# Geology and Monazite Content of the Goodrich Quartzite, Palmer Area Marquette County Michigan

GEOLOGICAL SURVEY BULLETIN 1030-F

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*By* R. C. VICKERS

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

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# GEOLOGY AND MONAZITE CONTENT OF THE GOODRICH QUARTZITE, PALMER AREA, MARQUETTE COUNTY, MICHIGAN

By R. C. Vickers


## ABSTRACT

The Palmer area, which is on the south limb of the Marquette synclinorium, consists of a downfaulted block of Precambrian sedimentary rocks about 4 miles long and three-quarters of a mile wide. The block is composed mainly of middle Huronian Ajibik quartzite and Negaunee iron-formation and upper Huronian Goodrich quartzite. Monazite occurs in the Goodrich quartzite as rounded detrital grains concentrated mainly in the matrix of quartz pebble conglomerate which is interbedded with coarse-grained quartzite.

Correlation of gamma-ray logs of drill holes which penetrate an apparent thickness of 1,100 feet of Goodrich quartzite and enter the underlying Negaunee iron-formation shows that most of the monazite occurs more than 300 feet above the base of the Goodrich quartzite. Drill-core specimens contain as much as 54 pounds of monazite per ton of rock. Outcrops of Goodrich quartzite, which are practically restricted to the lower 200 feet of the formation, contain an average of 2.9 pounds of monazite per ton. Samples from locally derived erratics contain as much as 110 pounds of monazite per ton.

Laboratory work indicates that more than 85 percent of the monazite is recoverable by gravity methods after grinding and sizing.


## INTRODUCTION

Abnormal radioactivity in specimens of Goodrich quartzite on rock dumps at the Old Volunteer and Old Maitland mines near Palmer, Marquette County, Mich., was detected in 1951 by Robert Reed, geologist working for L. P. Barrett, U. S. Atomic Energy Commission contractor. Analyses of the rock indicated that most of the radioactivity was caused by thorium. The locality was brought to the attention of the writer during an examination of radioactive materials in northern Michigan in August 1952, and subsequent chemical and spectrographic analyses of the samples indicated that the Goodrich quartzite contains locally as much as 0.37 percent thoria and 0.X percent each of Ce, La, Nd, Y, and Zr. Additional information concerning the radioactive material was obtained during 2 days of fieldwork in the Palmer area in November 1952 and in subsequent laboratory study.

Preliminary laboratory work indicated that most of the radioactivity is caused by detrital grains of thorium-bearing monazite in the matrix of pebble conglomerate of the Goodrich quartzite and that about 85 percent of the monazite is recoverable by gravity concentration after grinding and sizing.

To obtain further information concerning the geology of the Goodrich quartzite and the tonnage and grade of monazite-bearing rock that might be present in the Palmer area, 1 month was spent during the 1953 field season in mapping the Goodrich quartzite, sampling outcrops of the Goodrich, and gamma-ray logging three drill holes that penetrated the Goodrich. An examination was also made of many outcrops of Goodrich quartzite outside the Palmer area.

This report presents the results of the fieldwork together with the results of laboratory study. The work was done by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

## LOCATION, ACCESSIBILITY, AND HISTORY

The Palmer area, whose location is shown in figure 42, is about 3 miles south of Negaunee on Michigan Route M–35, Marquette County, Mich.; it includes parts of secs. 27, 28, 29, 30, 31, 32, 33, and 34, T. 47 N., R. 26 W. The area is served by a branch of the Chicago and North Western Railway.

The Palmer area, part of the Marquette iron district, has been a source of iron ore since the 1870's. About 17 million tons has been shipped from the area, of which about 25 percent has been produced from underground mines. The workings of several of the mines penetrated part of the Goodrich quartzite but are inaccessible at present.

## ACKNOWLEDGMENTS

The writer wishes to acknowledge the cooperation and interest of personnel of the Cleveland-Cliffs Iron Co., who made available the results of recent diamond drilling in the Palmer area and reopened a diamond-drill hole so that it could be gamma-ray logged. E. R. Randolph, geologist of the Cleveland-Cliffs Iron Co., assisted in the gamma-ray logging.

J. H. Eric assisted the writer in the fieldwork during August 1953, and L. P. Barrett, of the U. S. Atomic Energy Commission, supplied special information on the Marquette and Gwinn districts.

Equipment of the Department of Geology and of the Department of Mining and Metallurgy of the University of Wisconsin was used for the preparation and study of samples.

