THE PETROLOGY AND SEDIMENTATION OF THE LOWER PROTEROZOIC BARRON QUARTZITE, NORTHWESTERN WISCONSIN

A THESIS
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ABSTRACT

The Barron Quartzite of northwestern Wisconsin is a fine-grained, quartz-cemented, buff to red quartz arenite with minor interbedded argillite and a thin basal quartz-pebble conglomerate. The thickness of the Barron is at least 225 m (as shown by drill core) and may be greater than 400 m. Mafic dikes cut the Barron Quartzite but are as yet undated.

The primary framework component of the Barron Quartzite is common quartz (75%). Polycrystalline quartz (grains with 2 to 5 component crystals), stretched polycrystalline quartz (composites of numerous, suctured crystals), recrystallized polycrystalline quartz (grains made up of numerous, small, polygonal crystals) and vein quartz together make up approximately 16% of framework grains. Multicycle quartz grains (common quartz grains which have optically continuous overgrowths of quartz that have been abraded and surrounded by other overgrowths) are also present. Chert and iron-formation rock fragments occur but are rare. Feldspar is absent. Quartz cement, which occurs as optically continuous overgrowths on quartz grains, is common (approximately 9%) and hematite cement constitutes less than 1%. The heavy mineral suite is composed almost entirely of rounded zircon with minor rounded tourmaline and rutile, and minor magnetite.

A possible depositional environment for the Barron Quartzite is a braided alluvial plain which was superseded by a marine shelf environment. Paleocurrent data are variable. Most localities show a

unimodal pattern towards the south, indicating sediment transport form north to south. However, polymodal and bimodal-bipolar patterns are also present at some outcrops. A unimodal pattern probably indicates a fluvial depositional environment while a bimodal-bipolar pattern could suggest a tidally-influenced marine depositional environment.

The Barron Quartzite is probably correlative with several of the other Precambrian quartzites in the Lake Superior region, including the Baraboo, Sioux, Flambeau, Waterloo, and McCaslin Quartzites. Of these, the Baraboo is the best dated, probably having been deposited between 1760 and 1630 Ma (Van Schmus, 1978; Van Schmus and Bickford, 1981).

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CHAPTER I INTRODUCTION

Introduction

The Barron Quartzite is a pink to red quartz-cemented quartz arenite with minor interbedded argillite and a thin, basal conglomeratic zone. The Barron is discontinuously exposed over a 300 square mile area in northwestern Wisconsin. It is sub-horizontal and unmetamorphosed.

The precise age of the Barron Quartzite is unknown due to the inherent difficulty of dating a sedimentary rock and to the absence of an exposed basal or upper contact. The age range inferred for the Barron Quartzite of 1750 m.y. to 1630 m.y. (Van Schmus, 1975, 1980) is based on the assumption that the Barron is correlative with the Baraboo Quartzite of southern Wisconsin which was deposited during that time interval.

Purpose

The purpose of this thesis is fourfold:

1) to examine the lithology and sedimentary structures of the Barron Quartzite in order to present a detailed description of the formation.

2) to determine the depositional environment.

3) to determine the provenance.

4) to use the information gathered to determine possible correlative relationships between the Barron Quartzite and other Precambrian quartzites in the Lake Superior area.

Location

The Barron Quartzite is located in northwestern Wisconsin in parts of Washburn, Sawyer, Barron, and Rusk Counties (Fig. 1). The outcrop area covers approximately 483 square kilometers, extending from Hayward in the north to Weyerhauser in the south and Radisson in the east to Rice Lake in the west.

The latest geologic map of Wisconsin shows one large body of quartzite in Sawyer, Rusk, and northeast Barron Counties, one outlier to the northeast in central Sawyer County, and three small outliers to the west in Washburn County (Mudrey et al., 1982). The Barron Quartzite is expressed as the rolling hills of the 'Blue Hills' area. Relief here is considerable, with elevations varying from 1120 ft. to 1720 ft.

Outcrops are quite common in the southern part of the area and also along the eastern edge (Fig. 2). Detailed descriptions of outcrop locations are given in Appendix A. Outcrops are rarer in the middle of the area and non-existent in the north. The extent of the Barron in the northern reaches was verified on the basis of boulders, talus, and topography by Hotchkiss (1915). During this investigation, no outcrops

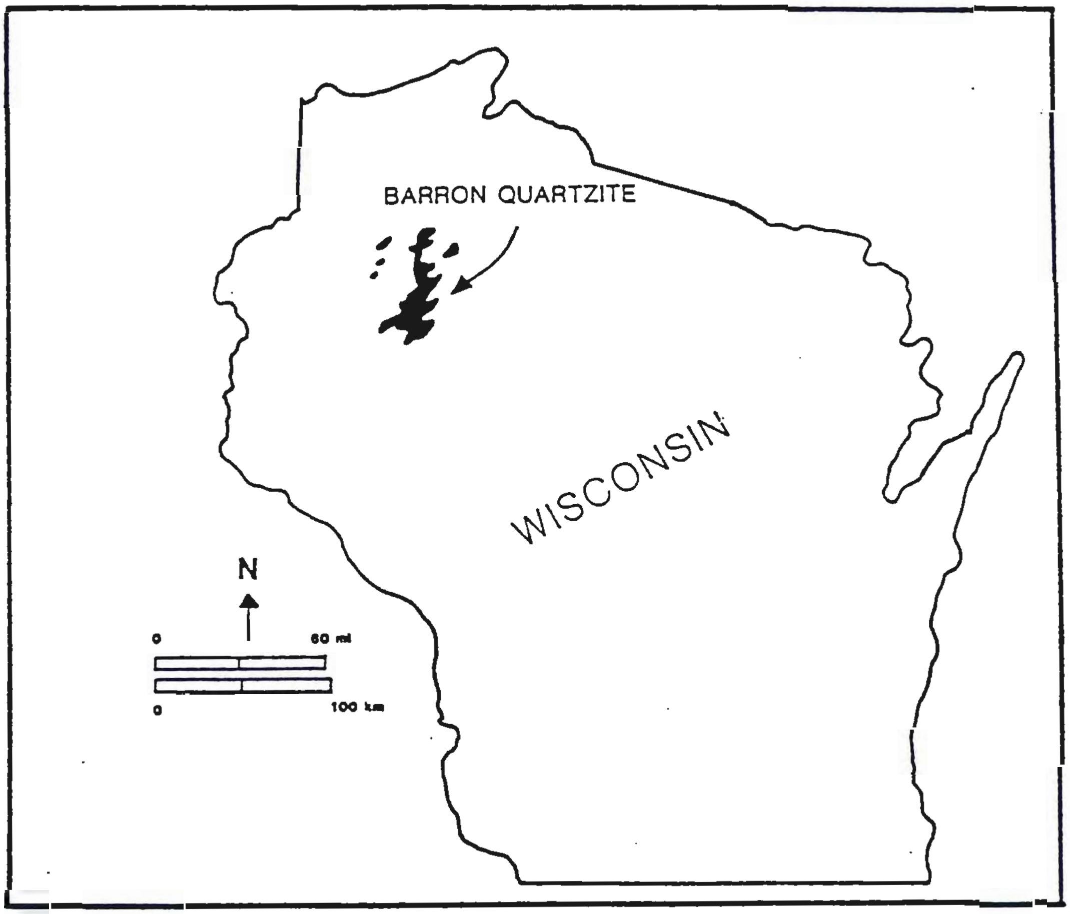


Figure 1. Location map of Barron Quartzite.

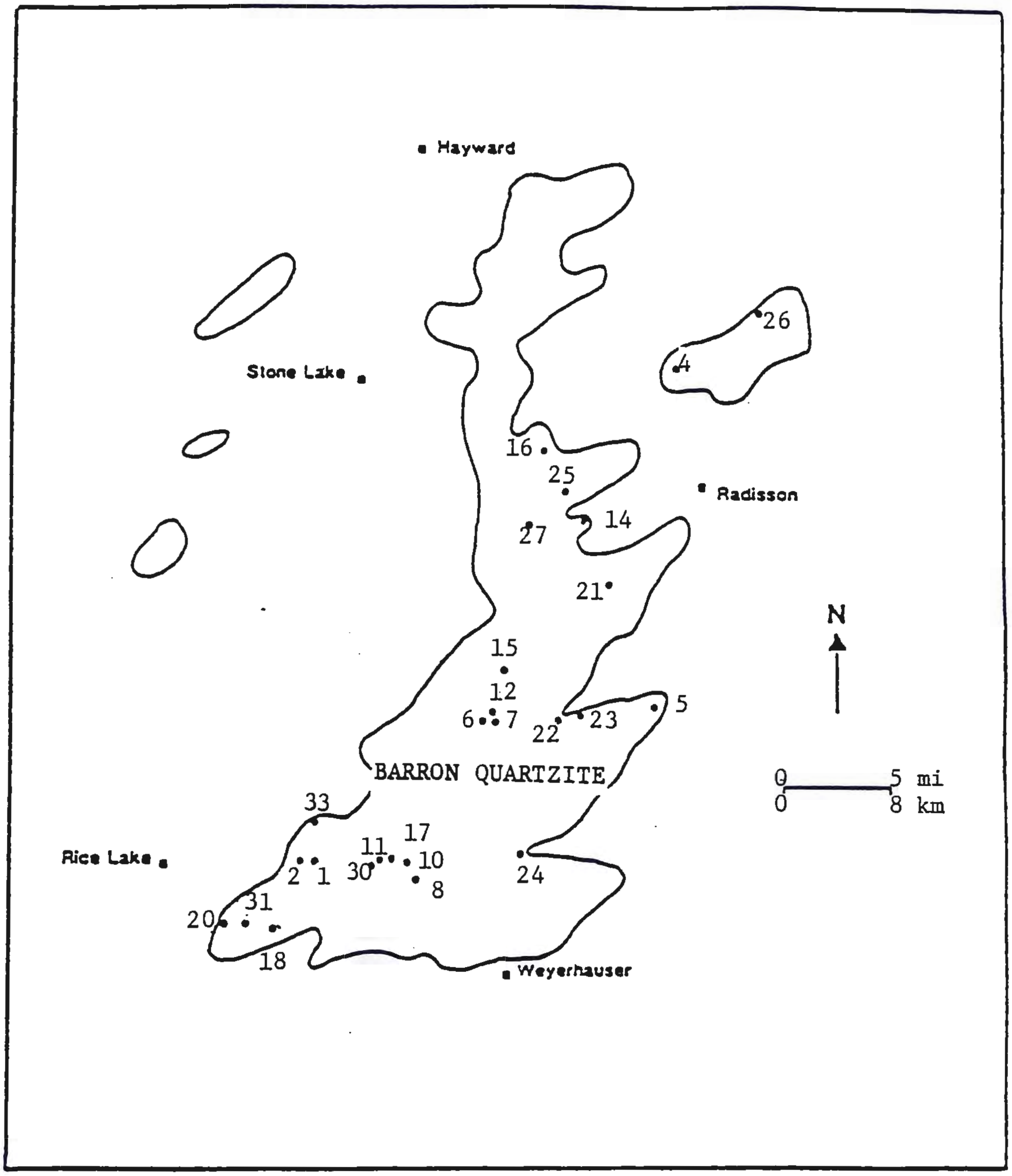


Figure 2. Location map of Barron Quartzite outcrops.

were observed in the northwestern area. However, boulders and talus of the Barron Quartzite were observed. Topographic highs also occur in this area. Therefore, Barron Quartzite is believed to be present as three outliers to the northwest.

Methods of Study

Field Work

Field work was conducted during the summer and fall of 1984. This consisted of outcrop and rock descriptions, sampling, and taking measurements of the orientations of cross-bedding, ripple marks, and trough axes.

Each outcrop was described and sampled from base to top with samples being taken every five feet and paleocurrent measurements grouped together in the same five foot intervals. This was done in order to note changes in lithology and/or cross-bed orientation through the formation. For each interval, the following procedures were performed:

1) samples were collected and numbered, with the tops of the samples indicated.

2) noted lithology, texture, color, bedding type (planar or lenticular) and bedding thickness.

3) measured orientations of cross-beds, noted type of crossbedding present (planar or trough), and made note of other structures present, their dimensions and orientations.

In all, 27 outcrops of Barron Quartzite were examined. Two drill cores were also examined and logged. A total of 175 measurements was made on cross-beds, 18 measurements were taken on other current features such as trough axes and ripple trends, and 151 samples were collected.

Laboratory Work

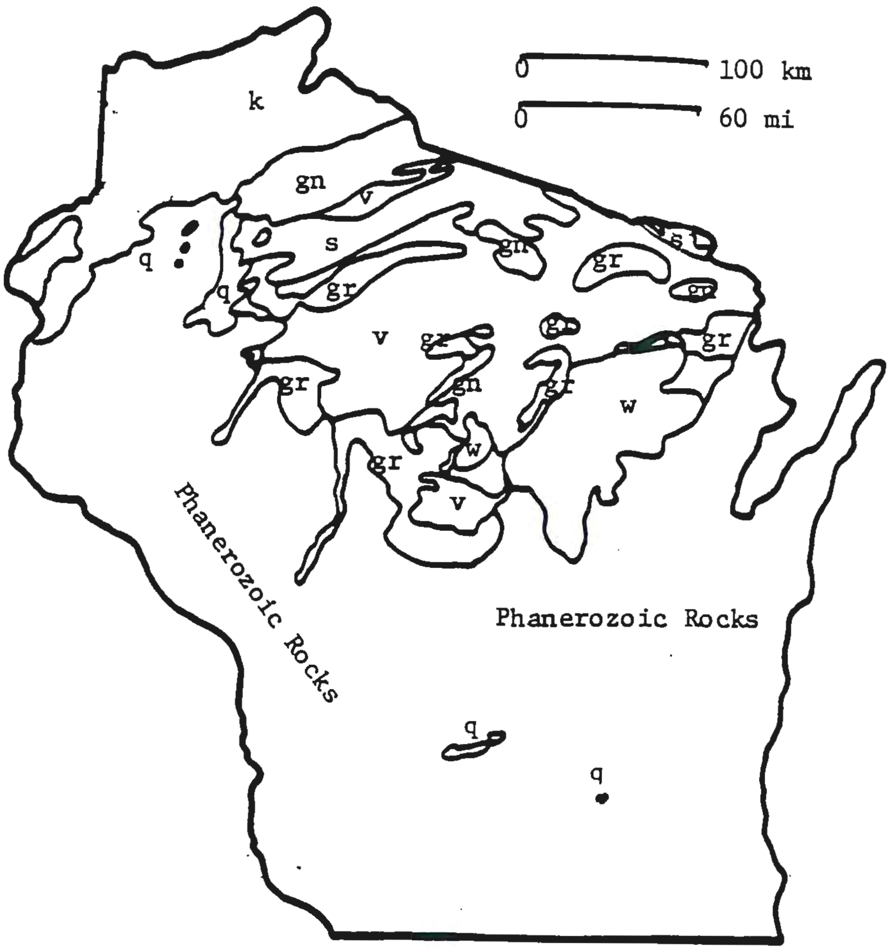
Laboratory work consisted of examination of hand specimens and thin sections, point-counting thin sections, staining heels for potassium feldspar, and preparation and counting of heavy mineral mounts. Seventy-five hand specimens were examined and described and thin sections of these specimens were also studied. A thin section description was completed for each; this included noting the minerals present, grain sizes, sorting and roundness. Thin sections were also scanned for multicycle quartz grains. Point counts were made of 60 thin sections, and 30 heels were stained for potassium feldspar. Thirteen mounts of heavy minerals were prepared and studied; 300 grains were counted in eight of the mounts. In addition, two drill cores of Barron Quartzite (accessible through the Wisconsin Natural History and Geologic Survey) were logged and an additional fourteen thin sections of core samples were examined.

REGIONAL GEOLOGY

The Precambrian of northwestern Wisconsin consists of Archean metavolcanics, granite, gneiss, and amphibolite, unconformably overlain by Lower Proterozoic strata of the Animikie Group. (Fig. 3). These in turn are unconformably overlain by the Lower Proterozoic Barron Quartzite. Keweenawan rocks top off the Precambrian in this region. The Keweenawan consists of a thick pile of volcanics and sedimentary rocks which form the Midcontinent gravity high. This gravity high extends from northern Minnesota into Kansas.

Post-Precambrian deposits consist of a Lower Cambrian or possibly Upper Precambrian conglomerate which overlies the Barron Quartzite, and Pleistocene glacial drift.

The Barron is considered to be a member of the stratigraphic division referred to as the Baraboo interval (Dott, 1983). the Baraboo interval includes the three major Precambrian red quartzites of the Lake Superior region - the Barron, Baraboo and Sioux (Fig. 4) - all probably deposited between 1450 and 1750 Ma (Dott, 1983). Other Precambrian quartzites in this region (the Waterloo and the McCaslin Quartzites) may also belong to this interval (Ojakangas and Morey, 1981).



Middle Proterozoic Rocks	k - Keweenawan igneous and sedimentary rocks w - Wolf River rocks
Lower Proterozoic Rocks	q - quartzite gr - granite, diorite and gneiss s - sedimentary rocks v - metavolcanics and metasediments
Lower Proterozoic or Upper Archean Rocks	gn - granite, gneiss and amphibolite

Figure 3. Geologic map of Precambrian rocks in Wisconsin (after Mudrey, et al, 1982).

