin.

The pattern of glaciation in eastern Baraga and western Marquette Counties, in the area between the Superior and Lake Michigan lobes, reflects the occurrence of rather high topography that separated the lobes and influenced their flow movement. Thus the sequence of glacial events as recorded in the glacial deposits is quite complex. The reader is referred to the recent detailed sedimentological study by Nordeng on auger drill sampling of part of this area (1975).

Figure V-1 - Depth to bedrock, Precambrian area,
northern Michigan.

Thickness of Glacial Overburden in Michigan and Wisconsin

For purposes of prospecting and exploration, whether by soil sampling or drilling, it is useful to have some knowledge of the overburden thickness, particularly if one is interested in sampling the basal till. Such an overburden thickness map is available for Wisconsin (Trotta and Cotter, 1973). For Michigan the writer has compiled similar data (Figure V-1) but the coverage is much less complete. However, it does provide some indication of the overburden thickness. Figure V-7, the preliminary map on the thickness of glacial deposits in Wisconsin, is similar but not identical to the map of Trotta and Cotter referred to above.

Figure V-7

PRELIMINARY MAP SHOWING THICKNESS OF GLACIAL DEPOSITS IN WISCONSIN

Cooperative Project of the U.S. Geological Survey and the
University Extension--The University of Wisconsin
Geological and Natural History Survey

Uranium and Metal Abundances in the Glacial Overburden

Hydrogeochemical Studies

General

Between June and October, 1957, the A.E.C. undertook a hydrogeochemical reconnaissance study for uranium in northern Michigan-Wisconsin (Illsley, Bills and Pollock, 1958; Kinne-
man and Illsley, 1962).¹ The purpose of this study, supported by geophysics, was to evaluate geochemical methods in an environment similar to that near Blind River, and hopefully to outline promising areas.

About 600 water samples were collected from streams and subsurface sources, in an area covering 6,000 square miles. The average regional coverage was two samples per township. Analyses were made for uranium, and total conductivity was determined and sulfate ion, to allow normalizing, and in some instances supporting analyses were run on solid samples. The results were most encouraging.

Background values of uranium in water ranged from less than 0.1 to slightly greater than 0.5 ppb. Several drainage areas in Michigan and Wisconsin show anomalous concentrations ranging from 0.8 to 10.4 ppb. The lowest values are found in Michigan in streams flowing over Lower Precambrian greenstones and schists. Higher values are found in streams

¹At the time that I wrote these pages, the only copy of the K.-I. paper available to me was one that lacked many important groups of pages and supporting maps. Today, 7/14/76, I received a complete copy (101 p., App. 45 p.) from W.F. Cannon of the U.S.G.S., too late to incorporate the data in this paper. The K.-I. paper contains much useful exploration data, and copies are available from this department.

draining Middle Precambrian metasediments, or what the authors term "post-Huronian" granitic rocks in the Southern Complex. Waters in northern Wisconsin have higher background values than those in Michigan, and anomalies are somewhat less pronounced, the maximum value being 2.8 ppb from a granitic terrain.

West Branch, Ely Creek, National Mine (Ishpeming Quad., Michigan)

Sweitzer Creek and its minor branches are southeast-flowing tributaries of the East Branch of the Escanaba River (Figure V-2). About two miles southwest of Escanaba, the vicinity of the West Branch Ely Creek (Secs. 21, 28, and 29, T47N, R27W) was selected for further study on the basis of abnormally high uranium content found in a reconnaissance water sample collected approximately ten miles downstream. As shown in Figure V-2, sampling traced the uranium to the West Branch, and further sampling indicated that the apparent source was from a small bog, 700 feet wide and 1,700 feet long, drained by West Branch, in Secs. 28 and 29. The investigators noted that all water samples containing greater than 2.5 ppb uranium come from near the inferred granite/Ajibik quartzite contact.

Buckroe Area (Negaunee Quadrangle, Michigan)

This small community is located about 12 miles northwest of Marquette in Sec. 2, T49N, R26W, near the shore of Lake Superior. Along the shore Jacobsville Sandstone occurs as a narrow strip from 1/4 to 3 miles wide, overlying unconformably a Lower Precambrian granite. Here the sandstone

Figure V-2 - Sample location and geological map of National Mine area, Marquette County, Michigan.

is represented by the lenticular sandstone facies, consisting of reddish brown, mottled sandstone, and micaceous shale.

No anomalous concentrations of uranium were detected in streams crossing the sandstone, but of six well samples collected in town, two (6.9, 1.4 ppb U_3O_8) are probably anomalous. The wells are in the Jacobsville Sandstone, from 14 to 110 feet deep.