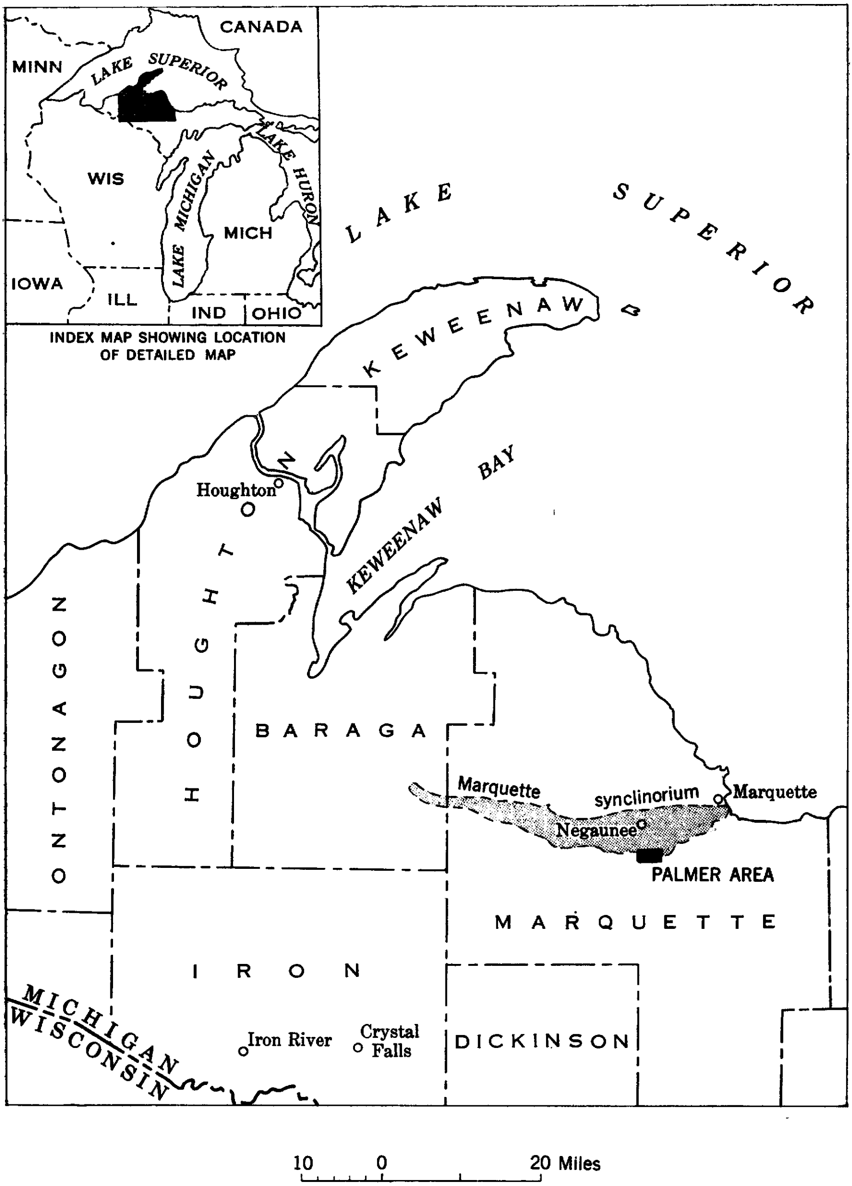


FIGURE 42.—Index map showing the location of the Palmer area, Marquette County, Mich.

## GEOLOGY

### GENERAL FEATURES

The Palmer area is on the south limb of the Marquette trough, a westward-plunging synclinorium about 40 miles long and from 1 to 6 miles wide, that is composed of Huronian rocks locally intruded by dikes and sills of diorite and minor amounts of granite. The position

<table>
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<tr><td colspan="2">Keewatin</td><td colspan="2">Kitchi schist and Mona schist</td></tr>
</table>

of the Palmer area in relation to the Marquette trough is shown in figure 42. The stratigraphy of the Marquette trough as given by Leith, Lund, and Leith (1935, opposite p. 10) is shown above.

The Palmer area consists of a downfaulted block of Huronian sedimentary rocks, about 4 miles long and three-quarters of a mile wide, which is separated from the main part of the Marquette synclinorium by an eastward-trending fault. All known outcrops of Goodrich quartzite are shown on the geologic map of the Palmer area (pl. 9), whereas outcrops of other formations are shown only to indicate the position of the Goodrich contacts and the general geology of the adjacent area.

## ROCK UNITS

According to Van Hise and Leith (1911) the sequence of Precambrian rocks in the Palmer area is as follows:

| *Series* | *Formation* | *Approximate thickness (feet)* |
|---|---|---|
| Upper Huronian | Goodrich quartzite | 850 |
| Middle Huronian | Negaunee iron-formation | 1,000 |
| | Ajibik quartzite | 150 |
| Archean | Palmer gneiss | ----- |

Other interpretations of the geology in the Palmer area have been proposed more recently. The Palmer gneiss is believed by Lamey (1935, p. 1137–1161) to consist mainly of metamorphosed lower and middle Huronian rocks. Furthermore, according to Tyler and Twenhofel (1952, p. 118–128), the Negaunee iron-formation and Goodrich quartzite of Van Hise and Leith in the Palmer area are correlated with the Goose Lake iron-formation member of the Siamo slate and the Siamo slate, respectively.