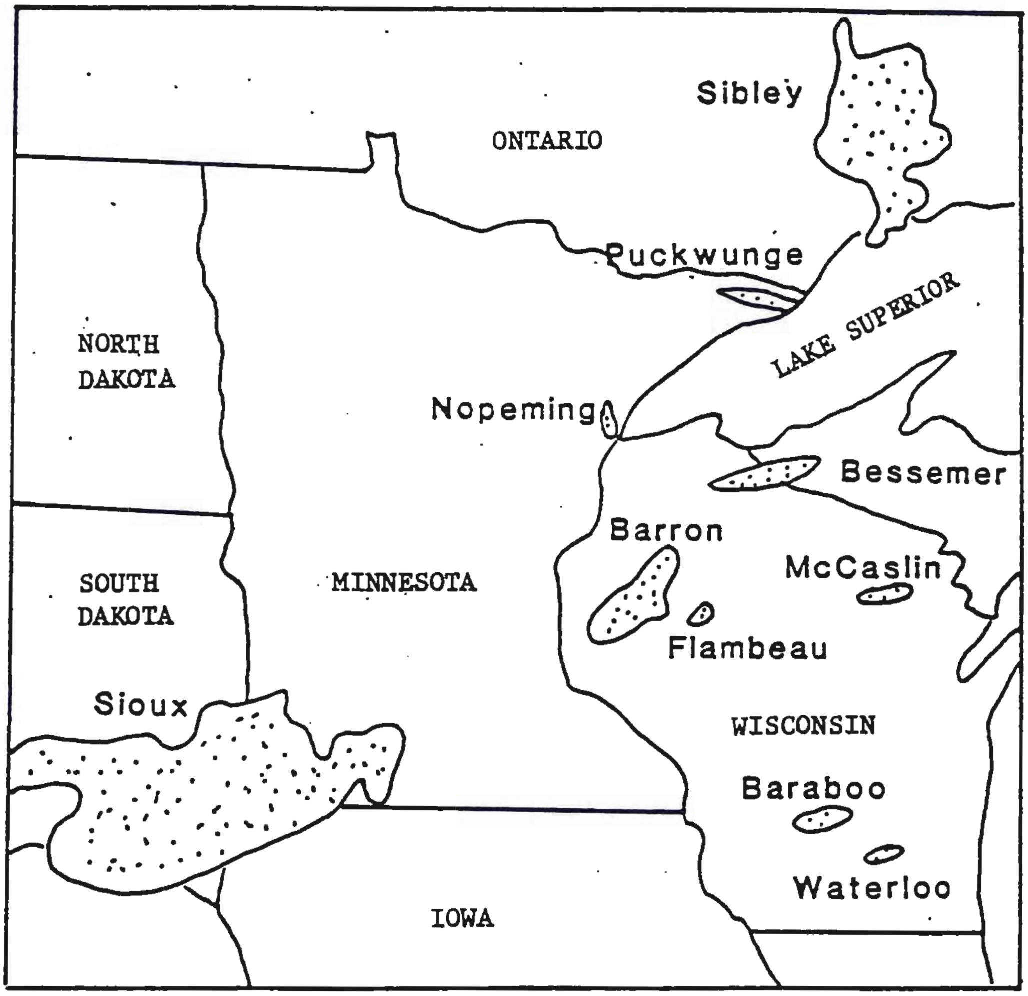


Figure 4. Proterozoic quartzites of the Lake Superior region.

PREVIOUS WORK

The Barron Quartzite has not previously been examined with any great detail regarding petrography, sedimentation, and provenance. Most of the previous work on the Barron was related to geologic mapping of northern Wisconsin or correlation of the Barron with other Precambrian quartzites. The primary studies concerning the Barron Quartzite are summarized below.

Chamberlin, 1879 and 1882

The first record of the Barron Quartzite was by T. C. Chamberlin in 1879. In this publication, only 2 outcrops of Barron were noted. The Barron was classified as Huronian in age and pipestone layers were described. In an 1882 survey of the geology of Wisconsin, the Barron and Flambeau Quartzites were grouped as the Barron Quartzite and were correlated with the Baraboo, New Ulm, and Sioux Quartzites.

Van Hise and Leith, 1911

In this U. S. G. S. Monograph, the Barron and Flambeau Quartzites are considered as one and mapped as undifferentiated Huronian. However, an opinion is given that they may represent two or three different series. Outcrops that are now known as Flambeau Quartzite are correlated with the Baraboo Quartzite (assigned a Lower Huronian age) while the ridges forming the Barron are considered to have a "younger aspect" and are considered to possibly be Keweenawan.

Hotchkiss, 1915

In 1915, the Wisconsin Geological and Natural History Survey published Mineral Lands in Part of Northwestern Wisconsin. In this report, the Barron was mapped and described. Hotchkiss assigned the Barron to the Upper Keweenawan based on the assumption that the Barron overlay Keweenawan 'traps'. The Flambeau Quartzite (considered separate from the Barron) was assigned to the Huronian. A geologic map showed the Barron as having three small southern outliers and four outliers to the north of the main body of quartzite. The maximum thickness of the Barron was given as approximately 600 ft. Hotchkiss also proposed the possibility that the area mapped as Barron Quartzite was actually underlain by two unconformable quartzites. He believed that a quartz arenite found above a conglomerate containing Barron cobbles was also part of the Barron Quartzite. Regarding the provenance of the Barron; according to Hotchkiss, the formations underlying the Barron Quartzite were " . . . bevelled off so completely as to yield almost no debris to the quartzite."

Hotchkiss and Bean, 1929

In Mineral Lands of Part of Northwestern Wisconsin the Barron is again listed as Keweenawan but it was acknowledged that it could be older, possibly Huronian in age.

Leith, Lund, and Leith, 1935

On a geologic map in this professional paper, the Barron Quartzite (combined with the Flambeau) is again assigned to the Upper Keweenawan but with a question mark. The quartzites are grouped with conglomerates, sandstones, arkoses, and shales that are considered to be, in part, possibly of Cambrian age.

Dott and Dalziel, 1972

In this paper, the correlative relationships of the Barron Quartzite were briefly explored. The Baraboo, Sioux, and Bessemer Quartzites were interpreted as probably being correlative with the Barron. The depositional environment proposed for the sedimentation of these quartzites was a subsiding shallow-water shelf.

Utzig, 1972

Utzig compared the Flambeau with the Barron Quartzite. His conclusion was that there was not a direct correlation between the Barron and Flambeau. His X-ray analyses showed kaolinite to be the only clay mineral present in the Barron. Diaspore and iron-oxide were found to be present as authigenic minerals and rutile and zircon were the only detrital heavy minerals identified.

Routledge, Parrish, and Leigh, 1981

In this U. S. Department of Energy publication, the authors discussed the potential for uranium deposits in the Barron. The Barron was cited as a potential host for uranium deposits for the following reasons: the Barron is Precambrian °Y 'in age, it has a large depositional basin, its original thickness was possibly several thousand meters, the lithology is quartzite to sandstone, and sedimentation was, at least partly, fluvial.

Campbell, 1981

Campbell briefly described the Barron and compared the Barron and Flambeau Quartzites. He concluded that the source of the Barron was probably quartz-rich sedimentary rocks. Paleocurrent directions for the Barron were found to be from south/southwest to north/northeast and also from north to south. A fluvial or marine environment was interpreted for the sedimentation of the Barron. Finally, the author concluded that the Barron and Flambeau probably were correlative although they may have been deposited in slightly different tectonic and/or sedimentary environments.

Dott, 1983

In this 1983 publication, Dott included the Barron Quartzite in the Baraboo interval (of 1450 to 1750 m.y.) and correlated it with the Baraboo and Sioux Quartzites. The sources of these quartzites were considered to be quartz-bearing silicic volcanics plus sedimentary, plutonic, and minor metamorphic rocks. He concluded that evidence points to either a fluvial or marine environment for the quartzites; he interpreted at least the upper part of the Baraboo to be definitely marine.

Greenberg and Brown, 1984

Greenberg and Brown interpreted the Barron to be part of an epicontinental deposit. They proposed 3 depositional models for the Baraboo interval rocks, a marine transgression model, a complex basin model, and a model which involved multiple sequences separated by major unconformities. The authors considered the latter two of these models to be the most plausible.

Ojakangas, in press

In a review paper on quartzites of the Lake Superior region, Ojakangas divided the quartzites into two distinct groups; a northern, younger group, probably 1100 to 1200 m.y. old, and a southern group of older (1750 to 1630 m.y. old) quartzites. The "Baraboo interval" Quartzites of Dott (1983) - the Sioux, Baraboo, Barron, Flambeau, McCaslin, and Waterloo Quartzites- are fully discussed in the report. His conclusions are as follows:

1) The quartzites are mineralogically and texturally mature.

2) The sand of the formations is probably largely of first cycle origin with significant contributions from older sediments.

3) The environment of deposition was probably a braided river-alluvial plain that was possibly superceded by a tidally-influenced marine environment.

4) The source area was low-lying, deeply-weathered, vegetationless, wind-abraded, and the rivers flowed form north to south.

5) The Barron, Sioux, Flambeau, and Waterloo Quartztites are lithologic correlatives, probably deposited between 1750 and 1630 Ma.

6) Deposition was on a stable, peneplaned landmass.

CHAPTER II THICKNESS, BASAL CONTACT, LITHOLOGY, AND SEDIMENTARY STRUCTURES

Thickness

The total thickness of the Barron Quartzite is unknown since exposure is discontinuous. Because the top of the Barron is eroded, only a minimum thickness of the formation can be estimated. Drill cores through the Barron near Rice Lake, Wisconsin show that the quartzite is at least 198 m thick. Hotchkiss estimated the thickness of the Barron to be approximately 600 feet (180 m) based on the difference in elevation between the base of the formation and the tops of the highest hills in the area (Hotchkiss, 1915).

In this study, the thickness was estimated by using the distance between two outcrops (taken perpendicular to the strike of bedding) and, using an average dip of 7 degrees. The total thickness thus calculated is 400 m. The two outcrops used for this calculation are located in the south-central part of the area and are outcrops #8 and #11 of Figure 2. This estimate of thickness assumes that no major fault movement has occurred between the two outcrops. Because this is an assumption, the estimate of 400 m is equivocal.

Basal Contact

The basal contact of the Barron Quartzite is exposed at two outcrops - #5 and #24 in Figure 2. At outcrop #5, a red regolith containing white quartz pebbles (2 mm - 3 cm) unconformably underlies the Barron. The regolith overlies a strongly foliated biotite gneiss with large quartz "eyes." At outcrop #24, a dark purple slate occurs as basement rock under the Barron. No upper contact of the Barron Quartzite is exposed. However, an overlying breccia containing Barron Quartzite cobbles and boulders is exposed at two locations (#19 and #29 of Fig. 2). At outcrop #29, the breccia is exposed on the same hill as the Barron (within 0.5 km) but the actual contact between the two is not exposed.

Lithology

The Barron Quartzite is comprised of three different lithologies: quartz arenite (Fig. 5), siltstone, and quartz-pebble conglomerate. Quartz arenite is by far the most abundant rock type; the latter two types together total less than one percent of the column. A generalized column of the Barron is shown in Figure 6.

The color of the quartz arenite is consistent at the outcrop level but varies throughout the field area. Colors are dependent on the amount of hematite present, and range from white (one outcrop) to buff to salmon to red to purple. Liesegang banding is common where the quartz-arenite is red.

Figure 5. Quartz arenite in the Barron Quartzite.

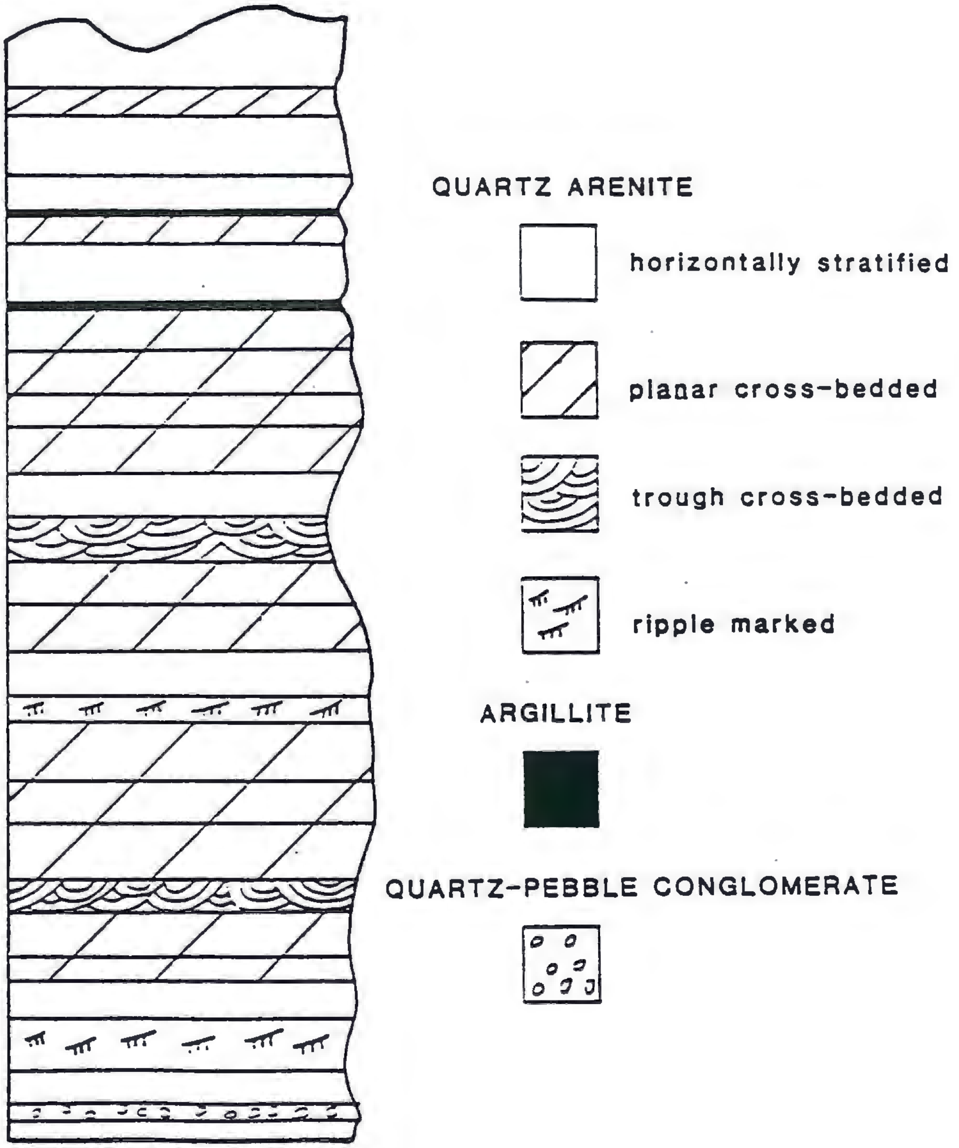


Figure 6. Generalized column of the Barron Quartzite.

In general, the quartz arenite is made up of well-sorted, rounded quartz grains that are fine to medium-grained (0.25 to 0.55 mm); however, the grain size ranges from very fine sand to very coarse sand. Very rare grains of granule size are scattered in the lower portion of the column.

The argillite, or pipestone as it is commonly called, is found interbedded with the quartz arenite in the middle and upper sections of the formation (Fig. 7). The argillite is predominantly dark red in color with minor white areas seen in outcrop and in drill core. The argillite layers range in thickness from 1.5 com to 0.5 m. The argillite is finely laminated in some places; at one location, laminations 1 to 8 mm thick make up a 4 cm thick argillite bed.

The quartz-pebble conglomerate occurs at the base of the formation at one locality (#5 in Figure 2) and is approximately 8 cm thick (Fig. 8). It is composed of angular to sub-rounded white quartz pebbles surrounded by a matrix of purple, fine- to medium-grained quartz-cemented quartz sand (equivalent to the quartz arenite described previously). The quartz pebbles range in size from 2 to 5 cm.

Two drill cores of Barron Quartzite were examined and logged. A summary of the logs is shown in Figure 9. The location of drill hole #1 is the SW/SE/NW Sec. 15, T. 35 N., R. 10 W.. The location of drill hole #2 is SW/SE Sec. 20, T. 35., R. 10 W. The cores show very little variation in the quartz arenite. Argillite occurs in minor amounts in both cores. A dark greenish-gray lamprophyric dike or sill appears in the core from hole #2. It is 26 m thick and is highly altered in most

Figure 7. Argillite in the Barron Quartzite.

Figure 8. Quartz-pebble conglomerate in the Barron Quartzite.

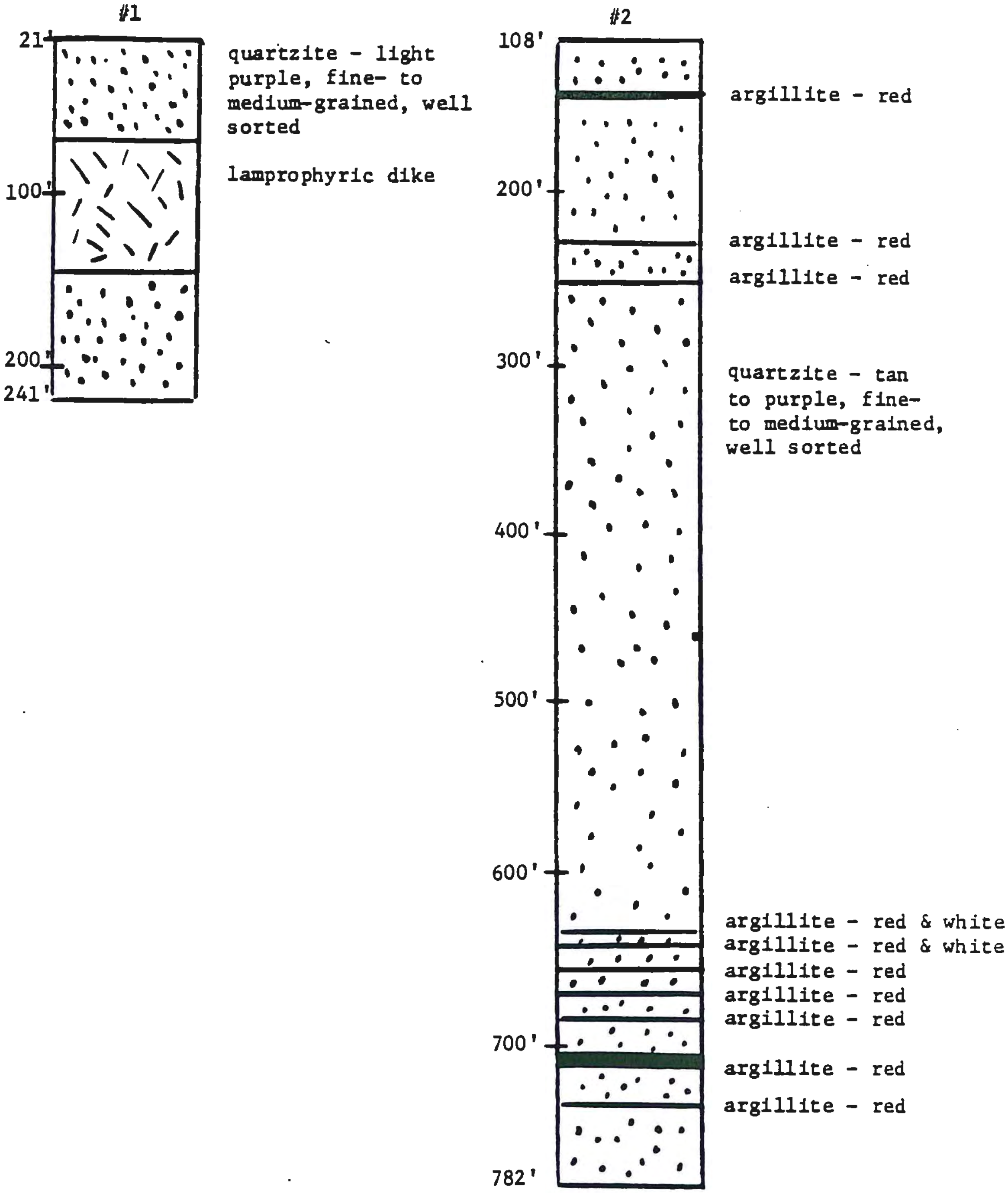


Figure 9. Barron Quartzite drill core logs.

places. A 1976 Wisconsin Geological and Natural History Survey log describes it as a layered magnetite-bearing lamprophyre dike or sill with a medium-grained intergranular texture. It is porphyritic at the top and fine-grained at the bottom. The dike (or sill) has not been dated.