Seven sandstone samples were found to have a mean uranium concentration of 2.2 ppb and a maximum value of 5.2 ppb. The sample was from bleached micaceous sandstone, near one of the wells which yielded water containing greater than background amounts of uranium. However, bleached rock does not contain every where higher uranium values than the red variety. The investigators note that the limited data suggests probable high uranium background for the sandstone, and the possible occurrence of small anomalous areas associated with bleached zones. They conclude: "Study of limited areas of favorability in the (Jacobsville) sandstone on the south shore of Lake Superior should be deferred. However, consideration should be given this formation as a possible host rock for low grade uranium deposits in the event that a need should develop for long range potential investigations in the area" (Kinneman and Illsley, p. 98-99).

Detailed Studies of Anomalies in Northeastern Wisconsin

The 20 pages dealing with this subject are missing from the copy made available to me. The section begins as follows: "The major drainage systems of northeastern Wis-

consin were sampled on a two sample per township basis for reconnaissance purposes. One hundred and twenty water samples were collected as being representative of an area of approximately 2400 square miles...." (Kinneman and Illsley, p. 60).

Uranium in Bog Soil

Many of the water samples that contain anomalous amounts of uranium were taken from streams that originate in, or flow through, swamps. On evaluating the situation the investigators conclude that some bogs may contribute uranium to water, whereas in general they seem to collect uranium. This collection is shown by a general correlation between the U_3O_8 content of bog material and ignition loss. However, the investigators note much variation in uranium content among streams flowing into and/or out of bogs.

Comparison of Airborne Radiometric and Hydrogeochemical Data for Part of Northern Michigan

Kinneman and Illsley note the similarity in the two sets of data (Figure V-3).

Soil Studies Northeast of L'Anse

Because of the availability of glacial sediment samples collected northeast of L'Anse by Nordeng in the course of his drilling program (1975), it was possible for an exploration group to have them analysed chemically for uranium, and by the fusion/AA technique, for total copper and zinc. The location of the sample points, and their metal values are shown in Figures V-4, V-5, and V-6. The copper and

Figure V-3 - Geochemical anomaly and radioactive map of portions of Marquette County, Michigan.

Figure V-4 - Uranium (U_3O_8) abundance in area east of L'Anse, is ppm by level. Level 1 (0-.5) frequency-155; 2 (0.51-1)-60; 3 (1.01-1.5)-14; 4 (1.51-2)-5; 5 (2.01-2.5)-3; 237 samples.

Figure V-5 - Zinc abundance in area east of L'Anse, in ppm by level. Level 1 (2-103 ppm) as frequency 226; 2 (104-205)-8; 3 (206-306)-2; 4 (307-408)-0; 5 (409-510)-1; 237 samples.

Figure V-6 - Copper abundance in area east of L'Anse, in ppm by level. Level 1 (0-3)-frequency - 188; 2 (3.06-6)-38; 3 (6.12-9)-8; 4 (9.18-12)-2; 5 (12.24-15)-1; 237 samples.

zinc analyses were done in the Department of Geology and Geological Engineering analytical laboratory, at Michigan Technological University. The SYMAPS were prepared by Leslie Hahn of this department. This work is the most detailed study, based on chemical rather than on radiometric analyses, for which uranium data is available from this region.

The maps show that the uranium and metal abundances are low, but attention is directed to the cluster of higher uranium values in the northern part of the sampled area.

The only other soil geochemical study is for basemetals (Segerstrom, 1968).

Rock Geochemistry

Another part of this report presents data on the uranium and thorium concentration in normal bedrock samples as well as in mineralized areas (Part I).

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APPENDICES

APPENDIX I

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APPENDIX II

Road Logs to Radioactive Occurrences

SYENITE DIKE (29)

NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 7, T48N, R25W, Marquette County

<u>Mile</u>	<u>Directions</u>
0.0	Brookton Corners (2.5 miles west of the City of Marquette) at intersection of US-41 and Co. Rd. 492. Proceed north on Co. Rd. 492.
2.0	Road bends around to West and SW. R.R. tracks come close to road here. Sandy logging road goes north. Proceed on foot on logging road to north.
250'	Logging road forks -- outcrop is immediately to west.

GOODRICH OUTCROPS PALMER AREA (32)

SW $\frac{1}{4}$, Sec. 29, T47N, R26W, Marquette County

<u>Mile</u>	<u>Directions</u>
0.0	M-35 at bridge over Warner Creek (4 miles south of Negaunee). Proceed south and enter village of Palmer.
0.5	Turn left, proceed east on unmarked road along bottom of ridge. Smoke stack marking site of the old Isabella mine location is on top of hill. Continue up hill around sharp turn to right to near base of smokestack.
0.95	Isabella mine location. Exposures of Goodrich quartzite and conglomerate overlying iron formation is located 100 feet to SE of road.

GOODRICH BOULDER (33)

S $\frac{1}{2}$, S $\frac{1}{2}$, Sec. 30, T47N, R26W, Marquette County

0.0	Intersection Empire Mine Road and M-35 at southern outskirts of Palmer. Proceed west on Empire Mine Rd.
0.1	Just before crossing R.R. tracks, turn left on dirt road.
0.3	Boulder is located 20 feet west of road.