The correlation of the quartzite that overlies the iron-formation in the Palmer area with the Goodrich quartzite of the Marquette range proper, as proposed by Van Hise and Leith, is accepted by the writer because of the lithologic similarity of the quartzite mapped as Goodrich in the Palmer area to known Goodrich quartzite in outcrops about 5 miles to the northwest near the center of the Marquette trough; the presence of monazite both in the quartzite in the Palmer area and in outcrops of known Goodrich quartzite; and the absence of abnormal radioactivity in the Siamo slate (see table 1) in the Marquette trough.

### PALMER GNEISS

The highly metamorphosed rocks along the southern boundary of Huronian rocks in the mapped area were assigned to the pre-Huronian Palmer gneiss by Van Hise and Leith (1911, p. 255–256). This interpretation is followed in the present report, but some of these rocks may represent metamorphosed lower or middle Huronian sedimentary rocks in accordance with the interpretation of Lamey (1935).

These rocks are granite, granite gneiss, diorite, amphibolite, chlorite schist, sericite schist, dolomite, and quartzite.

### AJIBIK QUARTZITE

The recognition of the Ajibik quartzite is difficult, because it grades from a massive, dense, white or reddish quartzite with scattered beds of conglomerate to a highly sericitized and granitized quartzose rock. Some of the rocks mapped as Ajibik quartzite may consist in part of lower Huronian Mesnard quartzite which has a similar lithologic character. The Ajibik quartzite is probably about 300 feet thick in the eastern part of the mapped area and thins to about 50 feet in the western part.

### SIAMO SLATE

The Siamo slate was not recognized in the Palmer area by Van Hise and Leith (1911). However, several outcrops of interbedded coarse-grained quartzite and sericitic slate occur in the SW¼ sec. 28 and NW¼ sec. 30 (pl. 9), and these have been designated on the map as Siamo slate. These beds dip about 60° to the northeast, overlie the Ajibik quartzite, and underlie the Negaunee iron-formation.

### NEGAUNEE IRON-FORMATION

The Negaunee iron-formation overlies the Ajibik quartzite in most of the Palmer area and consists of alternating laminae of red jasper and specular hematite or of interbedded gray chert and fine-grained hematite, possibly specular. Interbedded with the chert and hematite are many beds of coarse quartzite. At the Moore mine (S½ sec. 28) many lenses and beds of coarse quartzite and conglomerate, some of which contain cobbles as large as several inches in diameter, are associated with the iron-formation. Some of the lenses have been interpreted by Tyler and Twenhofel (1952, p. 123) as filled channels that were cut in the iron-formation, but H. L. James (1954, written communication) believes that they are in infolded masses.

The true thickness of the Negaunee iron-formation in the Palmer area is probably about 800 feet. However, the thickness is not uniform and in places much, if not all, of the Negaunee iron-formation may be absent because of faulting. Thinning of the iron-formation on the flanks of the major folds has also probably occurred. Other geologists have interpreted the thinning and local absence of the iron-formation in the Palmer area as caused by pre-Goodrich erosion.

### GOODRICH QUARTZITE

In the Palmer area the Goodrich quartzite is composed of a locally developed basal cobble or boulder conglomerate which grades upward into interbedded coarse-grained quartzite and pebble conglomerate.

Locally the lithologic character of the basal conglomerate varies and is dependent upon the character of the subjacent formation. At the Isabella mine (SW¼ sec. 29) the lower part of the Goodrich is composed almost entirely of cobbles and boulders of granite and schist derived from the early Precambrian to the south and also abundant jaspilite derived from the underlying Negaunee iron-formation. Locally, as at the Old Volunteer mine (on section line between secs. 30 and 31), the basal part of the Goodrich contained enough specular hematite fragments to constitute ore. The local abundance of iron-formation fragments in the lower part of the Goodrich indicates that erosion of the underlying iron-formation was taking place during Goodrich time. Because of the difference in competence between the two formations, as evidenced by the complex folding in the iron-formation as contrasted with the gentle folding in the quartzite, the contact is commonly faulted, and the Goodrich seems to rest with angular unconformity on the underlying Negaunee iron-formation.