Sedimentary Structures

Sedimentary structures present in the Barron Quartzite are bedding, planar cross-bedding, trough cross-bedding, symmetrical and asymmetrical ripple-marks, and casts of mudcrack fillings.

Bedding in the Barron is typically tabular and is traceable across outcrops although lenticular beds do occur. Beds range in thickness from 3 cm to 50 cm (Fig. 10).

Cross-bedding is common although it is not present at every outcrop. Both planar and trough cross-bedding occur; planar cross-bedding is by far the most abundant. Two-hundred and nineteen cross-sets were measured; of these, approximately 85% are planar. The planar cross-sets are straight or curved and have planar and parallel to sub-parallel bounding surfaces (Fig. 11).

The average thickness of the planar cross-sets is 3.6 cm. (The cross-sets range in thickness from 1 to 10 cm). The average length is 13 cm; the mean dip inclination is 22 degrees (Fig. 12).

Figure 10. Tabular bedding in the Barron Quartzite.

Figure 11. Planar cross-sets in the Barron Quartzite.

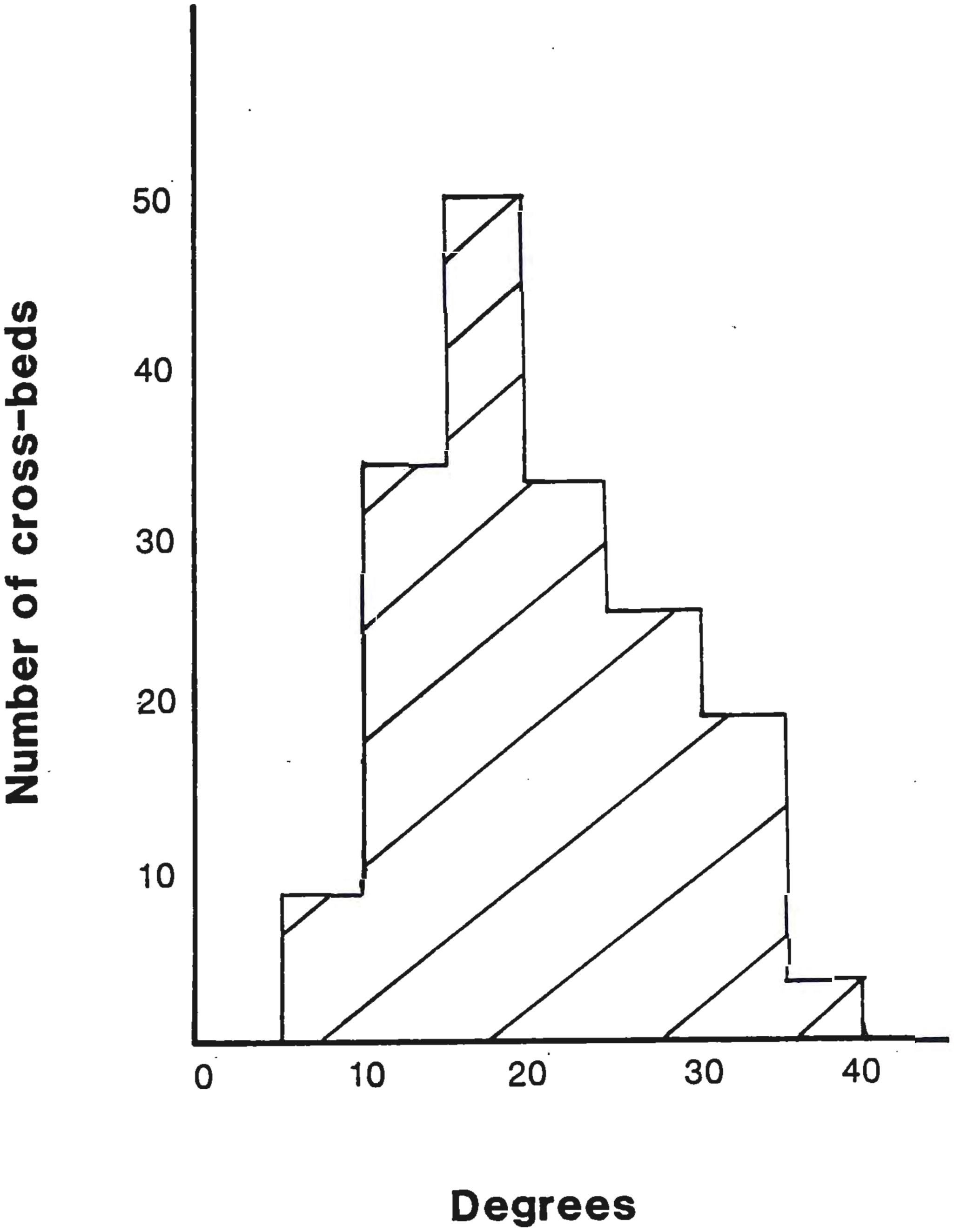


Figure 12. Histogram of cross-bed inclinations.

The remaining 15% of cross-sets are classified as troughs. The laminae in trough cross-sets are curved and are tangential to the underlying surface (Fig. 13).

Large scale troughs were observed at some locations. The largest has a thickness of one meter and a length of four meters.

Ripple marks are abundant at some outcrops and are absent at others. Both symmetrical and asymmetrical ripples are present and both straight crested and sinuous crested ripple types were observed (Fig. 14 and 15). The average ripple wavelength is 5 cm and the average wave height is 0.7 cm. The ripple index of a formation is a statistical parameter that helps to describe the dimensions of ripple marks. The ripple index is calculated by dividing the wave length by the wave height (Tanner, 1967). The overall ripple index of the Barron Quartzite is 9.

Casts of mudcrack fillings (Fig. 16) are rare and were observed in the quartz arenite at only two locations, #8 and #24 of Figure 2.

Figure 13. Trough cross-bedding in the Barron Quartzite. (Scale of trough is approximately 3m x 0.7m)

Figure 14. Ripple marks in the Barron Quartzite.

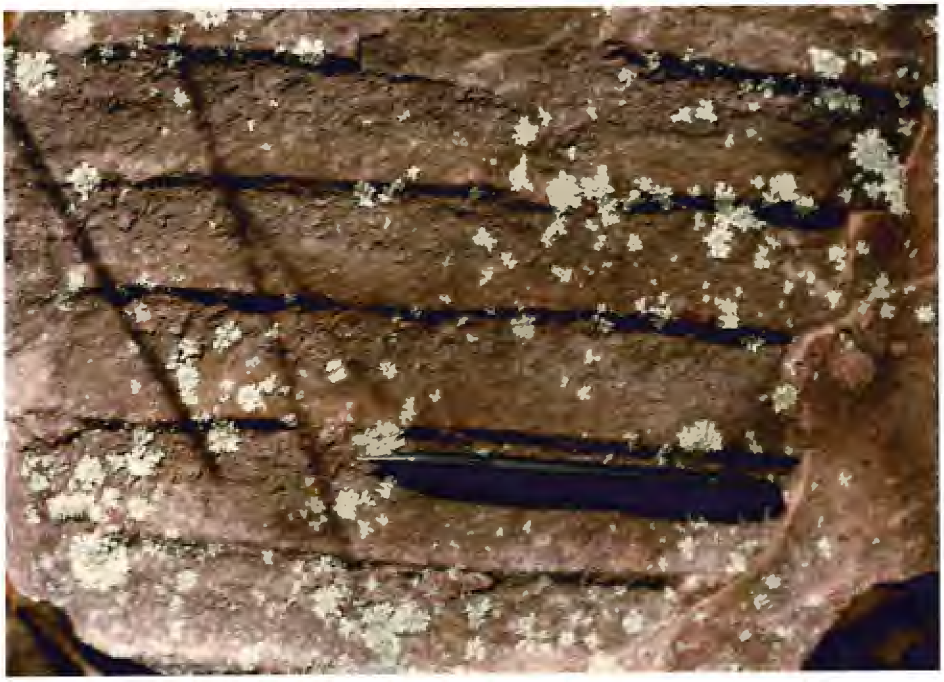


Figure 15. Ripple marks in the Barron Quartzite.

Figure 16. Mucdracks in the Barron Quartzite.

CHAPTER III STRUCTURE

Exposures of the Barron Quartzite show little deformation. The formation has low dips of approximately five to ten degrees toward the west/northwest, except for one exposure in the northeastern outlier where fault movement has produced vertical beds. The general attitudes of bedding are shown in Figure 17. There appears to be a broad structural basin in the large, central portion of the formation.

The Barron is highly fractured at some outcrops but this is not typical of the formation. Faults, which are magnetically inferred (Mudrey, et al, 1982), are also shown in Figure 17. The amount and direction of movement along these faults remain uncertain except for where the basal conglomerate of the Barron is faulted. The basal quartz-pebble conglomerate along with basement gneiss and regolith was probably vertically displaced by faulting along a river trending approximately east-west located at #5 in Figure 2 (Routledge and others, 1981). If large blocks of quartzite were elevated, the formation may be repeated.

Dates proposed for the mild warping, titlting, and shearing of the formation are 1400 m.y and 1200 m.y. (Routledge et al, 1981).

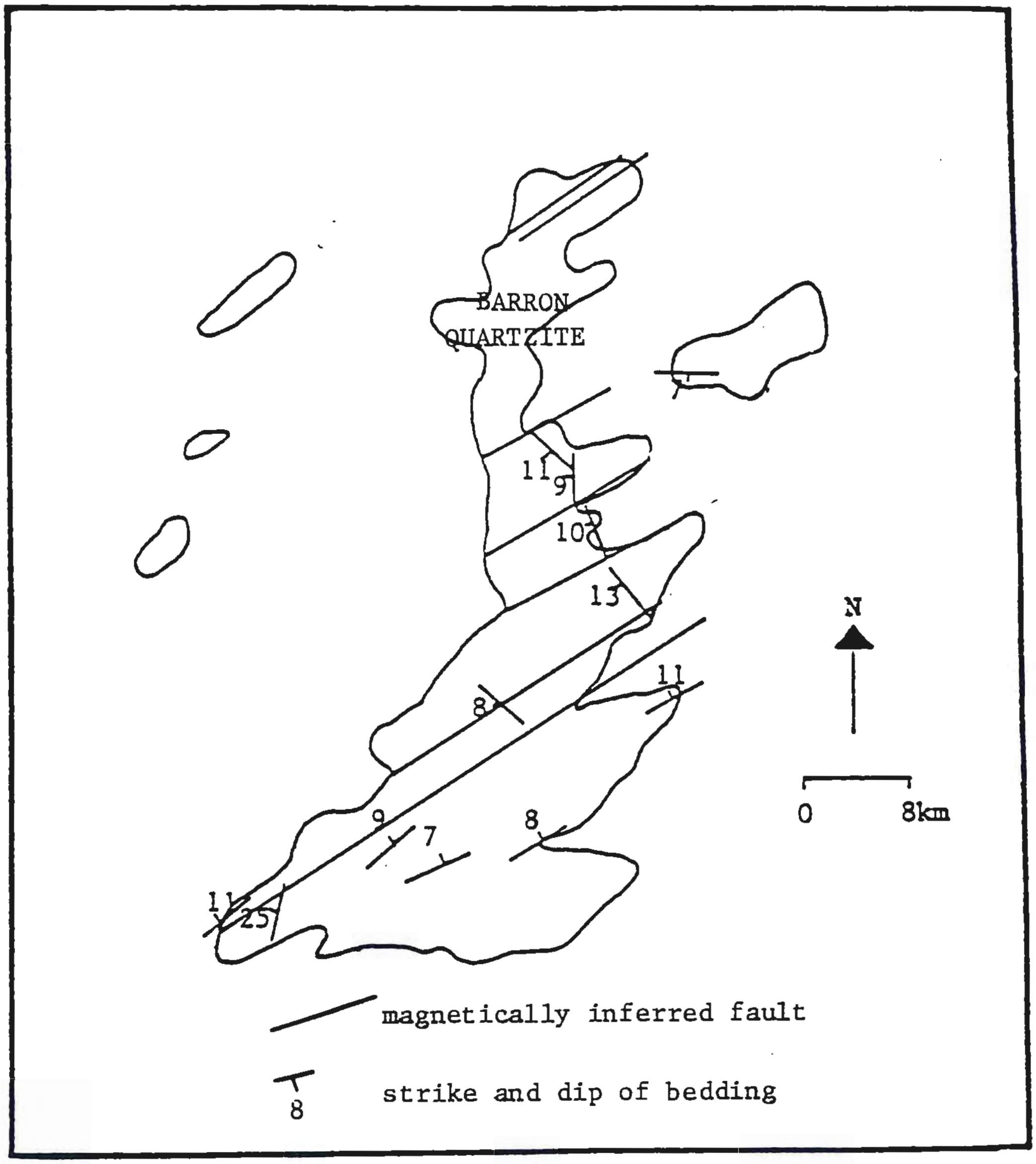


Figure 17. Structure of the Barron Quartzite.
(Faults from Mudrey et al, 1982)

CHAPTER IV PETROGRAPHY

Procedure

One hundred thin sections of samples from outcrops of the Barron Quartzite were examined; an additional 17 thin sections from two drill cores through the Barron were also studied. Of these, 60 thin sections were point-counted. Six hundred grains were counted on each thin section by making six traverses across each thin section perpendicular to bedding and counting 100 grains per traverse. The results of point-counting are shown in Table 1.

Each thin section that was point-counted was described. Minerals present, grain sizes, and degree of sorting and roundness were recorded. All thin secitons were also scanned to check for multicycle quartz grains. Thirty heels were stained for potassium feldspar.

Mineralogy

Framework grains:

Four quartz types make up the vast majority of framework grains of the Barron Quartzite: common quartz, polycrystalline stretched quartz, polycrystalline recrystallized quartz, and vein quartz.

Common quartz grains are composed of single quartz crystals, with or without undulatory extinction (Fig. 18). Common composite quartz

Table 1. THIN SECTION POINT COUNT RESULTS
(Numbers in %, * = less than 1%)

SAMPLE # AND LOCATION	CQ	CQI	CCQ	VQ	PSQ	PRQ	CH	HPQ	TQ	M	QC	HC	KM	OM	TC&M
J84-94 (22)	78	3	2	4	2	1	-	*	89	-	9	2	-	-	11
J84-88 (23)	65	4	1	5	9	*	-	-	87	-	14	2	-	-	16
J84-144 (5)	75	6	1	5	1	*	-	-	87	-	10	2	1	-	13
J84-129 (5)	76	6	1	2	2	*	-	-	87	*	1	1	1	-	13
J84-23 (11)	70	4	1	10	2	*	-	-	87	*	5	8	8	*	13
J84-24 (11)	72	3	1	5	7	1	-	1	88	*	10	2	-	-	11
J84-25 (11)	60	2	2	11	6	1	-	-	80	*	15	4	1	-	20
J84-26 (11)	73	1	1	5	5	1	*	-	86	-	10	5	*	-	14
J84-27 (11)	63	3	1	6	2	1	*	*	75	-	18	6	1	-	25
J84-29 (11)	71	4	1	7	2	*	-	*	85	-	9	5	1	*	15
J84-30 (11)	72	1	1	6	3	7	-	*	86	-	9	5	-	-	14
J84-138 (11)	75	3	2	4	3	1	-	-	87	-	11	2	*	-	14
J84-139 (11)	78	7	2	4	1	*	-	-	87	*	10	3	-	-	13
J84-140 (11)	68	2	1	7	5	1	-	*	83	-	13	4	-	-	17
J84-141 (11)	78	1	1	5	3	1	-	-	88	-	9	3	-	-	12
J84-142 (11)	66	4	1	8	6	1	-	-	85	-	12	3	1	-	15
J84-143 (11)	76	1	1	4	5	*	-	*	86	-	10	2	*	-	12
J84-66 (24)	76	2	2	4	3	1	-	*	87	*	10	3	*	-	13
J84-67 (24)	79	3	1	3	1	*	-	-	87	-	12	2	-	-	13

CQ - common quartz
CQI - common quartz with inclusions
CCQ - common composite quartz
VQ - vein quartz
PSQ - polycrystalline stretched quartz
PRQ - polycrystalline recrystallized quartz
CH - chert

HPQ - hematite-rich polycrystalline quartz
TQ - total quartz
M - magnatite
QC - quartz cement
HC - hematite cement
OM - other matrix
TC&M - total cement and matrix

Table 1. (Continued)