GREENS CREEK SLATE TRENCH (18)

- 0.0 Palmer-Intersection of M-35 and Co. Rd. 565. Proceed south on Co. Rd. 565.
- 1.0 Take left fork at junction of 565 and 476. (Remaining on 565)
- 4.7 On right hand side is access road to CCI tailings basin. Proceed on original road.
- 4.85 Dirt road to right takes you to the trench.
- 5.35 End of dirt road & Kerr-McGee trench.

GREENS CREEK PEGMATITE (31)

SW $\frac{1}{4}$, Sec. 35, T46N, R26W, Marquette County

- 0.0 Co. Rd. 565 at dirt road to trench. Proceed south on 565.
- 1.0 Crossing over Greens Creek.
- 1.6 Intersection Co. Rd. MF (continue on 565 south).
- 7.7 Intersection - County Rd. 565 and M-35. Proceed north on M-35.
- 9.4 Bridge over Greens Creek.
- 9.7 Prospect is on east side of road. Pit 10' deep.

VOELKER PROSPECT (30)

SW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 11, T46N, R26W, Marquette County
(Coming from South)

- 9.7 Greens Creek Granite Prospect -- continue north on M-35.
- 12.8 Dirt road to right. Proceed on this dirt road to the East.
- 13.1 Logging roads intersect, keep to left.
- 13.9 Road forks. On foot take trail going S50E. Proceed 350' to the bank of the Escanaba River. (The river is deep here). Walk upstream about 100 feet to an old beaver dam where you can cross the river. Prospect is 100 yds. east across the river between two granite knobs. There is a shallow prospect pit about 3 feet deep.

VOELKER PROSPECT (30)

SW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 11, T46N, R26W, Marquette County
(Coming from North)

- 0.0 Palmer - proceed south on M-95.
- 5.0 Dirt road to left. Proceed on this dirt road to the east.
- 5.3 Logging rocks intersect, keep to left.
- 6.1 Road forks. On foot, take trail going S50E. Proceed 350' to bank of the East Branch Escanaba River. (The river is deep here.) Walk upstream about 150 feet to an old beaver dam where you can cross in about 2 feet of water. Prospect is 100 yards east across the river between two granite knobs. There is a shallow prospect pit, about 3 feet deep.

LEITCH AND ISHAM PROSPECTS (36) (37)

N $\frac{1}{2}$, NW $\frac{1}{4}$, Sec. 13, T42N, R29W

S $\frac{1}{2}$, S $\frac{1}{2}$, Sec. 12, T42N, R29W, Dickinson County

- 0 Felch -- proceed west on County Road 569.
- 3.2 Turn north on road to Six Mile Lake.
- 5.3 Public access to Six Mile Lake - turn right.
- 5.5 Bridge over Six Mile Creek. Proceed northeast 2.4 miles.
- 7.9 Prospect is in the granite scarp on the right.
- 7.9 Proceed on original dirt road northeast an additional 0.1 mile.
- 8.0 Turn east onto sandy road, proceed 0.2 miles.
- 8.2 Prospect is in granite scarp.
- 0.0 Felch -- proceed north on County Road 581 approximately 4.5 miles.
- 4.5 Turn left and proceed south and west approximately 1.5 miles.
- 5.7 At new dam site on the Sturgeon River. Proceed on foot to first outcrop to the southwest of the west end of the dam -- this is the original prospect site. Abnormally radioactive granite is found extending from the dam eastward along strike hundreds of feet.

LEITCH AND ISHAM PROSPECT (22)

NW $\frac{1}{4}$, Sec. 7, T42N, R28W, Dickinson County

- 0 Felch -- proceed north of Norway Lake.
- 2.1 Take road to left, proceed north.
- 4.3 Turn left.
- 4.7 Access to new wildlife refuge and dam. Proceed west on foot.
- 4.8 Prospect is 200 feet southeast of dam in low outcrop (no pit here, but a lot of broken rock).

BIG ERIC'S CROSSING (40)

NW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 35, T52N, R30W, Baraga County

HURON RIVER OCCURRENCE (13)

NW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 1, T51N, R30W, Baraga County

- 0.0 Intersection of Main and Broad Streets, L'Anse, Michigan. Proceed east on Main Street.
- 15.1 Crossroads, continue straight ahead.
- 20.2 Junction, take right fork.
- 21.5 Big Eric's Crossing over the Huron River. Radioactive occurrence is to the north of the bridge 300 ft. in the granite just NE of the main stream flow.
- 21.5 Big Eric's Crossing. Continue on original road.
- 22.1 Junction, take middle fork.
- 23.1 Logging road, fork to the right. Jeep or on foot from here.
- 23.3 Cross over creek in road.
- 23.6 End of road at the pitchblende occurrence on the east branch of the Huron River. Pitchblende exposed in bank of river near falls and also in several areas upstream from falls. Several drill pipes in ground here.