Except for the local development of boulder and cobble conglomerate near the base of the formation, the Goodrich quartzite consists almost entirely of alternating beds of coarse quartzite and pebble conglomerate. The thickness of the observed pebble conglomerate beds ranges from about 2 inches to 2 feet. The pebble conglomerate beds are separated by beds of coarse sand, which range from 1 foot to 10 feet or more in thickness. These lithologic relationships are based on outcrops of only the lower 200 feet of the Goodrich. The lower part of the Goodrich is fairly well exposed in the Palmer area, but only one exposure is known which is definitely more than 200 feet from the base. Because monazite is most abundant in beds of pebble conglomerate and because gamma-ray logs show an increase in monazite content in the middle and upper parts of the formation, the percentage of pebble beds probably increases similarly in those parts of the formation.

The maximum thickness of Goodrich quartzite penetrated by diamond drilling in the Palmer area is about 1,100 feet. The true stratigraphic thickness of the formation is not known because no sediments younger than the Goodrich quartzite were penetrated in the diamond drilling, and no information is available on the amount of folding that might be present.

### DIKE ROCKS

An eastward-trending metadiabase (H. L. James, 1954, written communication) dike occurs in the N½ sec. 31 and the S½ sec. 29. The total thickness of the dike is not shown in any of the several outcrops but the writer believes it ranges from 50 to 100 feet. An outcrop of sheared metadiabase(?) in the SW¼ sec. 28 is along the strike of the metadiabase dike and is probably a sheared and altered portion of the dike. Others (Tyler and Twenhofel, 1952, p. 123–124) have interpreted this outcrop as being pyroclastic material in the iron-formation.

Hotchkiss [1] has reported a northward-trending dike about 30 feet wide in the underground workings of the Old Volunteer mine.

### STRUCTURE

The interpretation of the structure of the Palmer area is complicated by the lack of good exposures. The main structural features are the

[1] Hotchkiss, W. O., 1903, Some changes in the geology of the area about Palmer, Mich.: Unpublished Bachelor of Science thesis in files of Univ. Wis. Library, Madison, Wis.

major eastward-trending Palmer fault, which separates the Palmer area from the main part of the Marquette synclinorium, and several other faults of smaller displacement. The general dip of the rocks in the Palmer area is northward, but locally in the Negaunee iron-formation the rocks are tightly folded and highly contorted.

The Palmer fault, originally described by Hotchkiss,[2] has a vertical displacement of probably 1,000 to 3,000 feet, and its position on the surface has been inferred chiefly on the basis of topography (pl. 9). A fault-line scarp is formed by steep south-facing hills composed of lower(?) and middle Huronian quartzites, in contrast to the relatively flat valley to the south which is underlain by the more easily eroded upper Huronian Goodrich quartzite.

According to Hotchkiss,[3] the Volunteer fault is known mainly from diamond drilling at the Old Volunteer mine; it probably extends eastward as evidenced by the brecciation in quartzite along the north side of the hill of Ajibik quartzite in the N½SW¼ sec. 28.

The fault in the S½ sec. 28 and trending southeast through the N½ sec. 34 is inferred to explain the northwestward-trending hill composed of Ajibik quartzite in the SW¼ sec. 28. This quartzite has been designated as Goodrich quartzite by other writers (Van Hise and Leith, 1911, pl. 17), but it is believed by the writer to be Ajibik, as it exhibits no abnormal radioactivity and is a hard dense white to reddish fine-grained pure quartzite and lithologically is very similar to known Ajibik quartzite in outcrops north of the Palmer fault.

The structural relationships at the Old Maitland mine (W½ sec. 30) are not known. Abundant pieces of Goodrich quartzite occur on the dump near the shaft, but the nearest outcrop of Goodrich is about 2,000 feet east of the shaft. Geologic information in the area of the Old Maitland mine is scanty, but there probably is a downfolded or downfaulted segment of Goodrich quartzite in the vicinity of the shaft.

The absence of the iron-formation between the Ajibik quartzite and the Goodrich quartzite in the SE¼ sec. 30 is probably due to faulting. Slickensided surfaces in Ajibik quartzite near the center of sec. 30, where the road crosses the railroad, strike N. 55° W. and dip vertically. The thinning of the iron-formation in the N½ sec. 31 may be due to flowage of material from the more steeply dipping flanks of the major folds.

The occurrence of Goodrich quartzite near the east side of the New Richmond pit (sec. 27) is probably due to a small downfolded or downfaulted block of quartzite into the iron-formation.

[2] Hotchkiss, W. O., 1903, op. cit., p. 35–42.

[3] Idem, p. 28–35.