SAMPLE # AND LOCATION	CQ	CQI	CCQ	VQ	PSQ	PRQ	CH	HPQ	TQ	M	QC	HC	KM	OM	TC&M
J84-68 (24)	79	1	2	2	1	-	-	#	85	-	13	2	#	-	15
J84-69 (24)	78	2	2	3	1	-	-	1	85	#	11	2	1	-	14
J84-80 (24)	76	3	1	5	1	1	-	#	87	#	10	2	#	#	12
J84-81 (24)	79	3	#	3	1	#	-	-	87	1	10	2	1	#	13
J84-82 (24)	76	3	#	3	2	-	-	-	85	-	13	3	-	-	16
J84-83 (24)	77	2	1	4	3	1	1	-	88	-	9	2	1	-	12
J84-84 (24)	74	4	2	4	2	-	#	#	85	#	10	4	#	-	14
J84-145 (24)	66	6	4	7	5	3	#	-	90	-	8	2	-	-	10
J84-146 (24)	72	4	1	3	6	3	#	-	90	#	8	2	1	-	10
J84-147 (24)	77	3	1	1	1	-	-	-	83	#	13	4	1	-	17
J84-39 (13)	69	4	#	7	7	5	#	#	93	-	4	3	#	-	7
J84-40 (13)	74	3	2	4	2	#	#	1	85	#	11	3	-	-	14
J84-41 (13)	76	3	3	4	1	-	-	-	86	-	10	4	-	-	14
J84-12 (8)	78	3	1	5	4	#	-	-	91	-	8	1	#	-	9
J84-15 (8)	82	3	2	4	1	-	-	-	92	-	7	#	#	-	8
J84-52 (20	75	1	1	4	5	3	-	#	89	#	8	3	#	-	11
J84-42 (14)	81	4	-	3	#	1	-	-	89	#	8	2	1	-	11
J84-31 (12)	77	3	-	3	1	1	-	#	84	-	14	2	-	-	16
J84-136 (33)	81	5	#	3	1	1	-	-	90	-	8	1	-	-	10
J84-137 (34)	78	2	-	4	2	1	-	1	87	-	10	1	-	1	12
J84-51 (18)	79	1	-	4	1	#	-	-	86	-	11	3	1	-	14
J84-45 (15)	83	#	-	5	4	#	-	-	91	-	6	2	-	-	9

CQ - common quartz
CQI - common quartz with inclusions
CCQ - common composite quartz
VQ - vein quartz
PSQ - polycrystalline stretched quartz
PRQ - polycrystalline recrystallized quartz
CH - chert
HPQ - hematite-rich polycrystalline quartz
TQ - total quartz
M - magnatite
QC - quartz cement
HC - hematite cement
OM - other matrix
TC&M - total cement and matrix

Table 1. (Continued)

SAMPLE # AND LOCATION	CQ	CQI	CCQ	VQ	PSQ	PRQ	CH	HPQ	TQ	M	QC	HC	KM	OM	TC&M
J84-95 (26)	74	2	3	7	3	1	-	*	89	-	10	1	-	1	11
J84-96 (26)	84	1	2	4	1	*	-	-	92	-	7	1	-	*	9
J84-98 (26)	84	1	1	5	1	*	*	*	92	-	7	1	-	-	8
J84-100 (4)	78	3	1	4	2	*	-	*	89	-	8	2	1	-	11
J84-47 (16)	84	1	-	6	2	*	-	-	87	-	4	3	-	-	7
J84-49 (16)	86	1	-	7	3	-	-	-	92	-	3	1	-	*	3
J84-71 (25)	72	7	*	6	4	*	-	-	88	-	9	3	-	-	12
J84-73 (25)	70	8	1	4	3	-	-	*	85	-	12	3	-	-	15
J84-53 (21)	70	4	3	5	9	-	-	*	90	-	7	3	-	-	10
J84-55 (21)	79	2	1	3	4	1	-	*	89	-	7	2	1	2	11
J84-56 (21)	76	4	1	5	7	*	-	*	92	-	6	-	1	-	8
J84-58 (21)	80	3	1	4	4	*	-	-	91	-	7	2	-	*	9
J84-59 (21)	73	4	1	6	6	1	-	-	91	-	8	-	1	*	9
J84-60 (21)	73	7	1	6	4	*	-	*	90	-	8	1	1	-	10
J84-61 (21)	81	3	*	4	2	-	-	-	90	-	8	1	1	-	10
J84-64 (21)	82	2	*	4	2	1	-	-	91	-	8	1	1	-	9
J84-33 (7)	73	4	2	4	2	1	-	*	83	-	15	2	-	-	17
J84-92 (22)	75	1	1	4	5	3	-	*	89	*	8	3	*	-	11
J84-93 (22)	67	2	2	7	5	9	*	*	91	-	2	2	*	-	9

CQ - common quartz
CQI - common quartz with inclusions
CCQ - common composite quartz
VQ - vein quartz
PSQ - polycrystalline stretched quartz
PRQ - polycrystalline recrystallized quartz
CH - chert
HPQ - hematite-rich polycrystalline quartz
TQ - total quartz
M - magnatite
QC - quartz cement
HC - hematite cement
OM - other matrix
TC&M - total cement and matrix

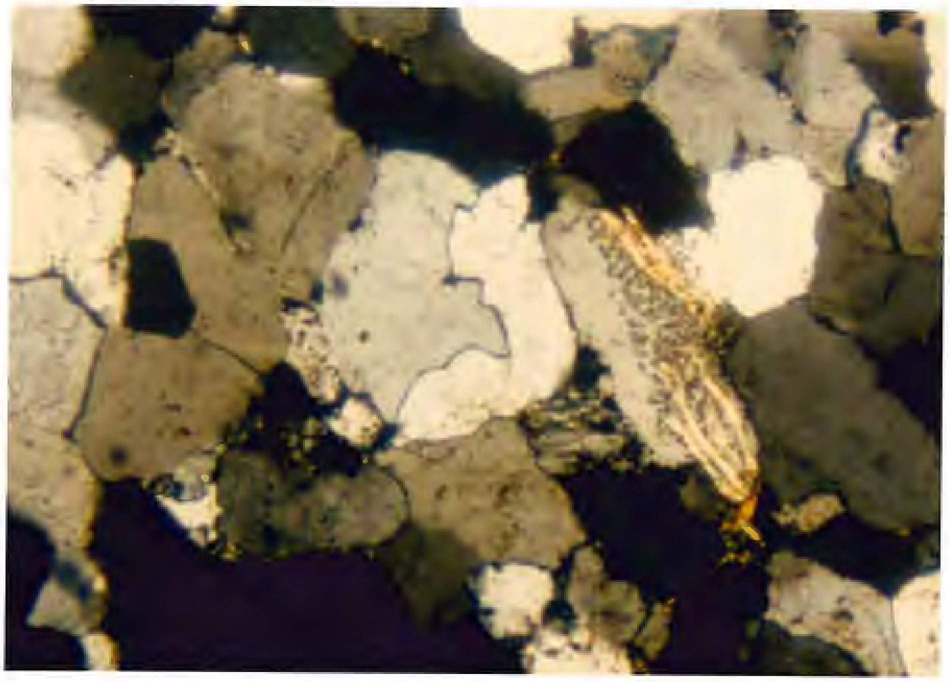


Figure 18. Photomicrograph of common and common-composite quartz grains. (The common-composite grain is in the center of the photomicrograph; common quartz grains surround it. Field of view is 1.3mm x 1.1mm)

grains composed of two to five large crystals (Fig. 18) are also included in this quartz type. Common quartz is most likely derived from plutonic rocks, but could also derive from volcanic or metamorphic rocks. Some of these grains, although originally from plutonic, volcanic, or metamorphic rocks, could also have been derived from a quartz sandstone. A sedimentary origin is indicated by the presence of some multicycle quartz grains. Also included in this category of common quartz is common quartz containing inclusions (Fig. 19); the most common inclusions are green and brown tourmaline and zircon. common quartz makes up 83% of the Barron Quartzite and constitutes 94% of all grains present.

Polycrystalline stretched quartz grains are made up of numerous, small, undulose crystals that are sutured together. Boundaries between composite crystals are characteristically serrated (Fig. 20). these grains are commonly well-rounded and are usually larger that most grains present in thin section. Stretched polycrystalline quartz grains are probably indicative of a metamorphic origin. These grains constitute 3% of the Barron.

Polycrystalline recrystallized quartz grains are composed of numerous, small, polygonal crystals with straight or lobate boundaries between crystals (Fig. 21). Like stretched polycrystalline grains, these are also commonly larger than most grains and are well-rounded. Recrystallized polycrystalline quartz grains constitute 0.8% of the Barron Quartzite. These grains, like stretched polycrystalline grains,

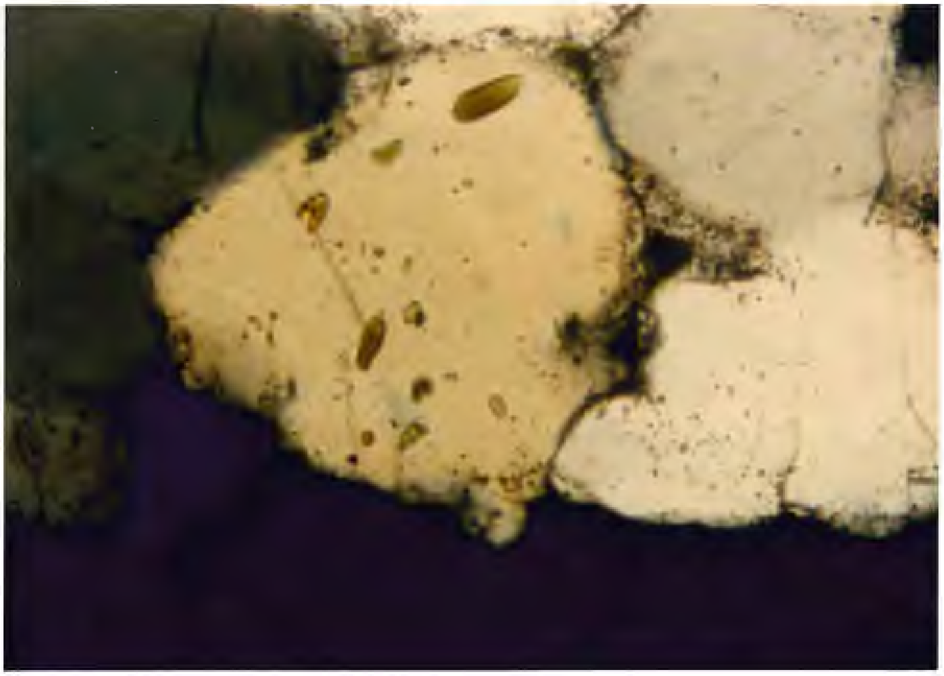


Figure 19. Photomicrograph of common quartz with inclusions of tourmaline. (Field of view is 0.5mm x 0.42mm)

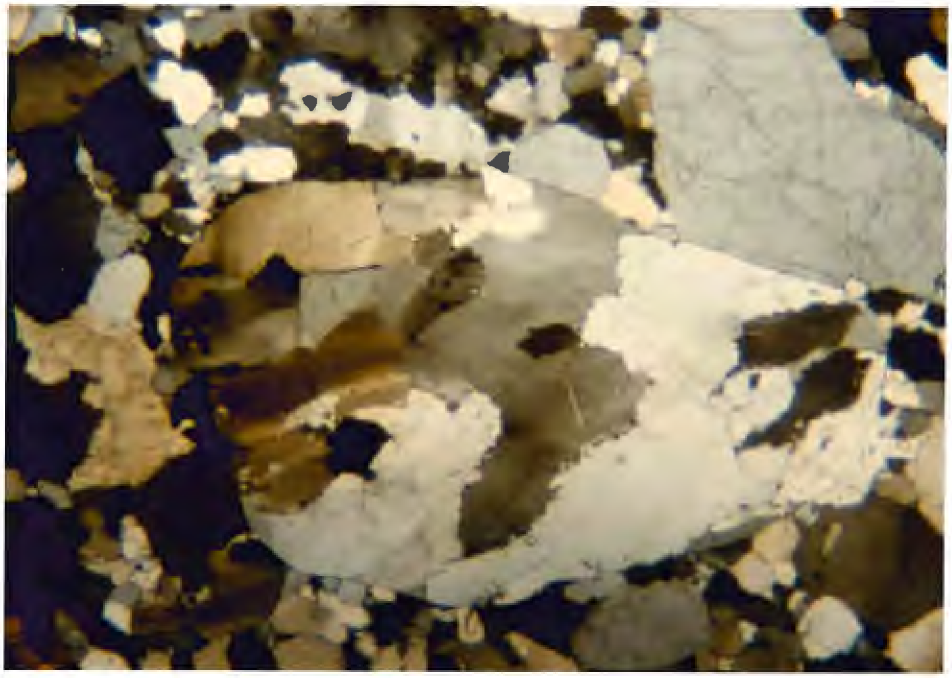


Figure 20. Photomicrogrpah of polycrystalline stretched quartz. (Field of view is 2.0mm x 1.7mm)

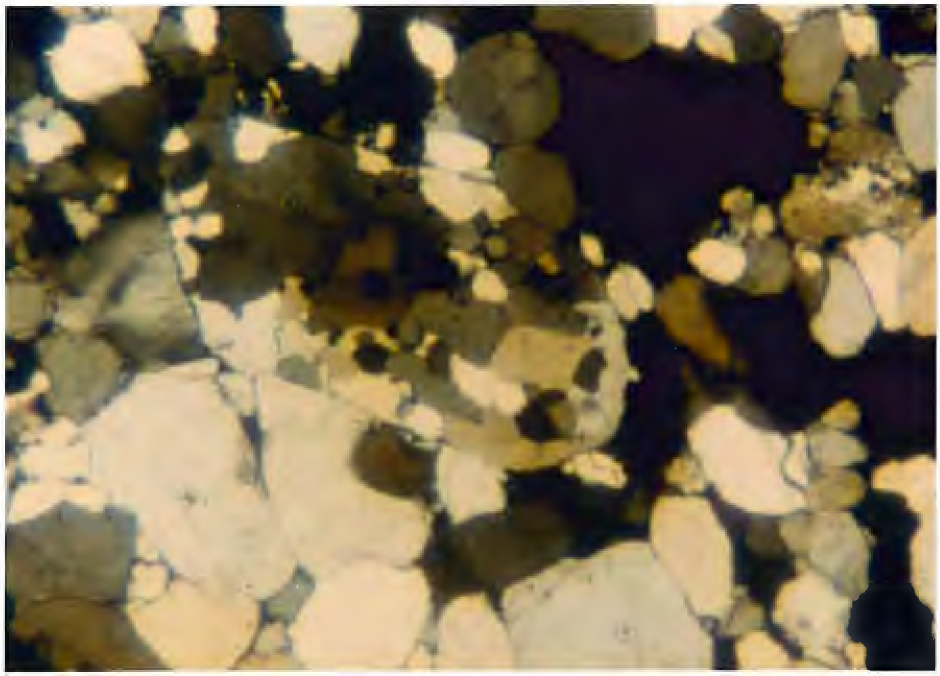


Figure 21. Photomicrograph of polycrystalline recrystallized quartz. (Field of view is 2.0mm x 1.7mm)

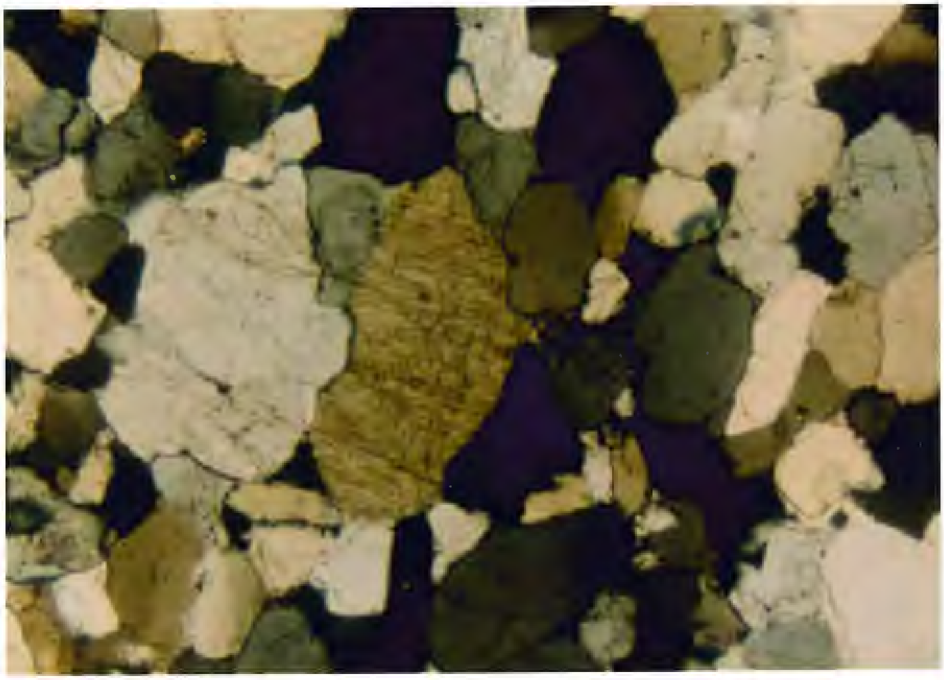


Figure 22. Photomicrograph of vein quartz. (Field of view is 2.0mm x 1.7mm)

may be indicative of a metamorphic origin, either from a fine-grained quartzite or schist or from a recrystallized chert.

Vein quartz (Fig. 22) occurs as unit or polycrystalline grains and exhibits bubble planes or an overall dusky appearance. Vein quartz makes up 1% of the Barron Quartzite.

Chert and jasper are the two types of rock fragments present in this section. Chert grains are very fine-grained and exhibit pinpoint extinction. Grains of polycrystalline quartz that are extremely hematite rich are classified as jasper. Chert and jasper combined constitute less than 1% of the formation.

Another type of quartz grain present in the Barron Quartzite is multicycle quartz. These are common quartz grains which have optically continuous overgrowths of quartz that have been abraded and surrounded by a second overgrowth (Fig. 23). These grains are rare and were not included in point-counting results but were observed while scanning thin sections.

Magnetite and hematite do appear in grain form in minor amounts. No feldspar was found in any of the thin sections point-counted or in the 30 heels that were strained for potassium feldspar. Scans of the other thin sections also revealed no feldspar.