JOE FORSYTHE PROSPECT (38)

NW $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 13, T51N, R32W, Baraga County

- 0.0 Downtown L'Anse at blinking traffic light. Go north on Main St.
- 7.7 Bridge over Silver River.
- 8.7 Turn left on county road (sign for Echo Harbor Resort).
- 8.9 Turn left into gravel pit.
- 9.0 Turn right and park - proceed on foot.
- 0 Proceed on dirt road to N-NW.
- 250' Continue into woods, road will bend around to W and then to SW.
- 950' Intersection, take logging road to the right (N45W). Continue to NW 1250 feet.
- 2100' Intersection, take logging road to right (E-NE). Continue to NE 940 feet.
- 3040' Road begins to bend around to N-NW, continue another 200 feet.
- 3240' Prospect is the horseshoe shaped bulldozed area 550 feet long bending around to NE and NW.

HAGGET DIKE (39)

NE $\frac{1}{4}$, NE $\frac{1}{4}$, Sec. 13, T51N, R32W, Baraga County

- 0.0 Downtown L'Anse at blinking traffic light. Go north on Main St.
- 7.7 Bridge over Silver River.
- 8.7 Turn left on county road (sign for Echo Harbor Resort).
- 9.1 Road bends to east around outcrops. E-W section line meets road where it returns to near north course. Proceed on foot.
- 0' From section line marker on west side of road, follow section line 200 feet west.
- 200' From section line go 400' south.
- 600' Prospect is in low outcrops and trenches on side of hill.

GRAPHITE QUARRY (12)

Section line Secs. 9 and 16, T49N, R33W, Baraga County

- 0.0 Corner Main and Broad Streets, L'Anse, Michigan. Proceed south on Broad Street and continue north on U.S. 41.
- 3.1 R.R. crossing.
- 3.5 Take dirt road to left (Old U.S. 41).
- 8.0 Take logging road to left. Jeep or on foot from here.
- 9.5 End of road at quarry.

PORTLAND MINE (14)

N $\frac{1}{2}$, NE $\frac{1}{4}$, Sec. 26, T48N, R31W, Baraga County

- 0 Country Rd. 625 and U.S. 41, 1 mile east of Three Lakes. Proceed south on 625.
 - 0.7 Turn left on dirt road.
 - 1.0 Turn left at fork.
 - 1.2 Turn left on poor dirt road.
 - 1.8 At grand stock pile - poor rock piles and tailings are to left. Slate on dump here. Continue on dirt road past stock pile.
 - 1.9 Turn right on grassy-dirt road.
 - 2.2 Take center road, straight ahead.
 - 2.4 Open pit is to left side of road.
-] These are private roads.

SARGENT PROSPECT (27)

(Coming from South)

- 0.0 M-95 at railroad crossing near Republic. Proceed north.
- 2.0 Bridge over Bruce Creek. Go down west side of bridge on the south side of the creek and swampy area S45E 160 feet from the guard rail, then S20W into the bush. Prospect is a 12-foot deep pit beside a 15-foot granite scarp which is trending N20E.

SARGENT PROSPECT (27)

W $\frac{1}{2}$, NW $\frac{1}{4}$, Sec. 32, T47N, R29W, Marquette County
(Coming from North)

- 0.0 Intersection M-95 and U.S. 41. Go south on M-95 toward Republic.
- 0.6 R.R. crossing
- 3.3 R.R. crossing
- 5.0 Bridge over Bruce Creek. Go down west side of bridge on the south side of the creek and swampy area. 160 feet S45E from the guard rail, then S20W into the bush. Prospect is a 12-foot deep pit beside a 15-foot granite scarp which is trending N20E.

REPUBLIC PROSPECT (28)

NW $\frac{1}{4}$, Sec. 6, T46N, R29W, Marquette County

- 5.0 Continue south on M-95 from Bruce Creek.
- 6.5 Granite gneiss outcrops on both sides of the road. Highest radioactivity is at north end of the outcrop on the west side of the road.
- 6.6 Michigamme River bridge.
- 6.7 Road to Republic and Republic Twp. beach.

ANDERSON-WIGGINS PROSPECT (11)

SE $\frac{1}{4}$, Sec. 35, T45N, R32W, Iron County

- 0.0 Intersection of U.S. 41 and U.S. 141 (15 miles south of L'Anse). Proceed south on 141.
- 3.6 Turn left at Covington, staying on 141.
- 30.7 Turn left on road to Deer Lake access.
- 31.1 Turn left on road to Deer River and Deer Lake.
- 32.0 Turn right on road to Deer Lake and Deer River.
- 33.4 Turn left to Way Dam.
- 34.6 Take road to left.
- 39.1 Take left fork (Deer Foot Lodge trail).
- 40.9 Turn left (sign says Pivatto's place).
- 41.0 At gate to Pivatto's cottage, take right fork.