## OCCURRENCES OF MONAZITE

### MINERALOGY

The monazite occurs as rounded to subrounded detrital grains in the matrix of quartz pebble conglomerate. The brownish-red to honey-colored monazite grains are generally 0.10 to 0.20 mm in diameter. The identification of the monazite was confirmed by the writer by X-ray powder diffraction photographs. Locally the monazite grains make up more than 50 percent of the matrix in the conglomerate, and several lenses of monazite grains as much as 2 mm thick were noted in thin sections. A sketch of a photomicrograph of a concentration of monazite in the quartzite is shown in figure 43.

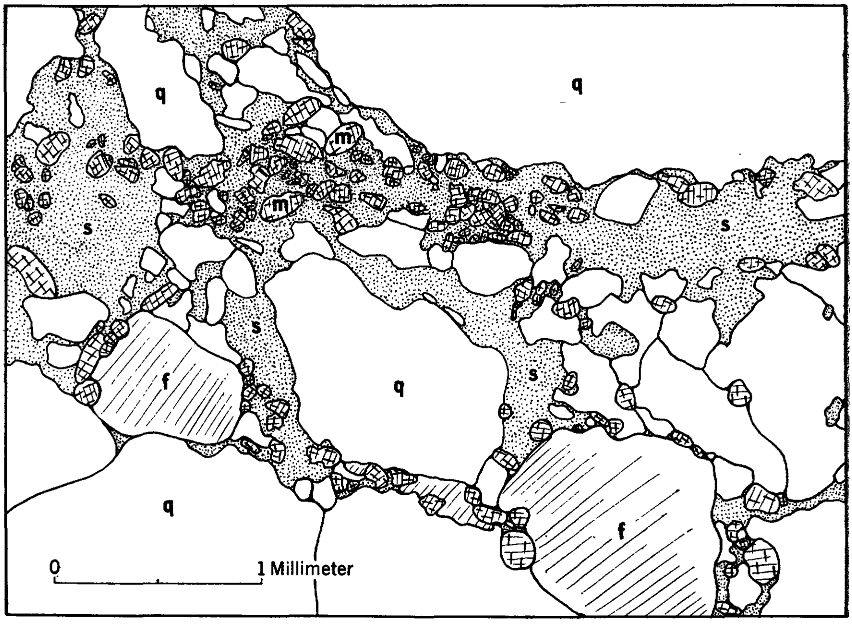


FIGURE 43.—Sketch of a photomicrograph (× 28) of Goodrich quartzite showing quartz (*q*), interstitial monazite (*m*), and altered feldspar (*f*). Stippled areas (*s*) are mainly sericite, chlorite, hematite, rutile, and magnetite.

Results of chemical and spectrographic analyses of a relatively pure sample of monazite are shown in table 1. X-ray powder diffraction data are shown in table 2.

The sample of monazite (about 92 percent pure) was extracted from a composite chip sample of several glacial boulders and selected mine dump samples. The sample is probably representative of the monazite in the Palmer area. The monazite was concentrated by gravity separation on a Wilfley table after grinding and sizing, and then further purified with a Frantz isodynamic separator and separated magnetically into two fractions to find out if the difference in magnetic susceptibility was related to a difference in chemical composition.

Heavy minerals other than monazite in the Goodrich are mainly hematite, magnetite, ilmenite, and rutile.

TABLE 1.—*Chemical and spectrographic analyses of monazite concentrates from the Goodrich quartzite, Palmer area, Marquette County, Mich.*

| | MMMc[1] | MMMd |
|---|---|---|
| **Chemical analyses [2]** | | |
| $P_2O_5$ | 19.4 | 19.3 |
| Rare-earth oxides (total) | 47.9 | 46.0 |
| $ThO_2$ | 7.6 | 7.4 |
| $SiO_2$ | 6.9 | 5.7 |
| $Fe_2O_3$ [3] | 5–10 | 5–10 |
| $Al_2O_3$ [3] | 5–10 | 5–10 |
| $TiO_2$ [3] | 1–5 | 1–5 |
| U | 0.18 | 0.17 |
| PbO [3] | 1–5 | 1–5 |
| Total | 94–112 | 91–109 |
| **Spectrographic analyses [4]** | | |
| Percent range: | | |
| More than 10 | Ce | Ce |
| 5–10 | P, Si, La, Th | P, Si, La, Th |
| 1–5 | Fe, Al, Nd, Pr, Pb | Pb, Fe, Al, Nd, Pr |
| .5–1 | Ti | Ti |
| .1–.5 | Dy, Mg, Gd, Er, Y | Dy, Gd, Y, Er, Mg |
| .05–.1 | Sm, Zr, Sr, Ca, Ni, Tm | Sm, Zr, Sr, Ca, Ni, Tm |
| .01–.05 | Yb, Ho, Co, V | Yb, Ho, Co, V |
| .005–.01 | B, Mn, Sc, Eu, Cu, Lu | B, Mn, Sc, Eu, Cu |
| .001–.005 | Ba | Lu, Ba |
| .0005–.001 | Cr | Cr |
| .0001–.0005 | Ag, Be | Ag, Be |

[1] Sample MMMc slightly more magnetic than sample MMMd. Specific gravity 4.63 (Berman balance determination of several grains).
[2] By Harry Levine, U. S. Geological Survey.
[3] Spectrographic analyses.
[4] By Katherine E. Valentine, U. S. Geological Survey.