Cement:

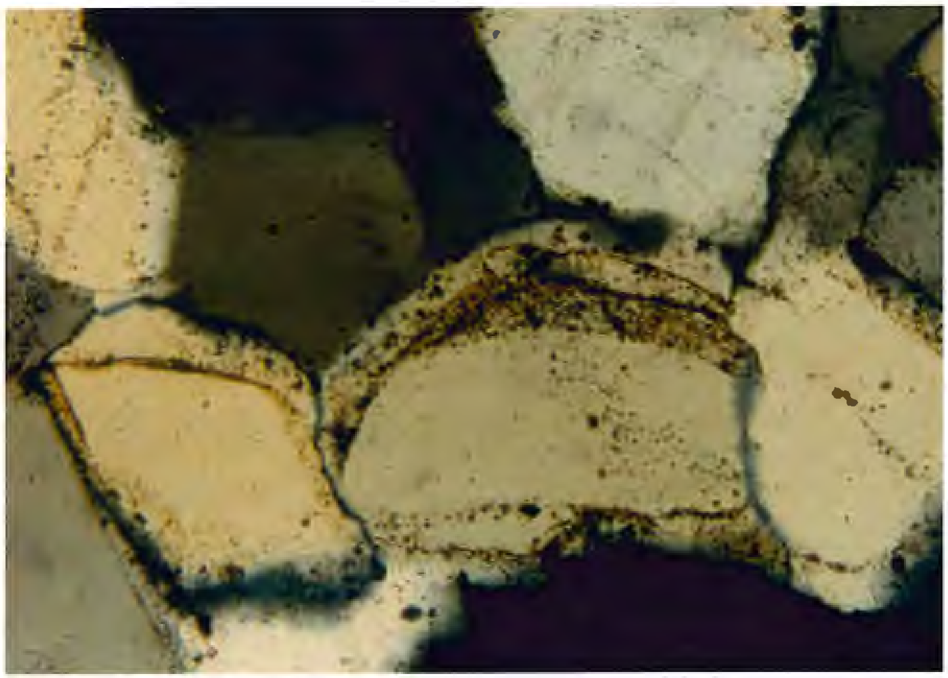


Figure 23. Photomicrograph of multicycle quartz. (Field of view is 0.50mm x 0.42mm)

Silica and hematite are present as cement. Hematite occurs as a thin red coating on quartz grains and in places it occurs more abundantly between quartz grains (Fig. 24). It constitutes 2% of the rock.

Silica is present as optically continuous overgrowths on quartz grains (Fig. 25). Since the quartz grains show no evidence of interpenetration (which would indicate a pressure solution origin of cement) the likely origin of the cement is from quartz precipitation from silica-supersaturated pore water.

Matrix:

The minerals present as matrix are kaolinite and sericite. Sericite occurs very rarely (0.08%) as tiny, yellow laths.

Kaolinite is slightly more abundant (0.3%) and appears in the matrix as brownish patches with low birefringence (Fig. 26). The kaolinite formed after the hematite and was deposited between quartz overgrowths (as can be seen in Fig. 26) and is therefore of diagenetic origin.

The relative abundances of all minerals present are shown in Figure 27.

Heavy Minerals

Procedure:

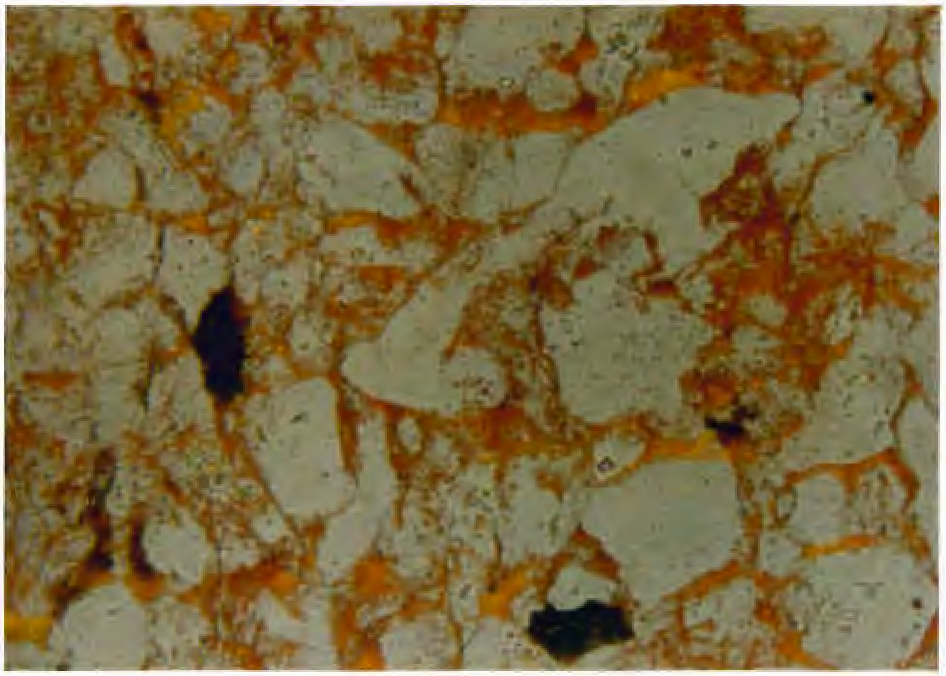


Figure 24. Photomicrograph of hematite cement. (Field of view is 2.0mm x 1.7mm)

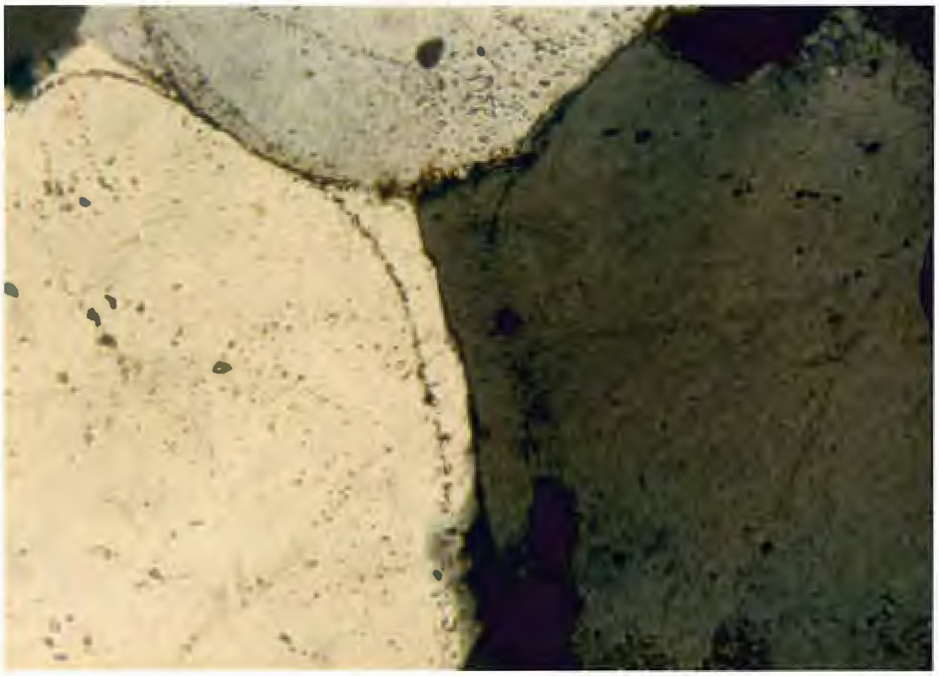


Figure 25. Photomicrograph of silica cement. (Field of view is 0.50mm x 0.42mm)

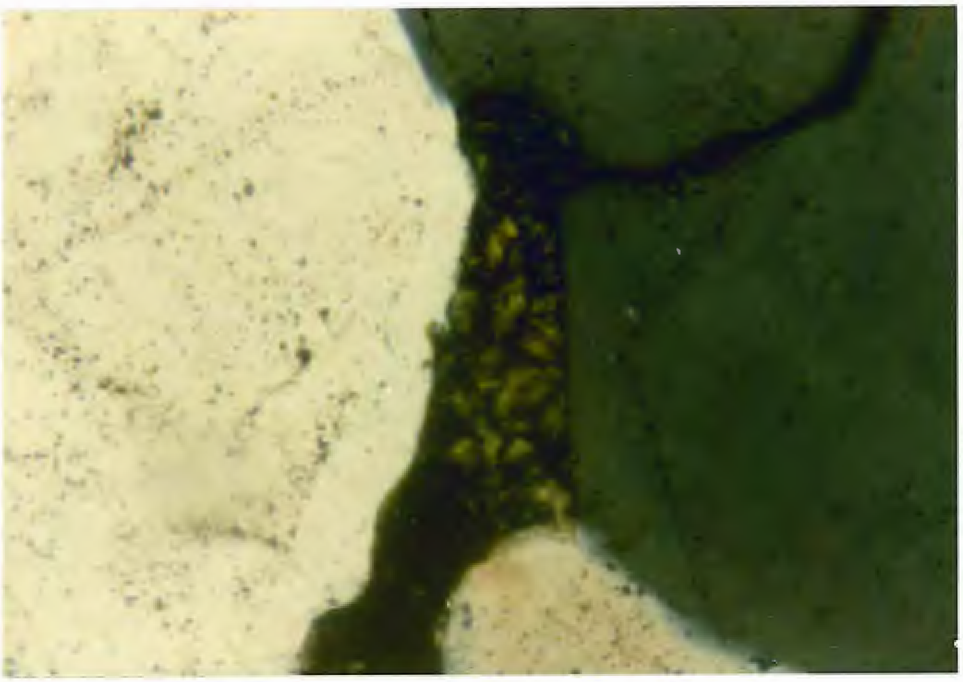


Figure 26. Photomicrograph of kaolinite. (Field of view is 1.3mm x 1.1mm)

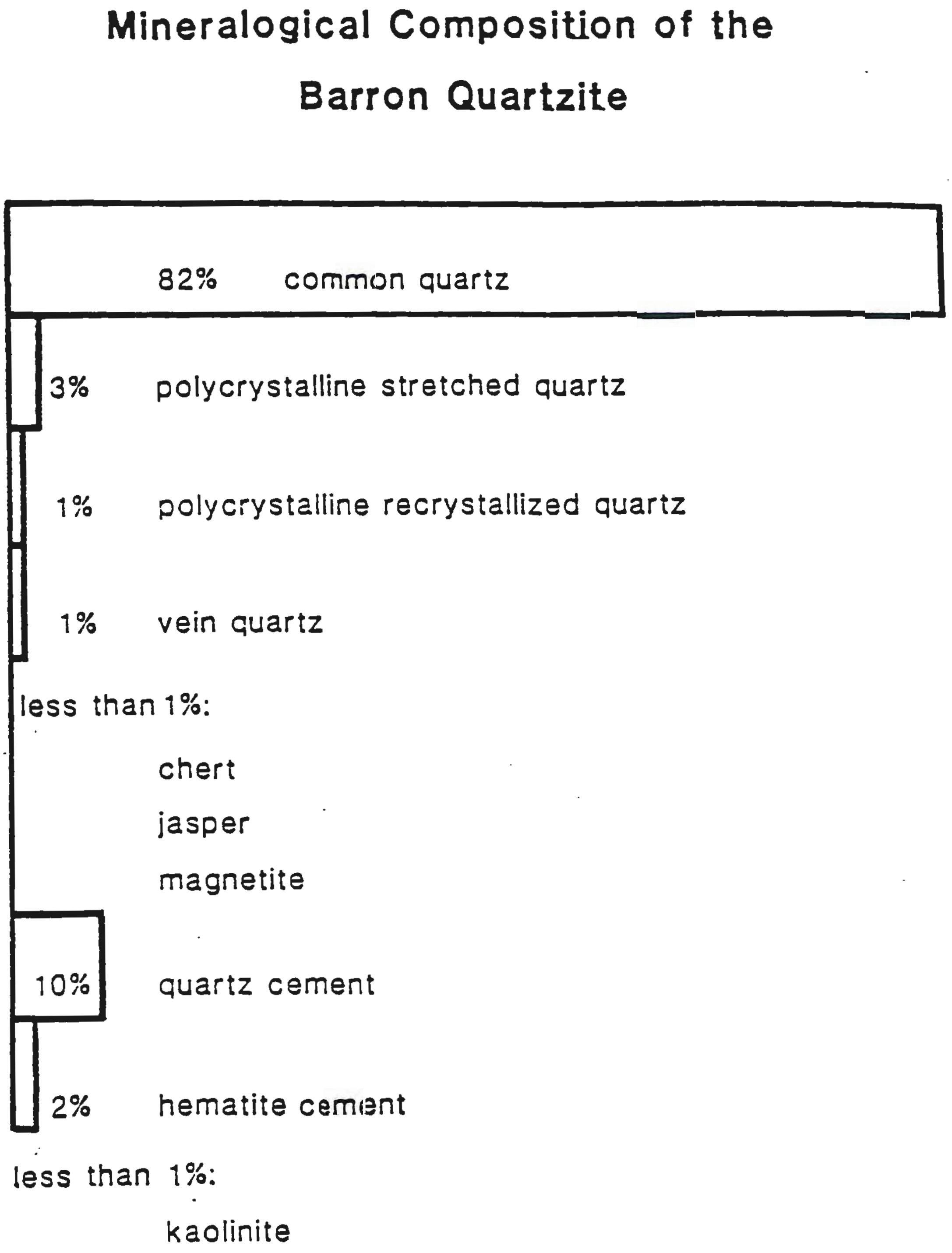


Figure 27. Mineralogical composition of the Barron Quartzite.

Thirteen samples were prepared for heavy mineral analysis. The procedure was as follows:

1) Sample was crushed with an electric crusher (or with a rock hammer) to approximately 1.5 mm size.

2) Sample was further crushed with a steel mortar and pestle using an up and down pounding motion in order to minimize breakage of minerals.

3) Crushed sample was sieved and material less than 0.5 mm was saved.

4) Sample was washed and then the water was decanted to remove clays.

5) Sample was dried and weighed.

6) Tetrabromoethane (d=2.9) was used to separate out the heavy minerals. Sample was poured into a separatory funnel containing tetrabromoethane. Mixture was periodically stirred, the heavies allowed to settle to the bottom and bled off. The remaining light minerals were also saved. Heavy and light minerals were washed with acetone and dried.

7) Magnetic minerals were removed from the heavy mineral residue with a magnet and saved.

8) Material was weighed and the percentage of heavy minerals, light minerals, and magnetic minerals present was calculated.

9) Heavy minerals were mounted in Canada balsam.

10) 300 non-opaque grains per mount were counted where possible.

Of the 13 samples prepared, only nine were counted. The entire heavy mineral residue of four of the samples was coated with hematite and/or magnetite, making accurate determination of the minerals present impossible.

Detrital, non-opaque heavy minerals:

Zircon is by far the most abundant heavy mineral present in the Barron Quartzite, making up 92% of the non-opaque heavy mineral suite. Six categories of zircon were differentiated for counting:

1) rounded and zoned
2) rounded and unzoned
3) sub-rounded and zoned
4) sub-rounded and unzoned
5) angular and zoned

6) angular and unzoned

Almost all of the zircon grains are rounded or subrounded. Table 2 shows the relative abundances of zircon shapes present. The zircon grains are colorless, light brown or yellow in color (Fig. 28).

Rutile is present but it is not abundant, making up only 2.4% of the heavy mineral suite. Colors of rutile present are: red, red-orange, yellow-orange, and yellow. Most grains are rounded or sub-rounded. An example is shown in Figure 29.

Tourmaline is also present, though rare, and makes up only 2% of the heavy mineral suite (Fig. 30). Color varieties present are: pleochroic light green - dark green; light brown - dark brown; yellow-green - olive; light brown - green; olive - dark green; and green - blue-green. Most grains are rounded or sub-rounded.

Clinopyroxene also makes up 2% of the non-opaque heavy mineral suite. Grains range in color from light green to light brown and most are sub-angular.

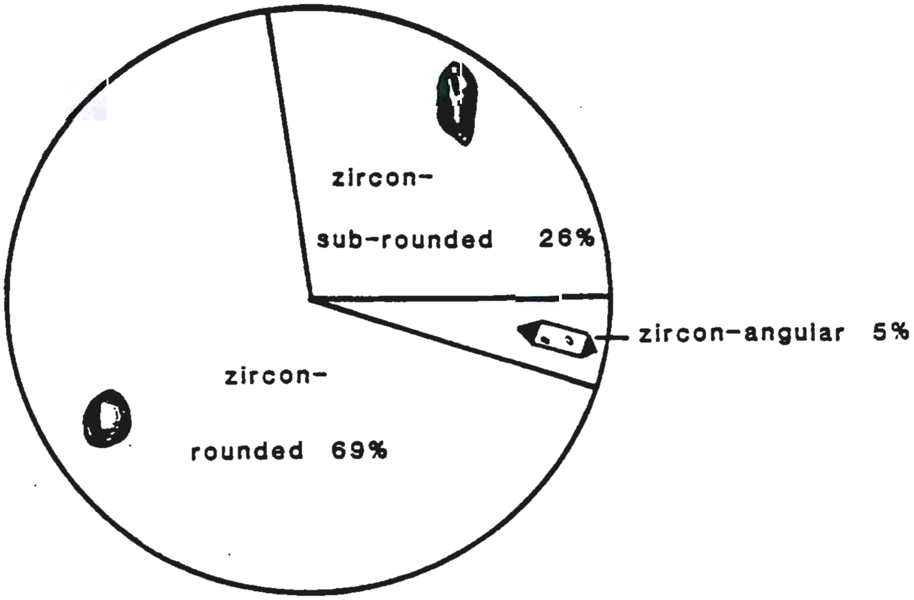
Ten apatite grains were found; all but one are either rounded or sub-rounded.

The remaining 3.5% of the suite of non-opaque heavy minerals consists of sub-angular orthopyroxene and hornblende (both 0.4%), rounded to sub-rounded sphene (0.2%), and a small number of grains that could not be identified. The relative abundances of non-opaque heavy minerals is shown in Table 3.