- 41.2 Turn left onto very poor road and proceed on foot from here.
- 0 Follow dirt road N25W 215 feet.
- 215' Follow dirt road W 370 feet.
- 585' Follow dirt road N40 W 640 feet.
- 1220' At intersection (old road going north) continue on original road S60 W, 760 ft.
- 1980' Take old foot trail to right (N20W). Continue on it 525 ft.
- 2505' Go west 150 feet.
- 2655' At falls in creek, go N40W, 170 feet to old prospect in granite.
- 2825' At prospect. Fallen tree has covered part of the prospect. Prospect pit is only about 2 feet deep -- following fracture in granite.

LAVATO'S OCCURRENCE (25)

NW¼, Sec. 12, T44N, R31W

- 0.0 Intersection of U.S. 41 and U.S. 141 (15 miles south of L'Anse). Proceed south on 141.
- 3.6 Turn left at Covington, staying on 141.
- 30.7 Turn left on road to Deer Lake access.
- 31.1 Turn left on road to Deer River and Deer Lake.
- 32.0 Turn right on road to Deer Lake and Deer River.
- 33.4 Turn left to Way Dam.
- 34.6 Take road to left.
- 39.1 Take right fork.
- 40.0 Turn left on private road. Proceed on foot N60E along old logging road.
- 3300' Glacial erratic (red gneiss) in road radioactive. Proceed 250' N20E from boulder.
- 3550' Radioactive sericitic shear cutting NW end of granite outcrop 4' high and 50' long. Proceed 275 feet north from sericitic shear zone.
- 3825' Flat granite outcrops with irregular radioactive zones.

BERGLAND PROSPECT (23)

NW $\frac{1}{4}$, SW $\frac{1}{4}$, Sec. 35, T49N, R42W, Ontonagon County

- 0.0 Bergland - Proceed east on M-28.
- 1.4 Turn left onto old M-28 (roadside picnic table). Continue east on old M-28.
- 1.5 Intersection of logging road with old M-28. Proceed on foot from here.
- 0' Take logging road to N-NE.
- 1000' Logging road forks - take left fork and proceed north.
- 1660' Logging roads intersect. Turn right and proceed N-NE.
- 2720' Prospect is on side of hill to the left.

INDIANA COPPER MINE (24)

NW $\frac{1}{4}$, NW $\frac{1}{4}$, Sec. 27, T51N, R37W, Ontonagon County

- 0.0 Intersection of M-26 and M-38 near Algomah.
- 1.0 Algomah Trading Post.
- 2.3 Bridge over West Branch Firesteel River.
- 3.0 Bridge over East Branch Firesteel River.
- 4.7 Turn right on dirt road to Indiana copper mine.
- 4.95 Dump from the old Indiana mine (lavas) continue.
- 5.6 Take fork to right.
- 5.8 New Indiana copper mine dump is on left hand side.

Dirt road to Indiana copper mine is approximately 18.8 miles south of Twin Lakes on M-26.

Baraga County - Showing locations of the Graphite
Quarry and Taylor Mine.

Baraga County - Showing locations of the Huron River Occurrence, Big Eric's Crossing, the Joe Forsythe Prospect and Haggett Dike.

Baraga County - Showing the location of the Portland Mine.

Dickinson County - Showing the location of three Leith and Isham Prospects.

East Gogebic County - Showing the location of Erikson Prospect.

Iron County - Showing the locations of the Sherwood Mine, James Mine, Wauseca Mine, Cardiff Mine, Zimmerman Mine, and Buck Mine.

East Iron County - Showing the locations of Anderson Wiggins Prospect, Lavato's Occurrences, Book Mine, Mastadon Mine, Tobin Mine.

Southwest Marquette County - Showing the location of Sargent Prospect and Republic Migmatite.

North Marquette County - Showing the location
of Syenite Dike.

North Marquette County - Showing the locations of M & G Mine and Old Mine.

West Part Ontonagon County - Showing the location of the Bergland Prospect.

Northeast Ontonagon County - Showing the location of Indiana Copper Mine.

APPENDIX III

Theses, post-1960, on Northern Wisconsin Precambrian Geology

(See Index Map for Location)