TABLE 2.—*X-ray powder diffraction data of monazite from the Goodrich quartzite, Palmer area, Marquette County, Mich.*

[X-ray data by R. C. Vickers. Spacing obtained with a diffractometer calibrated with a silicon standard. Copper radiation, nickel filter, speed ¼° per min]

| *d* (*A*) | *Intensity estimated* | *d* (*A*) | *Intensity estimated* |
|---|---|---|---|
| 5.20 | 1 | 2.867 | 6 |
| 4.79 | 2 | 2.599 | 2 |
| 4.68 | 2 | 2.442 | 3 |
| 4.17 | 6 | 2.187 | 3 |
| 3.53 | 2 | 2.135 | 6 |
| 3.51 | 4 | 1.963 | 3 |
| 3.285 | 8 | 1.892 | 2 |
| 3.086 | 10 | 1.866 | 4 |
| 2.975 | 1 | | |

NOTE.—The above d-values agree very closely with those calculated by Pabst (1951, p. 63) from unit cell dimensions determined by Parrish (1939, p. 651–652) for a thorium-free monazite.

## DETERMINATION OF THE MONAZITE CONTENT OF SAMPLES OF GOODRICH QUARTZITE

The monazite content of all samples of Goodrich quartzite listed in this report was determined by comparing the beta-gamma activity of the sample with prepared standards. The standards were prepared by separating relatively pure monazite obtained from a composite sample of several glacial boulders and mine dump samples of Goodrich quartzite and then re-mixing various proportions of the monazite with the crushed rock from which the monazite had been separated. A graph was then plotted to show the relation of the monazite content of the standards to their equivalent uranium content (fig. 44).

The ordinate intercept at 0.002 percent eU represents the background radiation of the quartzite and may be due in part to small amounts of monazite that could not be recovered in the separation.

This method of monazite determination was used because a study of alpha-sensitive stripping film on thin sections of the quartzite indicated that almost all radioactivity of the quartzite was due to

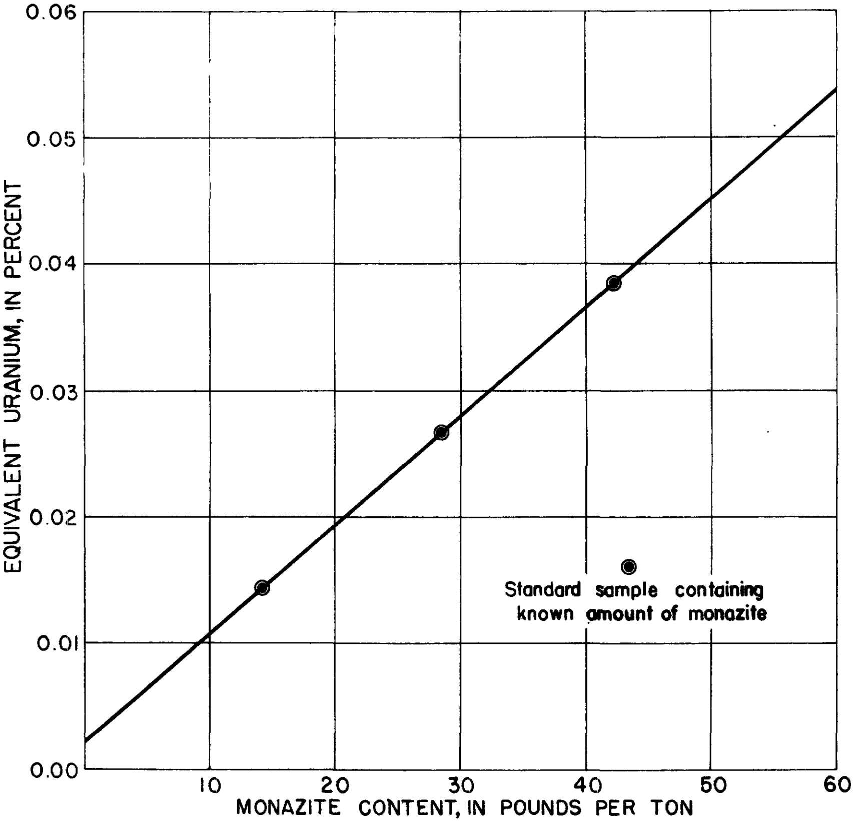


FIGURE 44.—Graph showing relationship between equivalent uranium and monazite content of samples of Goodrich quartzite from the Palmer area, Marquette County, Mich.