Opaque heavy minerals:

Table 2. Zircon Shapes
(figures in % total zircons)

Sample # and location	rounded	sub-rounded	angular
J84-52 (20)	66	31	3
J84-136 (33)	77	18	5
J84-25 (11)	44	41	15
J84-36 (7)	85	14	1
J84-77 (25)	66	26	8
J84-129 (5)	64	31	5
J84-69 (24)	67	28	5
J84-47 (16)	67	30	2
J84-102 (4)	72	24	4
Average:	68	27	5



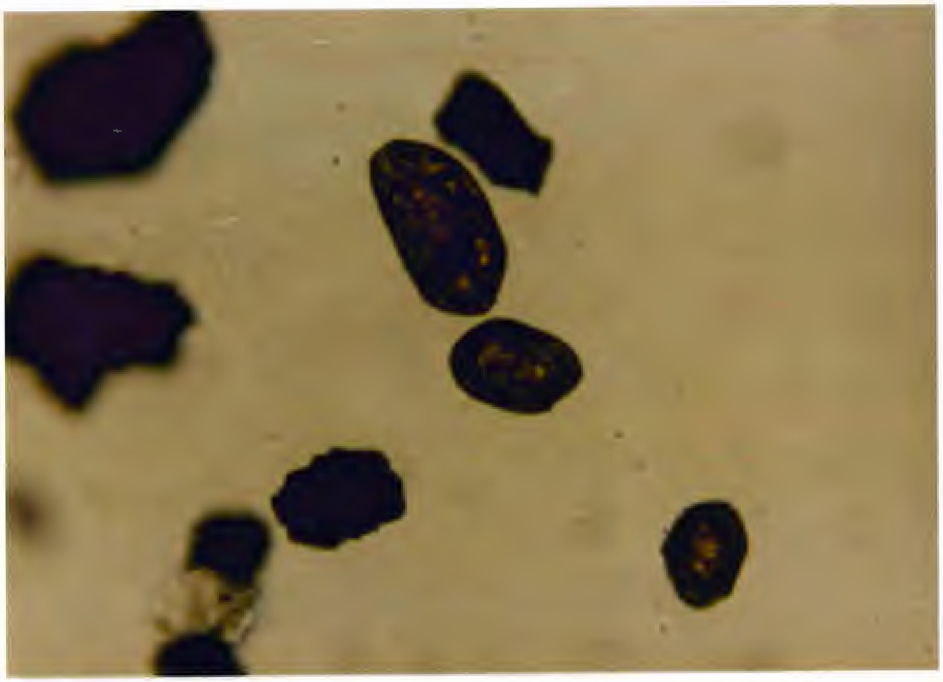


Figure 28. Photomicrograph of zircon. (Field of view is 0.50mm x 0.42mm)

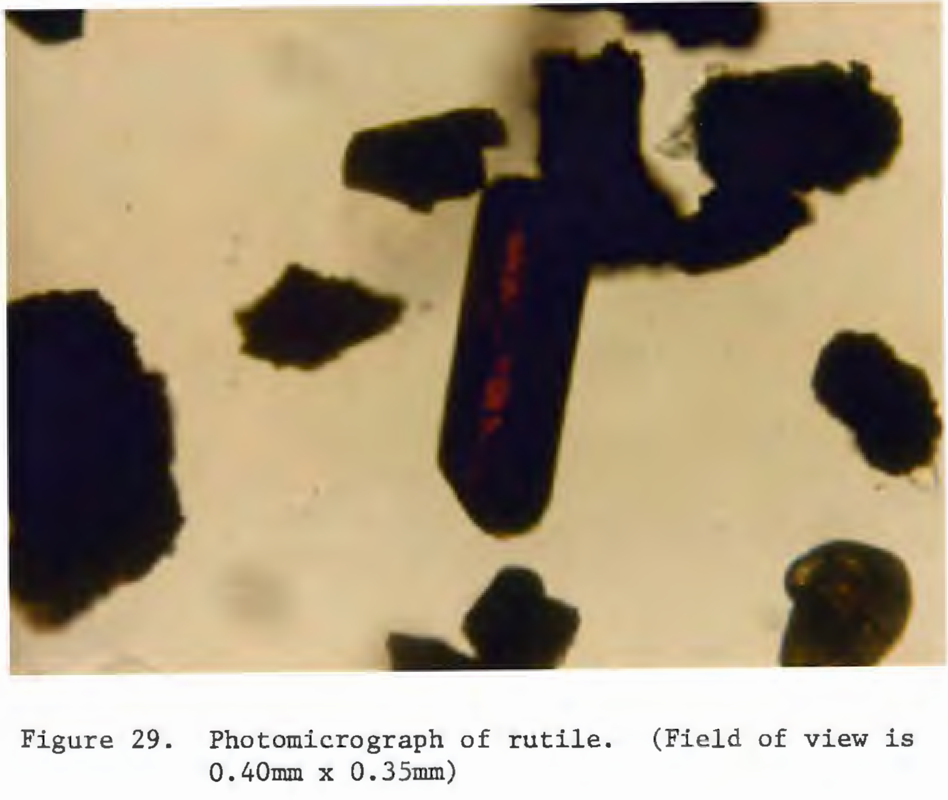


Figure 29. Photomicrograph of rutile. (Field of view is 0.40mm x 0.35mm)

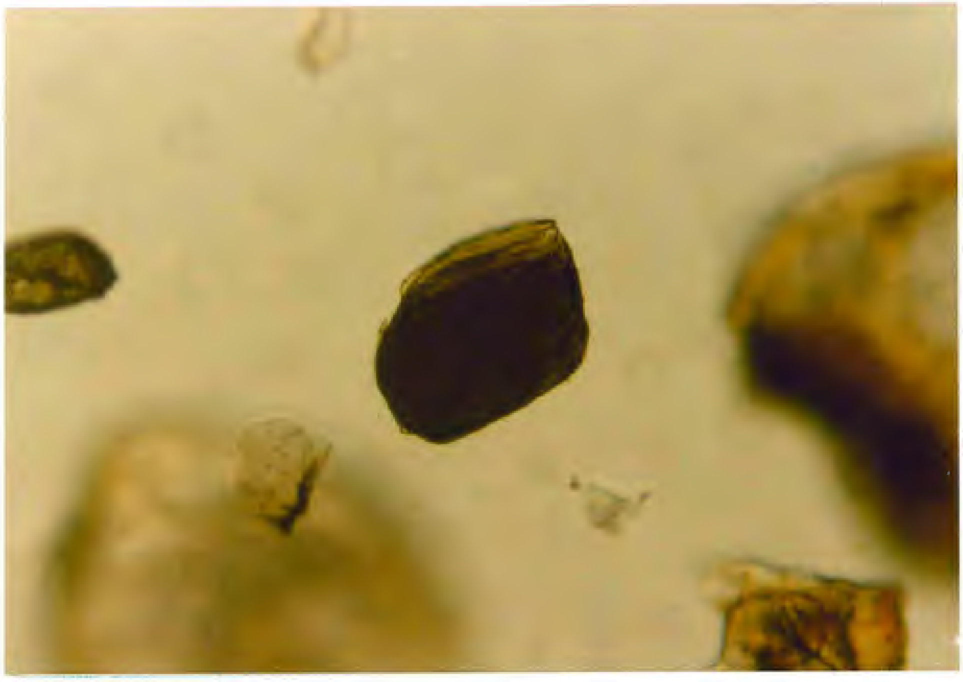
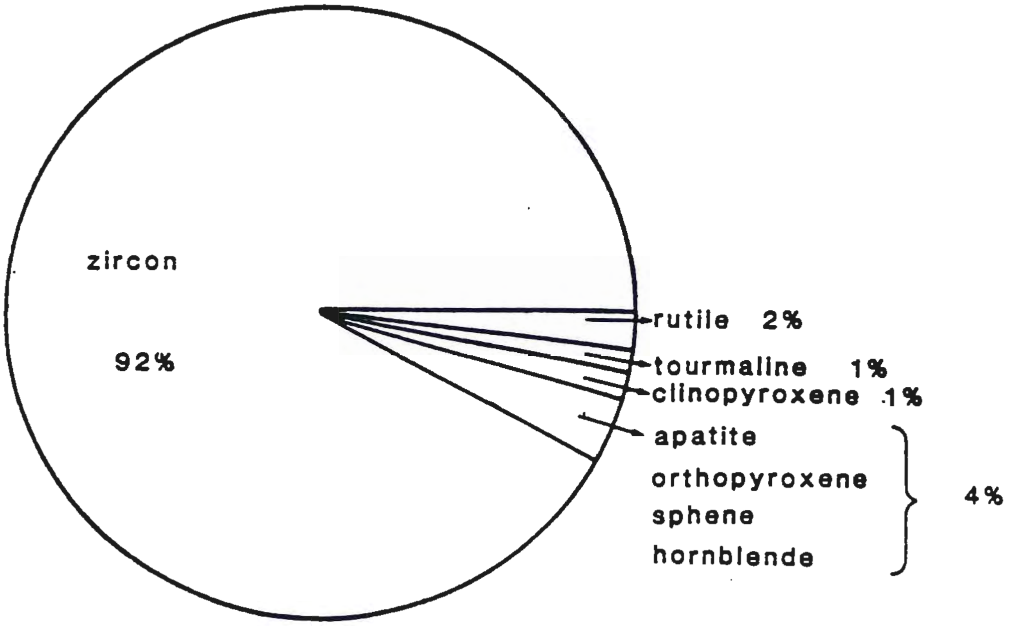


Figure 30. Photomicrograph of tourmaline. (Field of view is 0.50mm x 0.42mm)

Table 3. Heavy Mineral Grain Counts
(numbers in %, * = less than 1%)

Sample # and location	zircon	tourmaline	rutile	apatite	clinopyroxene	orthopyroxene	sphene	hornblende	unknown	total # grains counted
J84-52 (20)	96	2	*	*	-	-	-	-	-	300
J84-136 (33)	70	5	5	1	8	2	*	2	5	300
J84-25 (11)	92	3	2	2	-	-	-	-	-	87
J84-36 (7)	100	-	-	-	-	-	-	-	-	191
J84-77 (25)	99	-	*	-	-	-	-	-	-	300
J84-129 (5)	94	-	6	-	-	-	-	-	-	300
J84-69 (24)	99	*	*	-	-	-	-	-	-	176
J84-47 (16)	89	-	1	-	6	-	2	1	-	93
J84-102 (4)	92	3	3	1	*	-	-	-	-	153



Opaque heavy minerals present are hematite, magnetite, and leucoxene. Hematite (red to reddish-brown in reflected light) is present as angular grains and flakes, as rims around framework quartz grains, and in association with magnetite. Magnetite occurs as irregularly-shaped grains and flakes and is commonly hematitic. Magnetite constitutes an average of 26% by weight of all heavy minerals present. Leucoxene (yellowish-white in reflected light) occurs, in association with hematite, as rims around framework grains and as irregularly-shaped grains.

Conclusions from heavy mineral data:

The non-opaque, non-micaceous heavy minerals of a sediment can be useful in determining its provenance. The degree of rounding is an important characteristic in the determination of abrasion history.

The non-opaque heavy mineral suite of the Barron Quartzite consists almost entirely of zircon. The zircons are commonly rounded. Rounded rutile, rounded tourmaline, and angular to sub-rounded clinopyroxene are present in small amounts. Other heavy minerals are present in negligible amounts. Opaque minerals are hematite, magnetite, and leucoxene. This assemblage of rounded heavy minerals (both non-opaque and opaque) may indicate a sedimentary source (Pettijohn, Potter, and Siever, 1973, p. 304). Furthermore, since the great majority of heavy minerals present in the Barron Quartzite are stable to ultrastable (Pettijohn, Potter, and Siever, 1973, p. 305), the source areas was probably tectonically stable.

Classification

All point-counted thin sections were made from samples of the sandstone lithology of the Barron Quartzite. Thin sections of argillite or conglomerate were not point-counted. The entire sandstone portion of the Barron, which makes up at least 98% of the formation, can be classified as quartz arenite, according to the sandstone classification shown in Figure 31.

The Barron Quartzite is an exceptionally clean (matrix-free) quartz arenite.

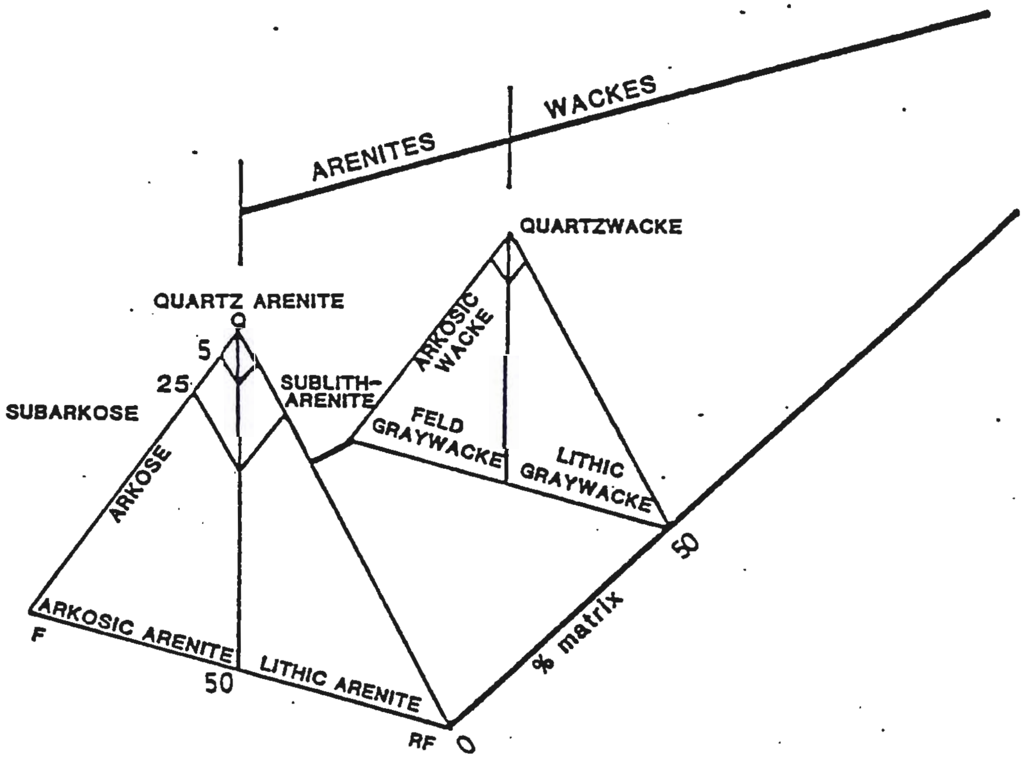


Figure 31. Classification of sandstones. (From Pettijohn, Potter, and Siever, 1973)

CHAPTER V SEDIMENTATION

Paleocurrent Data

Paleocurrent data were collected for the Barron Quartzite in order to determine the direction of sediment transport (to assist in the determination of paleogeography and source areas) and to help in the interpretation of the environment of deposition.

Many paleocurrent studies have been done on the Lake Superior region quartzites. Pettijohn (1957) summarized the cross-bedding attitudes of the Sioux, Baraboo, Waterloo, Barron, Sturgeon, Mesnard, Mississagi, and Lorrain Quartzites. He found a consistent southeasterly dip of cross-bedding for the quartzites. In his paper, data from the Barron Quartzite consisted of only four measurements of cross-bedding, giving a mean current direction of northeast to southwest.

Additional Barron Quartzite paleocurrent data were collected by Dott and Dalziel (1972). They made 191 cross-bed measurements plus an additional 17 measurements of trough axes. Vector means calculated for the Barron were widely dispersed, showing no conclusive trend.

Campbell (1981) studied cross-bedding of the Barron Quartzite at one outcrop and measured the orientations of 13 cross-beds and 15 asymmetric ripples. He suggested that paleocurrents flowed from northwest to southeast and believed the data represented a polymodal or bimodal-bipolar paleocurrent pattern. However, since data were very limited, the results are equivocal.

Since previous paleocurrent studies of the Barron have proved inconclusive, this study of paleocurrent data was undertaken in order to attempt conclusive determinations about paleocurrent directions and also to use paleocurrent patterns to say something about the depositional environment of the Barron Quartzite.

Sedimentary structures present in the Barron that are useful paleocurrent indicators are planar and trough cross-bedding and ripple marks. A total of 175 cross-bedding measurements were recorded. In addition, 11 ripple trends were measured and 7 trough axes orientations were recorded. In preparing the data, bedding was not rotated back to horizontal since it is nearly horizontal (usually less than 10 degrees) and the rotation would have had little effect on the resultant azimuth direction of cross-bedding.

Rose diagrams of cross-bedding are shown in Figure 32. Vector means are shown in Figure 33. They show an overall sediment transport direction to the southwest and southeast. Paleocurrent rose diagrams can also be helpful in a first approximation of depositional environment. Although most localities show unimodal distributions, bimodal and polymodal paleocurrent patterns do occur.

Trough axes measurements also indicate overall sediment transport to the southwest and southeast. Symmetrical ripple marks strike approximately east-west or northeast-southwest and one asymmetrical ripple measurement shows a paleocurrent direction of northwest to southeast (Fig. 34).