- 2 Koellner, S.E., 1974, The Stettin Syenite Complex, Marathon County, Wisconsin: Petrography and mineral chemistry of olivine, pyroxene, amphibole, biotite, and nepheline: M.S. thesis, Univ. of Wisconsin, Madison, 155 p.
- 3 Tabet, D.E., 1974, Structure and petrology of the Mellen Igneous Intrusive Complex near Mellen, Wisconsin: M.S. thesis, Univ. of Wisconsin, Madison, 81 p.
- 4 Ansfield, V.J., 1967, The geology of northwestern Rib Mountain Township: M.S. thesis, Univ. of Wisconsin, Madison, 84 p.
- 5 Weis, L.W., 1965, The origin of the Tigerton anorthosite: Ph.D. thesis, Univ. of Wisconsin, Madison, 65 p.
- 6 Roder, D.L., 1973, The petrology and chemistry of the Round Lake Intrusion, Northwest Wisconsin: M.S. thesis, Univ. of Wisconsin, Madison, 115 p.
- 7 Voight, D.J., 1970, A petrochemical and magnetic study of the volcanic greenstone in northwestern Marathon County, Wisconsin: M.S. thesis, Univ. of Wisconsin, Milwaukee, 94 p.
- 8 Hall, G.I., 1971, A study of the Precambrian greenstones in northeastern Marinette County, Wisconsin: M.S. thesis, Univ. of Wisconsin, Milwaukee, 80 p.
- 10 Cain, J.R., 1972, Petrology of a granitic terrain in northeast Wisconsin: M.S. thesis, Univ. of Wisconsin, Madison, 70 p.
- 11 Olmsted, J.F., 1966, Petrology of a differentiated anorthositic intrusion in northwestern Wisconsin: Ph.D. thesis, Michigan State Univ., Lansing, 155 p.
- 12 Cooper, R.W., 1973, Middle Precambrian and Keweenawan rocks north of the Gogebic Range in Wisconsin: M.S. thesis, Univ. of Wisconsin, Madison, 83 p.
- 13 Gerlach, T.M., 1966, The magnetic and textural character of the Macauley Granite: M.S. thesis, Univ. of Wisconsin, Madison, 113 p.

- 14 Lahr, M.M., 1972, Precambrian geology of a greenstone belt in Oconto County, Wisconsin and geochemistry of the Waupee metavolcanics: M.S. thesis, Univ. of Wisconsin, Milwaukee, 62 p.
- 15 Anderson, J.L., 1975, Petrology and geochemistry of the Wolf River Batholith: Univ. of Wisconsin, Madison, 297 p.
- 16 Myles, J.R., 1972, Petrology of a granitic terrain in northeast Wisconsin: M.S. thesis, Univ. of Wisconsin, Madison, 70 p.

Mancuso, J.J., 1960, Stratigraphy and structures of the McCaslin district, Wisconsin: Ph.D. thesis, Michigan State Univ., East Lansing, 101 p.

Appendix III. Location of Theses, post-1960,
on Northern Wisconsin Precambrian Geology.

PRECAMBRIAN GEOLOGY OF UPPER PENINSULA, MICHIGAN
SHOWING NONFERROUS METAL DEPOSITS
AND
RADIOACTIVE OCCURRENCES

GEOLOGY: Compiled by William A. Bodwell, Department of Geology and Geological Engineering, with cooperation of Michigan Geological Survey, U.S. Geological Survey, Institute of Mineral Research, Michigan Technological University, and several private corporations, under the direction of J. Kallioveski, 1972.

RADIOACTIVE OCCURRENCES: Compiled by Carol Johnson, 1976, under the direction of J. Kallioveski.
E.R.D.A. Contract AT(05-1)-1651.

SCALE 1:250,000

GENETIC CLASSIFICATION OF
RADIOACTIVE OCCURRENCES

- Supergene
- ◆ Primary
- Syngenetic
- 12 Number refers to radioactive occurrence in accompanying report.

LEGEND

Formations or units designated by predominant lithology

PALEOZOIC

- ss Paleozoic Limestone
- ps Paleozoic rocks, undivided
- UPPER PRECAMBRIAN OR CAMBRIAN
- ss Jacobsville Sandstone
- UPPER PRECAMBRIAN (KEWEENAWAN)
- ss Freda Sandstone
- ss Nonesuch Shale
- ss Copper Harbor Conglomerate
- ss Syenite
- ss Felsite, felsite porphyry
- ss Andesite
- ss Keweenaw diabase
- ss Basalt
- ss Portage Lake Lava Series
- ss South Range Lava Series
- ss Keweenaw quartzite

MIDDLE PRECAMBRIAN

Iron River - Crystal Falls
Menominee Area

- ss Stambaugh and Fortune Lakes Sates
- ss Hawassa Graywacke
- ss Rensselaer Iron Formation
- ss Dime Creek Sates
- ss Badwater Greenstone
- ss Michigan Graywacke
- ss Hemlock felsic volcanics

- ss Hemlock Greenstone

- ss Goodrich Quartzite
- ss Vulcan Iron Formation

- ss Felsch Formation (quartzite)

- ss Randville Dolomite
- ss Sturgeon Quartzite
- ss Fern Creek Formation (conglomerate)

LOWER PRECAMBRIAN

- ss Granite
- ss Granite to dioritic gneiss
- ss Metasediments of Solberg Schist and Six Mile Lake Amphibolite
- ss Fast Branch Arkose
- ss Outwash Greenstone