monazite. The accuracy of the method was checked by determining the monazite content of a sample by three methods. The methods and results are tabulated below.

| *Method* | *Monazite pounds per ton* |
|---|---|
| Grain count of heavy liquid fraction (plus 2.96 specific gravity) | 36.6 |
| Gravity (Wilfley table) and magnetic concentrate (Frantz isodynamic separator) | 34.9 |
| Equivalent uranium content (from graph) | 34.0 |

In using the radioactivity of the samples to determine their monazite content, it is assumed that the radioactivity of the monazite (due mainly to its thorium content) in the individual samples tested is about the same as the average radioactivity of the monazite in the composite sample that was used to prepare the standards, and that the ratio of other radioactive minerals to monazite is very low.

## DISTRIBUTION

The stratigraphic position and lateral extent of the monazite-bearing beds are known from (1) samples of outcrops which are mainly restricted to the lower 200 feet of the formation, (2) gamma-ray logs of three diamond-drill holes that penetrate an apparent thickness of 1,100 feet of the Goodrich quartzite, and (3) analyses of several diamond-drill core samples.

### RESULTS OF SAMPLING OF OUTCROPS

In most outcrops examined, the monazite was concentrated in narrow beds of pebble conglomerate from 2 inches to 2 feet thick and separated by beds of coarse-grained quartzite from 1 foot to 10 feet or more thick. Samples from the coarse sand beds contained as much as 6 pounds of monazite per ton, whereas samples from the pebble conglomerate beds contained as much as 23 pounds of monazite per ton.

Eighteen chip-channel samples were taken across the beds in most of the outcrops which represent only the lower part of the Goodrich quartzite. The total of the individual stratigraphic thicknesses sampled was about 65 feet. However, some of the samples from different outcrops may represent the same stratigraphic position in the Goodrich, and therefore the actual stratigraphic thickness sampled may be considerably less. Two of the samples taken from the lower part of the Goodrich contained 11.5 and 17 pounds of monazite per ton in beds 0.5 and 0.2 foot thick, respectively. The remainder of the outcrop samples contained less than 6 pounds of monazite per ton. The weighted average monazite content of all samples taken from the lower 200 feet of the Goodrich was 2.9 pounds per ton.

A sample of pebble conglomerate from the only quartzite outcrop that is known to be more than 300 feet from the base of the formation contained 23 pounds of monazite per ton. This outcrop is about 500 feet east of DDH–4, near the center of sec. 29 (pl. 9). The full thickness of the pebble conglomerate bed was not exposed, and, because of weathering, the attitude of the beds could not be determined. A scintillation-counter survey of the outcrop containing the pebble conglomerate indicated an average monazite content of about 6 pounds per ton.

Because of the relatively high monazite content found in many glacial boulders (as much as 110 pounds per ton) and from mine dump samples (as much as 50 pounds per ton), it was apparent that the higher grade monazite-bearing beds were not observed in outcrops.

### RESULTS OF GAMMA-RAY LOGGING OF DRILL HOLES

Three diamond-drill holes that penetrated the Goodrich quartzite were logged with a portable gamma-ray logging instrument consisting of a 1- by 12-inch Geiger-Müller tube in a waterproof probe, 700 feet of cable, and a portable survey meter. The meter deflection was recorded by the operator at 2-foot intervals and at all inflection points.

Two of the holes (DDH–3 and DDH–4) were drilled during the past 4 years by the Cleveland-Cliffs Iron Co. The third hole (DDH–101) was drilled during the early 1900's and was recently reopened by the Cleveland-Cliffs Iron Co. The results of the gamma-ray logging are shown in plate 10. DDH–5, also drilled many years ago, was logged but showed no anomalous radioactivity. This hole is just north of the Palmer fault and is probably in the middle Huronian Siamo slate. The water level in all the holes was within a few feet of the surface.

Because the logging reel was equipped with only about 700 feet of cable, the lower part of the Goodrich quartzite could be logged in only one drill hole (DDH–3); the gamma-ray log indicates that most of the radioactivity occurs more than 300 feet from the base of the formation. The sharp peaks of the gamma-ray logs are interpreted as being caused by relatively thin beds of monazite-bearing pebble conglomerate that contain from 20 to 160 pounds of monazite per ton. These monazite-rich layers are separated by beds of coarse quartzite which range from a few inches to a few feet in thickness.

The fairly close correlation between the gamma-ray logs suggests that the zones composed of more closely spaced monazite-bearing beds are persistent laterally for several hundred feet in a north-south direction. The persistence of the zones east and west of the cross section can only be inferred.