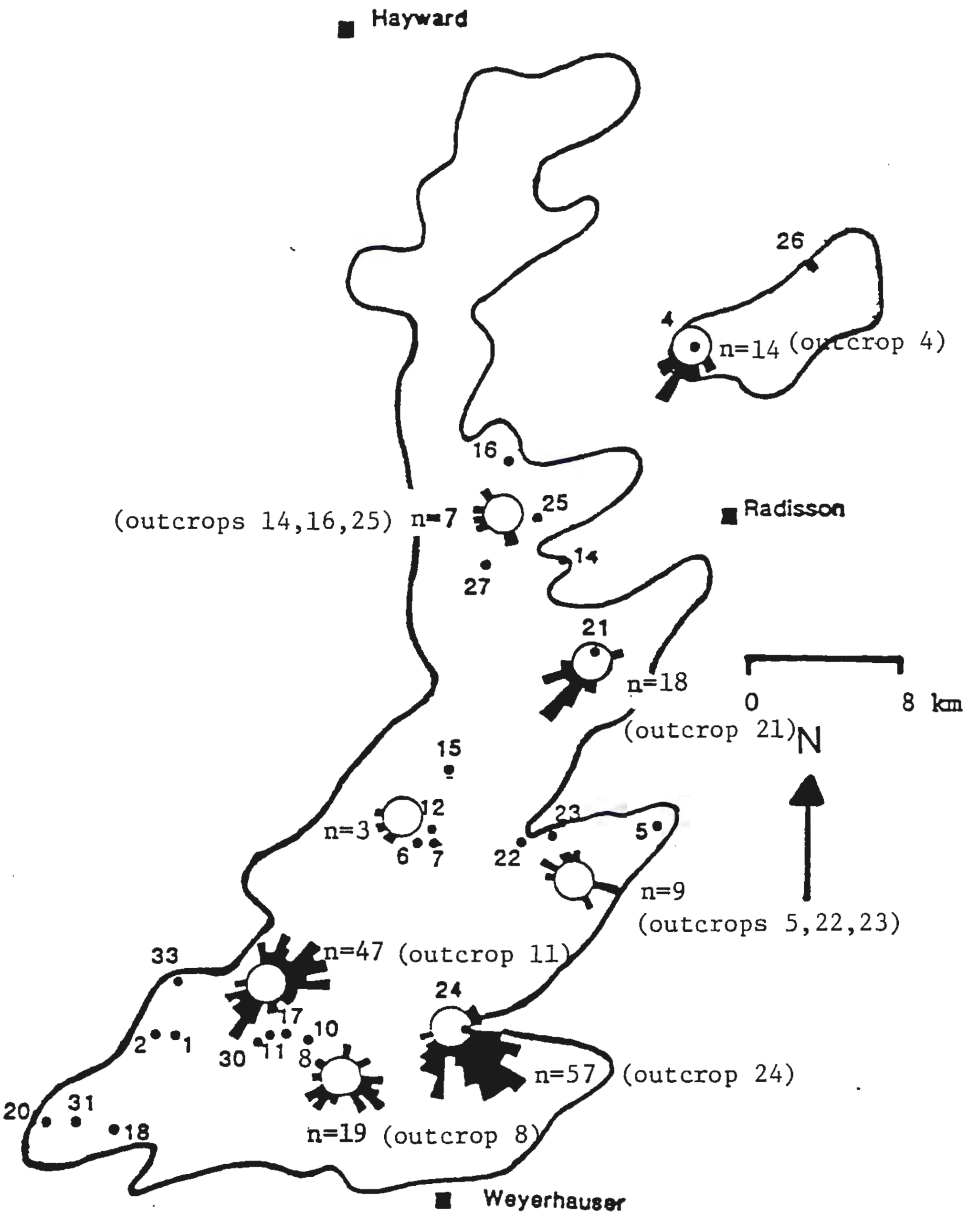


Figure 32. Cross-bed orientations in selected outcrops of the Barron Quartzite. (Only those outcrops with many measurements were used for rose diagrams)

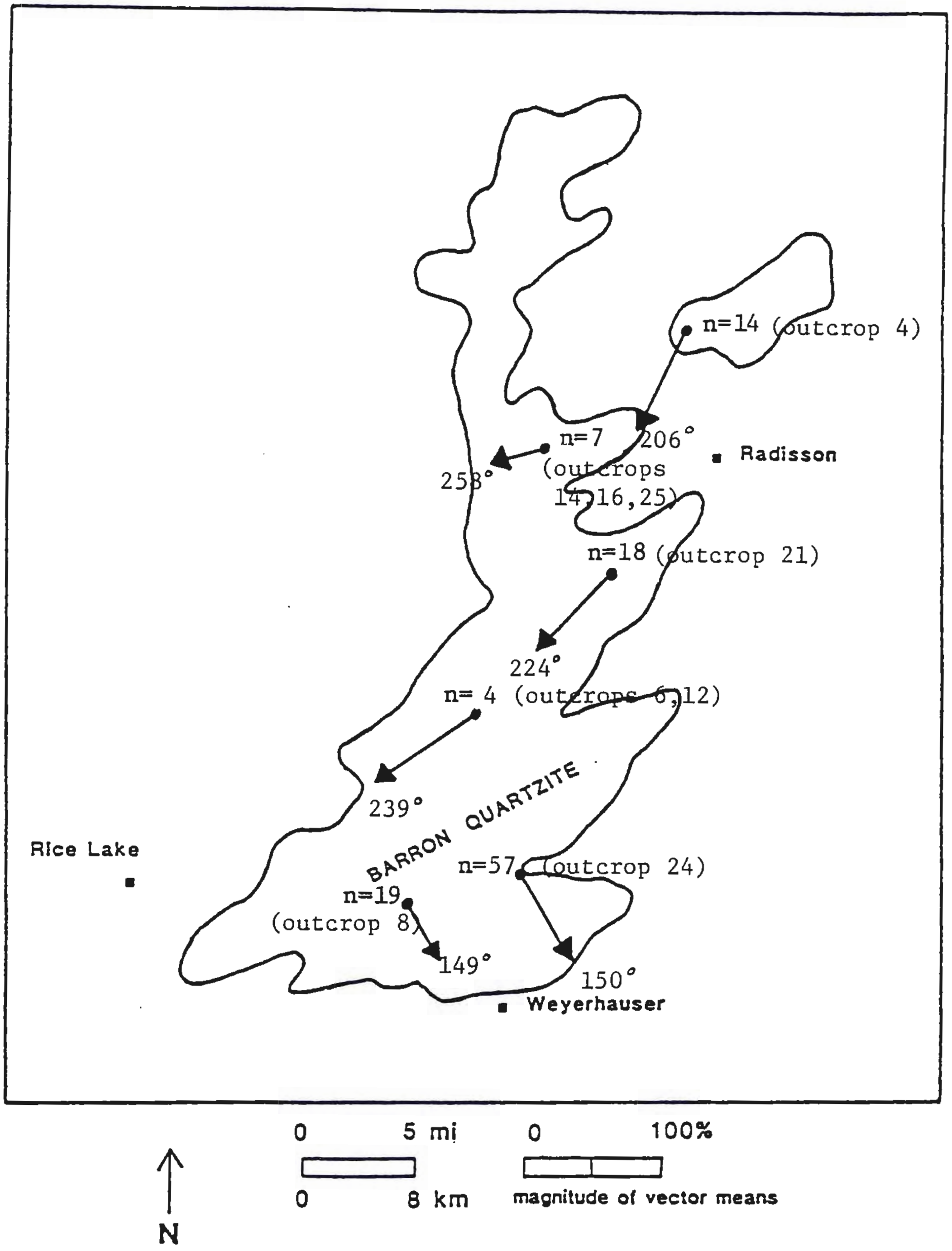


Figure 33. Vector means of cross-bedding in the Barron Quartzite.

(Locations shown are those displaying primarily unimodal patterns; base of arrow gives approximate location of measurements)

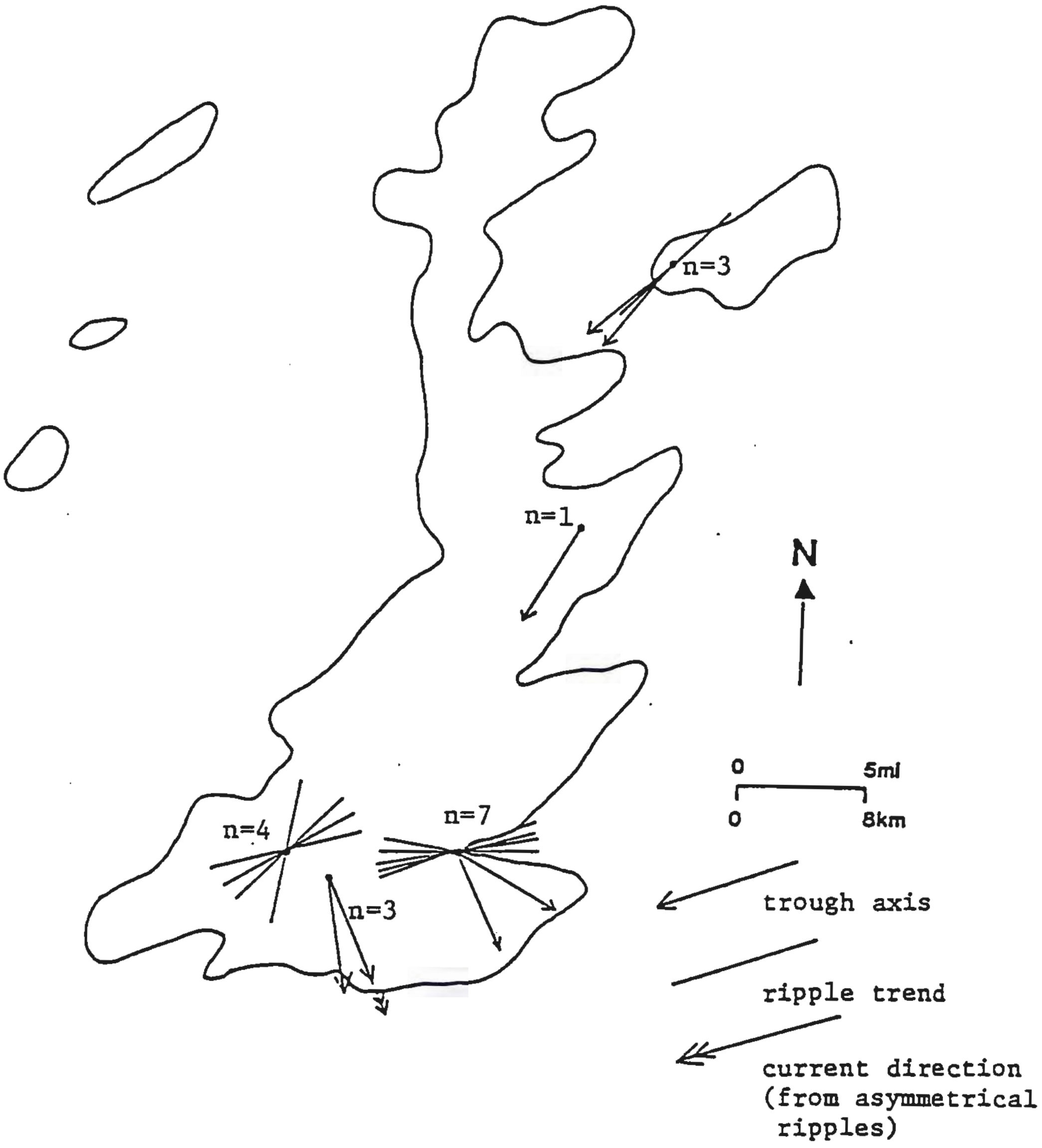


Figure 34. Current features in the Barron Quartzite.

The variance of cross-bedding is also helpful in determining the environment of deposition. A low variance is the result of a dominant slope, as in a fluvial environment. A high variance means that currents were more variable, as in a shallow marine or lacustrine environment, without a dominant paleoslope. Variances were calculated for different locations using the method described in Potter and Pettijohn (1977, p. 374-380). Variance calculations of cross-bedding in the Barron range from 1883 to 7390 (Fig. 35).

Interpretation of Environment of Deposition

Significant difficulties exist in the determination of the environment of deposition of a quartz arenite such as the Barron Quartzite. A major problem is the fact that no modern day examples of such sands are being deposited (Pettijohn, Potter, and Siever, 1973, p. 221). Most quartz arenites are of Paleozoic or late Precambrian age. Another problem is the probable multicycle origin of the sand in a quartz arenite. If the sand has been involved in more than one cycle of deposition, its texture can reveal little about the latest depositional environment since the rounding and sorting of grains could have taken place in any or all cycles of deposition.

In order to interpret the depositional environment of the Barron, all of the following characteristics must be considered: rock composition, texture, types of sedimentary structures present, and

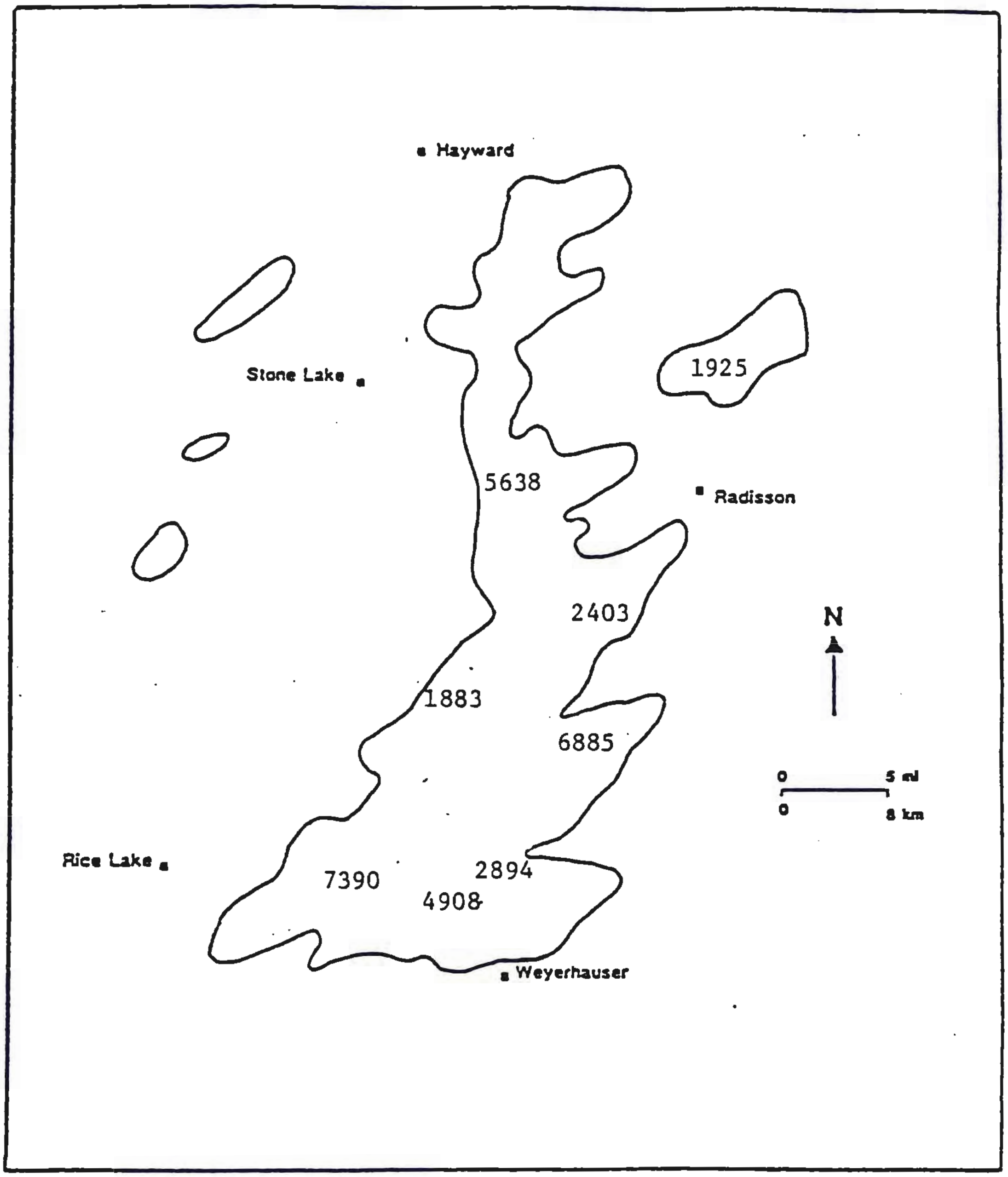


Figure 35. Variances of cross-bedding at eight outcrops of the Barron Quartzite.

paleocurrent patterns. A short recapitulation of these characteristics follows.

The dominant rock type in the Barron is a fine- to medium-grained quartz arenite. Minor interbedded argillite and a thin basal conglomerate are also present. The Barron is well-sorted and the grains are rounded. Sedimentary structures present are parallel bedding, planar and trough cross-bedding, asymmetrical and symmetrical ripple marks, and dessication cracks. Paleocurrent patterns are unimodal at most localities but bimodal and polymodal patterns also occur.

Such a mature quartz arenite, if derived from a pre-existing quartz sandstone, may not fit easily into a particular environment. It could have been produced in a variety of environments: eolian, fluvial, lacustrine, or marine. According to Kuenen (1960) though, to obtain such well-rounded grains, the sand was probably an eolian deposit at some point in time. However, an eolian depositional environment for the Barron can be ruled out. No frosted grains were observed. Furthermore, the ripple index suggests an aqueous medium of deposition; a ripple index of 15 or less is indicative of an aqueous environment while a ripple index of 17 or greater is indicative of an eolian environment. For the Barron Quartzite, the average ripple index is 8, suggesting an aqueous medium of deposition.

The ripple marks present do not help to differentiate between a fluvial, lacustrine, and marine environment. Since the formation of ripples is related to a given set of flow conditions which could exist in many environments, there is no direct relationship between ripple morphology and environment (Selley, 1976, p. 223). Similarly, the cross-bedding present does not limit environments of deposition. Planar and trough cross-bedding occur in fluvial, lacustrine, and marine environments and no particular style or scale of cross-bedding is characteristic of any particular agent and/or environment (Pettijohn, 1975, p. 109). However, the abundance of planar cross-bedding relative to trough cross-bedding does suggest that the most commonly occurring bedforms were linguoid and transverse bars and sandwaves which occur in the lower flow regime (Miall, 1978, p. 598).