- ss Granite
- ss Granite and dioritic gneiss
- ss Gneiss

- ss Migmatite
- ss Iron formation
- ss Mafic tuff
- ss Basaltic greenstone

- ss Granite
- ss Granite to dioritic gneiss
- ss Gneiss

- ss Migmatite
- ss Iron formation
- ss Mafic tuff
- ss Basaltic greenstone

- ss Granite
- ss Granite to dioritic gneiss
- ss Gneiss

- ss Migmatite
- ss Iron formation
- ss Mafic tuff
- ss Basaltic greenstone

- ss Granite
- ss Granite to dioritic gneiss
- ss Gneiss

- ss Migmatite
- ss Iron formation
- ss Mafic tuff
- ss Basaltic greenstone

- ss Granite
- ss Granite to dioritic gneiss
- ss Gneiss

- ss Migmatite
- ss Iron formation
- ss Mafic tuff
- ss Basaltic greenstone

- ss Granite
- ss Granite to dioritic gneiss
- ss Gneiss

- ss Migmatite
- ss Iron formation
- ss Mafic tuff
- ss Basaltic greenstone

- ss Granite
- ss Granite to dioritic gneiss
- ss Gneiss

- ss Migmatite
- ss Iron formation
- ss Mafic tuff
- ss Basaltic greenstone

- ss Granite
- ss Granite to dioritic gneiss
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- ss Migmatite
- ss Iron formation
- ss Mafic tuff
- ss Basaltic greenstone

- ss Granite
- ss Granite to dioritic gneiss
- ss Gneiss

- ss Migmatite
- ss Iron formation
- ss Mafic tuff
- ss Basaltic greenstone

- ss Granite
- ss Granite to dioritic gneiss
- ss Gneiss

- ss Migmatite
- ss Iron formation
- ss Mafic tuff
- ss Basaltic greenstone

SYMBOLS

- Geologic contact
- Fault
- Keweenaw dikes, projected mainly on the basis of negative magnetic expression
- Major native copper producing horizon, conglomerate or amygdaloid. Length indicates extent of mining along strike. Size of type indicates past production as follows:
 - > 1 billion pounds Cu¹
 - 0.1 - 1 billion pounds Cu²
 - 1 - 100 million pounds Cu³
- Moderate native copper producer; conglomerate, amygdaloid or fissure type - 1 million to 100 million pounds Cu
- Minor native copper producer; conglomerate, amygdaloid or fissure type - < 1 million pounds Cu
- Native copper prospect with surface and/or underground workings - no recorded production
- Native copper occurrence
- Precious metals prospect - recorded production
- Nonferrous metal prospect or occurrence, other than native copper
- Nonferrous metal prospect or occurrence, presence of mineral not verified
- Placer gold occurrence

ABBREVIATIONS

- Ag Silver
- Au Gold
- Cu Copper
- Mo Molybdenum
- Ni Nickel
- Pb Lead
- U Uranium
- V Vanadium
- Zn Zinc

- Federal-state highway
- State highway
- County highway

- Notes:
 - * Indicates fissure-type deposit
 - 1 White Pine deposit principally chalcocite

Additions J. Kallioveski, Sept. 1973

PRELIMINARY GEOLOGIC MAP OF GREEN BAY SHEET EXPLANATION

CENOZOIC Qal Quaternary alluvium
PALEOZOIC Pz Paleozoic sedimentary rocks, undifferentiated
PRECAMBRIAN

Age	Wausau Area	Lohrville-Redgranite Area	Wolf River Batholith
Uncertain, possibly younger than 1450-1500 m.y.	lg mg mv	Leucogranite Metagabbro Mylonite (various ages, but some younger than 1450-1500 m.y.)	
1450-1500 m.y.	ng qmv lgy sy spg hg	Nineville granite Quartz syenite Lamprophyre Syenite and nepheline Syenite Stensens Point grey granite Hogarty hornblende granite	rgm Red River porphyritic quartz monzonite wrgm Wolf River hornblende granite and quartz monzonite wqm Wausau quartz monzonite
Uncertain, possibly between 1450-1500 and 1640-1670 m.y.	a kqm ibc	Aplite Felsite quartz monzonite Intrusive breccia complex	
Uncertain, possibly between 1450-1500 and 1640-1670 m.y.	qf	Quartzite	
1640-1670 m.y.	ghg qm fv	Granite Heights granite Quartz monzonite Felsite volcanic and volcaniclastic rocks	g Granite
Uncertain, possibly 1640-1670 m.y.	di mv	Diorite and quartz diorite Trachyte Bafic volcanic rocks	
Uncertain, equal to or older than 1900 m.y.	gn	Gneiss	
Lithologic units of uncertain age designation	gu m sch	Granite to quartz, diorite and equivalent gneiss, undifferentiated Metamorphosed mafic rocks Schists	an Anorthosite (intruded by granitic rocks of the Wolf River Batholith)

Symbols
Contact, dashed where approximate or inferred
Fault, dashed where approximate or inferred
Shear zone, mylonite
Samples dated by Rb-Sr whole rock methods
● 1450-1500 m.y.
■ 1640-1670 m.y.