Accurate calibration of the gamma-ray logs in terms of actual monazite content is not possible because of the many variable factors involved and because of the lack of enough analyzed core for standardizing the instrument. The approximate monazite content can be estimated, however, by comparing the results of channel sampling of the lower part of the Goodrich with the values obtained on the gamma-ray log of DDH-3. If the average gamma-ray log value for the lower 200 feet of the Goodrich quartzite in DDH-3 is about 0.12 thousand counts per minute (background 0.05 thousand counts per minute), representing 2.9 pounds per ton, then a gamma count of 0.4 thousand per minute may indicate a monazite content of as much as 10 pounds per ton.

### RESULTS OF ANALYSES OF CORE

Specimens of core representing about 3 percent of the total core from diamond-drill holes DDH-3 and DDH-4 were scanned with a scintillation counter, and several 3-inch lengths of the core were found to be abnormally radioactive.

The specimens were analyzed with the following results:

| Field no. | Hole no. | Footage [1] | eU [2] | Monazite (pounds per ton)[3] |
|---|---|---|---|---|
| MM-113-52 | DDH-4 | 36-52 | 0.049 | 54 |
| MM-97-53 | DDH-4 | 523-532 | .014 | 14 |
| MM-98-53 | DDH-4 | 362-385 | .006 | 4 |
| MM-99-53 | DDH-4 | 567-585 | .013 | 13 |
| MM-100-53 | DDH-4 | 585-611 | .021 | 22 |
| MM-101-53 | DDH-3 | 30-36 | .007 | 6 |
| MM-102-53 | DDH-3 | 59-71 | .011 | 10 |

[1] Footage is the drilled interval from which a single specimen of core was saved and does not represent footage of entire sample. Actual length of core samples was about 3 inches for each sample.
[2] Analyses by S. P. Furman, U. S. Geol. Survey, Denver, Colo.
[3] Based on eU/monazite ratios of standard samples. (See p. 181.)

The location and monazite content of the samples are shown on the cross section, plate 10.

Because only a small percentage of core was available for study from the drill holes, the analyses of the core are of little value for quantitative appraisal. It is noteworthy that, although specimens of core from the lower 300 feet of the Goodrich quartzite from DDH-3 and DDH-4 were scanned with a scintillation counter, no abnormal radioactivity was detected.

### OCCURRENCES OF MONAZITE IN THE GOODRICH QUARTZITE OUTSIDE THE PALMER AREA

A brief examination with a scintillation counter was made of the Goodrich quartzite outside the Palmer area to determine the extent of the monazite-bearing beds. Outcrops of Goodrich quartzite were examined in several places in the Marquette trough including the Goodrich mine on the south side of the Marquette trough, the Blueberry mine on the north side, the Humbolt and Michigamme mines toward the west end, and in the city of Ishpeming in the east-central part of the Marquette trough. Only slight abnormal radioactivity was detected in the Goodrich at these localities. The highest radioactivity (0.05 mr/hr, background 0.02 mr/hr) was detected in an outcrop of Goodrich quartzite in the N½ sec. 20, T. 47 N., R. 27 W. A few grains of monazite were identified in thin sections from this outcrop, which is about 5 miles N. 75° W. of Palmer and is the closest occurrence of Goodrich quartzite in the Marquette trough to the Goodrich in the Palmer area.

In the Gwinn district, which is an outlier of upper Huronian rock about 12 miles southeast of Palmer, quartzite probably correlative with the Goodrich was found by L. P. Barrett to exhibit local abnormal radioactivity. The author re-examined the area briefly and found several local concentrations of monazite in a coarse arkosic quartzite that overlies and grades downward into a granite porphyry. Samples from this locality (SW¼ sec. 19, T. 45 N., R. 25 W.) contained as much as 9 pounds of monazite per ton. A scintillation-counter survey of the outcrops indicated that the monazite concentrations were of a very local extent.

## CONCLUSIONS

The study of the occurrence of monazite in the Goodrich quartzite in the Palmer area, Marquette County, Mich., shows that monazite is concentrated in beds of pebble conglomerate from a few inches to a few feet thick. Sampling of outcrops, which are mainly restricted to the lower 200 feet of the quartzite, indicates an average monazite content of only about 2.9 pounds per ton, but correlation of gamma-ray logs of diamond-drill holes that penetrate 1,100 feet of the Goodrich indicates that most of the radioactivity probably occurs more than 300 feet above the base of the formation. Individual beds of pebble conglomerate in glacial erratics contain as much as 110 pounds of monazite per ton.

The large tonnages of monazite-bearing quartzite suggest that this area should be considered as a potential low-grade monazite source.

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