RADIOACTIVE OCCURRENCES

J. Kallikowski, 1976
E.R.D.A. Cont. AT(05-1)-1651

Genetic Classification of Radioactive Occurrences:

- Supergene
- ◆ Primary

Radioactive Localities:

- W-1 Fred Ankam Farm
- W-2 Tigerton Dells, Sec. 15
- W-3 "F and K" Claims
- W-4 Radies Farm
- W-5 Marion Baseball Park
- W-7 Tigerton Dells, Sec. 10/15
- W-12 Radies Soft
- W-20 Wausaw Syenite Complex, (◆ zircon, ■ thorogummite)

Compiled by L.G. Medaris, Jr. and J.L. Anderson
Guidebook, 19th Inst. L.S.G. Madison, Wisc.

CARTOGRAPHIC LABORATORY UNIVERSITY OF WISCONSIN

EXPLANATION

PALEOZOIC Pz Paleozoic sedimentary rocks, undifferentiated

PRECAMBRIAN

uncertain, my "vlonite"

younger than 1450-1500 m.y.	sy hg	Syenite and meheline syenite Hogarty hornblende granite	bg wrgm hr hfp hs	Selonnia granite Self River hornblende granite and quartz monzonite Hager rhyolite Hager feldspar porphyry Hager syenite		
Uncertain, possibly 1450-1500 m.y.	kqm	Kalinka quartz monzonite	hqm pm hfg	Hay Creek quartz monzonite Peshigo monzonite and trachyandesite High Falls granite		
1640-1670 m.y.	ghg fv	Granite Heights granite Felsic volcanic and volcanoclastic rocks				
Uncertain, possibly 1640-1670 m.y.	di t mv	Diorite and quartz diorite Trachyte Mafic volcanic rocks			amqm Athena horn quartz monzonite	
1850-1910 m.y.						
					atqm ngd hig mqd dgn	Athelstone pink quartz monzonite Newingham gran- diorite Hoskin Lake granite Marinette quartz diorite Dunbar gneiss
Uncertain, possibly 1850-1910 m.y.					tfqd pvg nfv miv	Twelve Foot Falls quartz diorite Metagabbro Pemona felsic volcanic rocks McAllister inter- mediate volcanic rocks
Uncertain, equal to or older than 1850-1910 m.y.					bfv qfv gm	Beecher felsic volcanic rocks Quinneseq felsic volcanic rocks Quinneseq mafic volcanic rocks

- Ages Based on Stratigraphic Classification

Middle	pu	Paint River Group,
Precambrian		undifferentiated
	pr	Riverton iron
		formation
	pd	Dunn Creek slate
		Radwater mafic
		volcanic rock
	bmml	Michigamme slate
	sl	Saunders Formation

— Lithologic Units of Uncertain Age Designation

sl	Slate	sn	Anorthosite (intruded by granitic rocks of the Wolf River Batholith)	bc	Baldwin conglomerate	
				mqzt	Macassin quartzite	
				hqd	Hines quartz diorite	} possibly 1850-1910 m.v.
				mgm	Macaulay gneiss	
				wv	Waupee volcanic and volcanic- clastic rocks	

— General Lithologic Terms, Ages Uncertain

gu Granite to quartz diorite and equivalent gneiss
undifferentiated (in Rhineland area, 1640-1670 m.y.)
fyu Felsic volcanic rocks, undifferentiated (in
Rhineland area, 1640-1670 m.y.)
mvu Metamorphosed mafic volcanic rocks, undifferentiated

Symbols

—— Contact, dashed where approximate or inferred
 --- Fault, dashed where approximate or inferred
 ~~~ Shear zone, mylonite

Isotopically dated samples

1450-1500 m.y. 1640-1670 m.y. 1850-1910 m.y.

Rb-Sr, whole rock

U-Pb, zircon

Rb-Sr and U-Pb on same sample

RADIOACTIVE OCCURRENCES

J. Kalliokoski, 1976
E.R.D.A. Cont. AT(05-1)-1651

Compiled by L.G. Medaris, Jr. and J.L. Anderson
Guidebook, 19th Inst. L.S.G. Madison, Wisc.

CARTOGRAPHIC LABORATORY UNIVERSITY OF WISCONSIN

Sources of Data.

Leverett (1929), Thwaites (1956),
 Hughes (1963), Nordeng (1975),
 This work.
 (Wisconsin G.N.H.S. is publishing
 a new glacial map in late 1976)

- Symbols
- End Moraine
  - Drumlin orientation
  - Limit of Green Bay Lobe

MICHIGAN TECHNOLOGICAL UNIVERSITY PRESS
 GEOLOGICAL MAP SERIES, MAP 11A
 1976

END MORaine MAP
OF NORTHERN MICHIGAN-WISCONSIN.
 Compiled by J. KALLIOKOSKI.

MAP 4

19x12

END MORaine MAP

CHANDLER MOUNTAIN REGION

MAP 1

Scale 1:50,000

Geological Survey of Canada