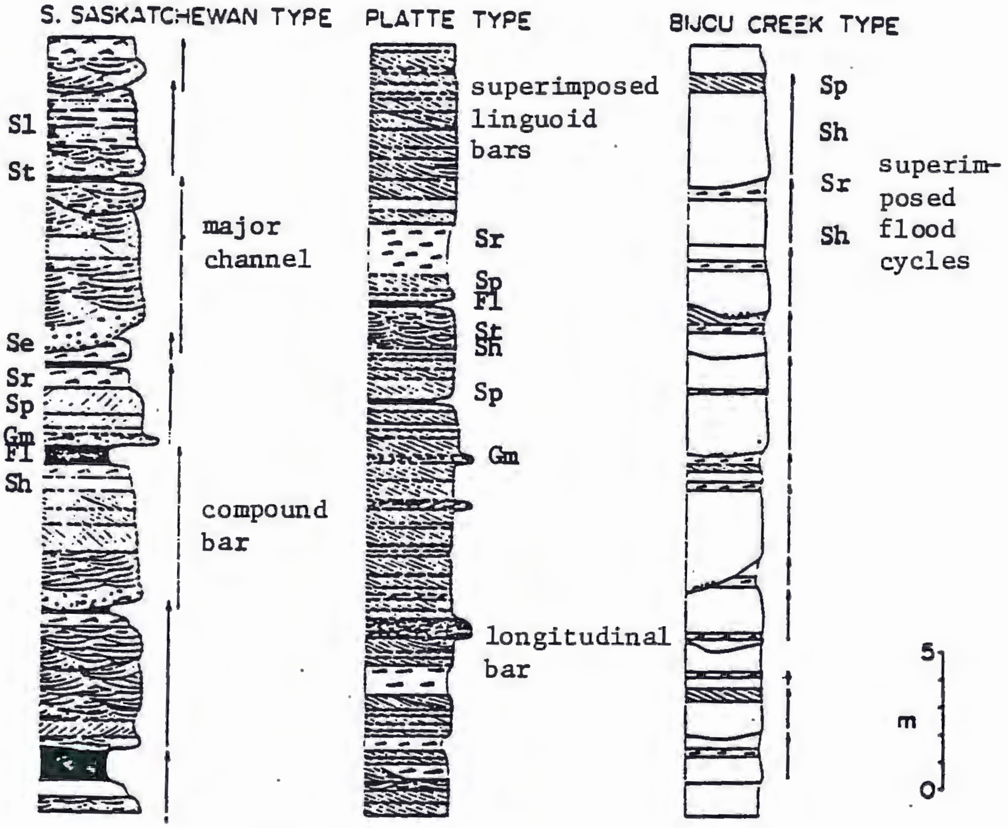
Dessication crack casts that appear at two locations (outcrop #8 and outcrop #24 in Figure 2) suggest that the sediment was intermittently exposed at some point in time. These sedimentary structures form in intertidal zones and in overbank mudflats of fluvial systems.

If deposition of the Barron occurred in a fluvial system, it most likely would have been a braided stream instead of meandering because of the lack of vegetation during the Precambrian. Cotter (1978) stated that virtually all pre-Silurian rivers were braided. Meandering rivers began to occur with the evolution of land vegetation which increased bank stability (Schumm, 1968). Braided streams consist of two or more channels divided by bars and islands; they are of lower sinuosity and carry a coarser sediment load than meandering rivers (Miall, 1977).

A braided stream system has been suggested as a possible depositional environment for the other Lake Superior area quartzites. Campbell (1981) concluded that a braided stream system probably deposited the Flambeau Quartzite. Weber (1981) postulated that a combination of a marine and fluvial depositional environment was most likely for the Sioux Quartzite and the probable environment of deposition of the McCaslin Quartzite was a braided stream (Olson, 1982). Dott (1983) suggested that the lower portion of the Baraboo Quartzite may be a fluvial deposit while the upper few hundred meters may represent a transition to a marine environment since the Seely Slate and the Freedom Dolomite (which contains banded iron-formation and mud-cracks), which conformably overlie the Baraboo, are probably marine deposits.

Miall (1978) proposed six facies assemblages that exist in gravel and sand-dominated braided river deposits. The Barron has facies similar to three of these models, the South Saskatchewan, Platte, and Bijou Creek types (Fig. 36). The South Saskatchewan type reflects the downstream portion of a braided river. The Platte type may represent a variety of the South Saskatchewan type, in which large bars and sand waves are the dominant mode of deposition instead of dunes. The Bijou Creek type is interpreted by Miall to be a proximal sandy braided stream deposit, occurring in areas lacking a gravel supply. It probably represents an environment dominated by flash floods since the abundance of the Sh (horizontally laminated sand) facies attests to high energy flow conditions.

For comparison, a vertical profile model of the Barron Quartzite which also illustrates cross-bed orientation is shown in Figure 37. This profile was compiled from three outcrops in the southern part of the outcrop area. This area, according to the Bedrock Geological Map of



Explanation of Facies Types

Gm - massive or crudely bedded gravel, horizontal bedding, imbrication

St - medium to very coarse sand, may be pebbly, solitary or grouped trough crossbeds

Sp - medium to very coarse sand, may be pebbly, solitary or grouped planar crossbeds

Sr - very fine to coarse sand, ripple marks of all types

Sh - very fine to very coarse sand, may be pebbly, horizontal lamination, parting or streaming lineation

Sl - fine sand, low angle crossbeds

Se - erosional scours with intraclasts, crude crossbedding

Fl - sand, silt, and mud, fine lamination, very small ripples

Figure 36. Facies assemblages in braided-river deposits. (After Miall, 1978)

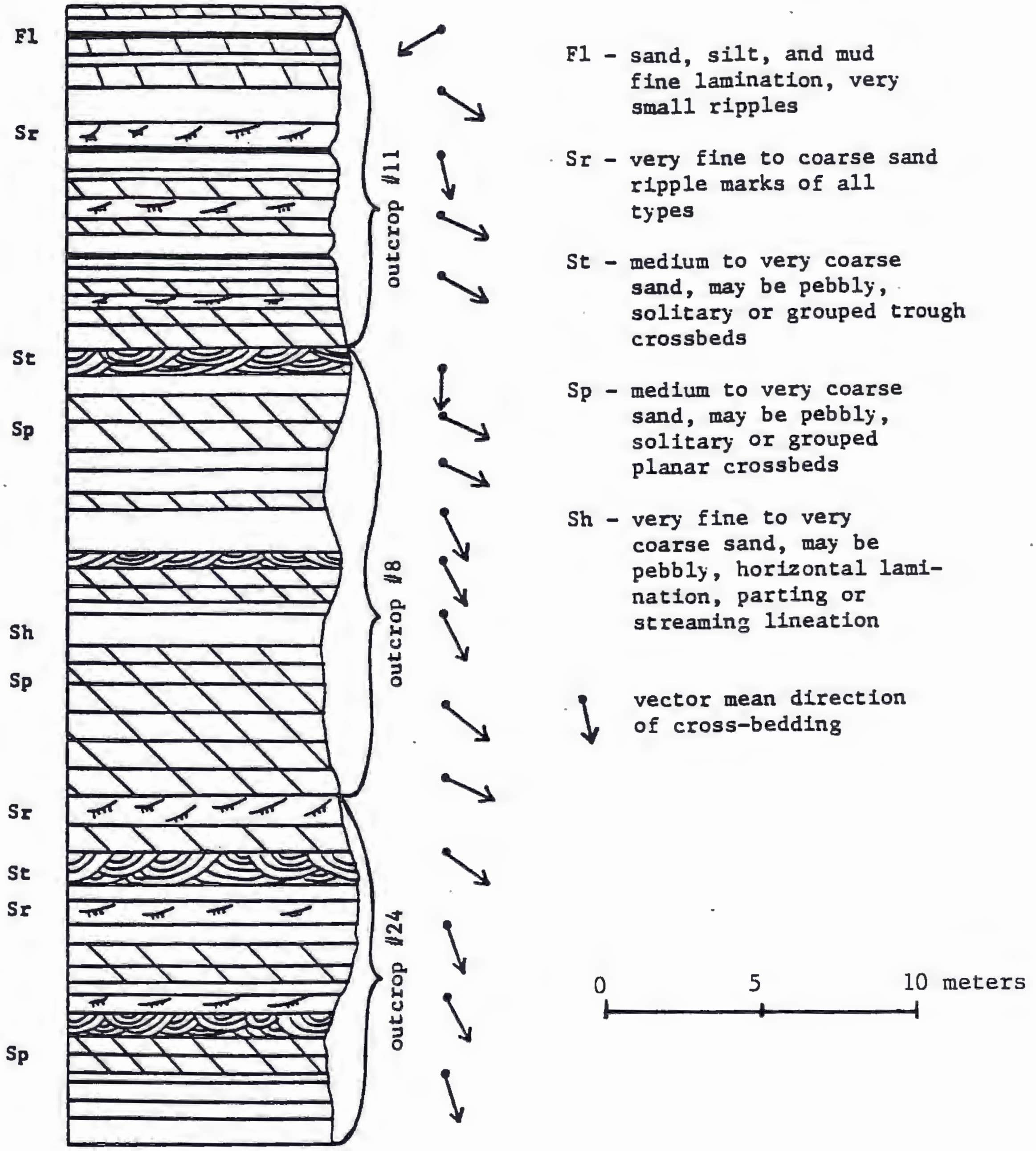


Figure 37. Vertical profile of the Barron Quartzite.

Wisconsin (Mudrey et al., 1982) is not cut by faults and it is assumed that these three outcrops make up an undisturbed stratigraphic sequence. All of the facies present in Miall's three models are also present in the Barron: planar cross-bedded sand, horizontally laminated sand, trough cross-bedded sand, sand with ripple marks, and laminated to massive sand, silt, and mud. Although the gravel facies does not occur at the outcrops used to produce the Barron profile, conglomerate is present in the basal portion of the formation. The quartz-pebble conglomerate of the Barron is very thin (approximately 8 cm) and occurs as a one to two pebble thick layer approximately 10 cm above the lowermost exposure of the Barron quartzite (outcrop #5, Fig. 2). Such a gravel sheet would most likely form as a lag deposit during a period of high discharge in a fluvial system (Hein and Walker, 1977). The fact that the beds of quartz arenite exhibit very little cross-stratification here is additional evidence for the presence of a high flow regime environment.

The paleocurrent data are helpful in determining the sedimentational history of the Barron. Unimodal paleocurrent distributions are indicative of fluvial environments while marine environments may have unimodal, bimodal, or polymodal patterns. A tidally-influenced marine environment would, ideally, have a biomodal-biopolar distribution. As shown in Figure 32, most localities show unimodal patterns, suggesting fluvial deposition although the unimodal pattern could reflect sediment transport parallel to a shoreline. A polymodal distribution does occur at one location, however, and one location has a bimodal-bipolar distribution.

Variances of cross-bedding are also somewhat mixed. A variance of 4,000 to 6,000 is indicative of a fluvial depositional environment while a variance of 6,000 to 8,000 indicates a marine environment (Potter and Pettijohn, 1977, p. 111). Six of the eight locations in which many cross-bed measurements were made have variances of under 6,000 (Figure 35).

The presence of dissimilar paleocurrent patterns and variances may be explained by examination of Figure 38 which illustrates the change in paleocurrent patterns and variance from the base, the middle, and top of the formation using the same, presumably undisturbed, stratigraphic sequence of Figure 37. The variance for the basal outcrop is 2894 and the paleocurrent pattern is strongly unimodal. Both of these facts suggest a fluvial environment. The variance of the middle outcrop is somewhat higher at 4908, but it is still in the fluvial range and the paleocurrent pattern, though somewhat more spread out, is unimodal. The top outcrop has a variance of 7390 (in the marine range) and a bimodal-bipolar paleocurrent pattern, indicating a tidally-influenced marine environment. This would suggest a change in depositional environment from fluvial at the base and middle of the formation to marine near the top.

Furthermore, if the Barron Quartzite and the Baraboo Quartzite are correlative (correlation will be discussed in the next chapter), there is additional evidence to suggest a marine depositional environment for

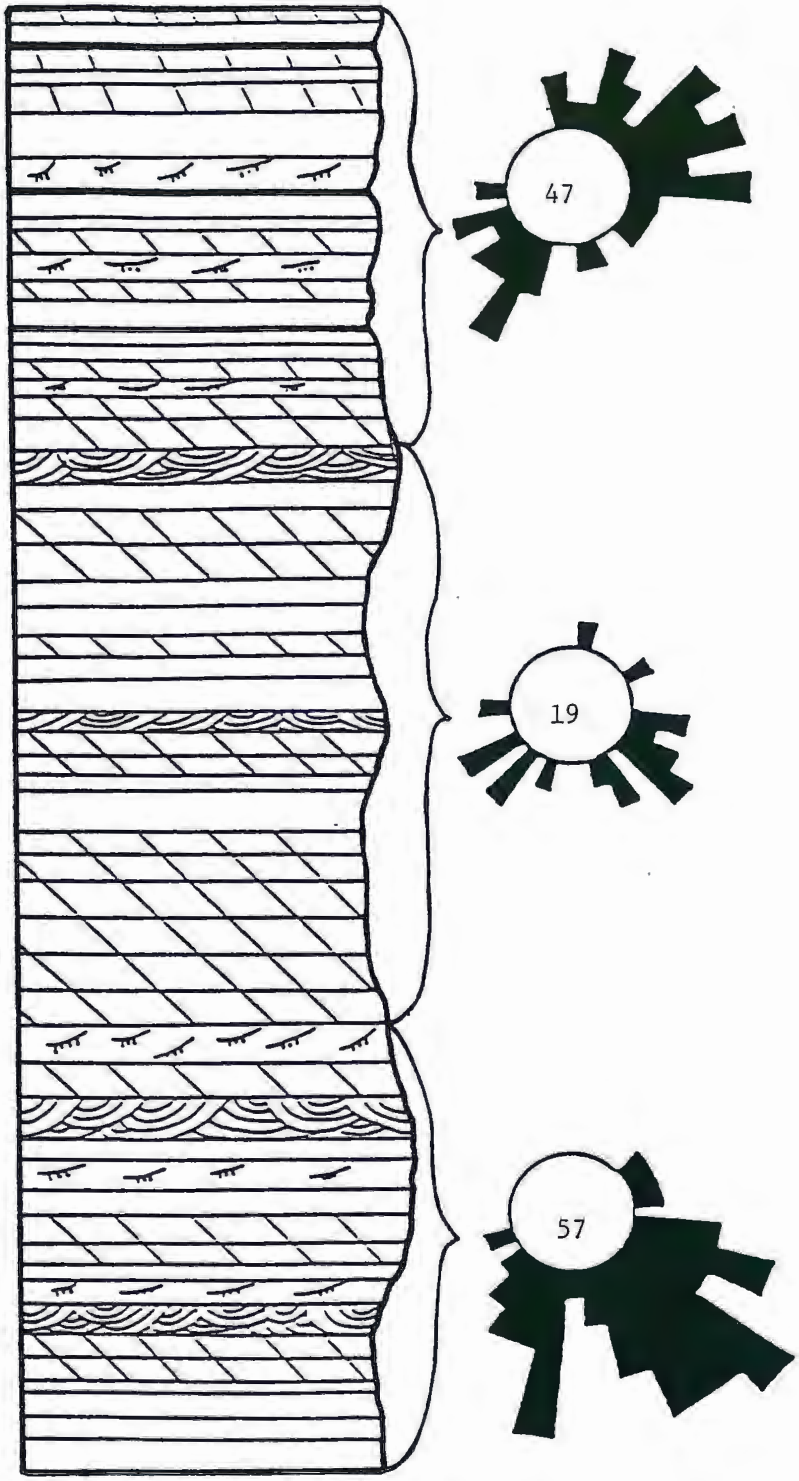


Figure 38. Vertical profile of the Barron Quartzite showing change in inferred paleocurrent directions.

the top of the sequence since the Seely Slate and Freedom Dolomite, which conformably overlie the Baraboo, are considered to be marine deposits (Dott, 1983).

It has also been concluded that the Sioux Quartzite, which is inferred to be correlative with the Barron, was deposited in a combination of fluvial and marine environments. It is interpreted to be fluvial at the base and marine in its upper parts (Ojakangas and Weber, 1984).

In view of all of the characteristics of the Barron Quartzite that have been considered, the proposed depositional environment of the Barron Quartzite is a braided alluvial plain which was superseded by a tidally-influenced marine shelf environment.

Provenance

Many characteristics of the Barron Quartzite indicate a sedimentary source. Texturally, the Barron is very mature. It is well-sorted and the grains are rounded to well-rounded. Such a mature sand would most easily be produced from a pre-existing sandstone. Suttner and others (1981) concluded that the majority of ancient quartz arenites are multicycle in origin and that first-cycle quartz arenites cannot be produced under average conditions of weathering, transportation, and deposition. The authors studied Holocene sands derived from granitic rocks which were theoretically subjected to tens of thousands of kilometers of transport and deposited in a high-energy littoral environment. They found that only approximately 5% of samples of this Holocene sand became compositionally "super mature" or greater than 95% quartz. However, it must be noted that mature quartzose sands can be produced without multicycle reworking. Recent work by Franzinelli and Potter (1983) has shown that rivers draining low-lying, high rainfall regions and underlain by either Precambrian or Precambrian and Paleozoic rocks produce sands that are exceptionally pure quartz arenites. Very important in the production of these quartz arenites is a tropical climate and low relief to allow prolonged weathering.

The heavy mineral suite is very limited and consists almost entirely of rounded zircons. Rounded tourmaline and rounded rutile are also present. The ZTR index, which is calculated by dividing the number of zircon, tourmaline and rutile grains by the total number of nonopaque heavy minerals (Hubert, 1962) is 96. Such a high ZTR index implies that the formation is very mature and most likely was derived from reworked sediments (Potter, Pettijohn, and Siever, 1973, p. 304).

Some angular to sub-rounded pyroxene grains do occur. Since these grains are not rounded like the rest of the heavy mineral suite, the pyroxene may represent the presence of an additional, non-sedimentary source for the Barron, possibly a basic igneous source.

Quartz grains with abraded quartz overgrowths surrounded by second, optically continuous, quartz overgrowths are seen in thin section. These "multicycle" quartz grains are rare but they are additional evidence pointing to a sedimentary source for the Barron. Since quartz overgrowths are easily decoupled from framework grains, as explained by

Anderhalt (1984), it would be expected that grains with multiple overgowths in a quartz arenite would be rare, even if the formation was multicycle. Grains that show no double overgowths could be multicycle grains which lost overgowths during transportation.

Chert and jasper rock fragments were also observed in thin section. These rock fragments definitely attest to sedimentary sources of chert and possibly iron-formation.

Paleocurrent indicators point to a northern source for the Barron Quartzite since paleocurrents, in general, flowed from northeast to southwest and northwest to southeast. There are many quartzites and iron-formations located north of the Barron which may have served as source material.

In northern Wisconsin, the Lower Proterozoic Palms Quartzite and the Ironwood Iron-formation of the Animikie Group are possible source rocks. Many formations of the Marquette Range Supergroup in northern Michigan including the Mesnard Quartzite, the Ajibik Quartzite, the Negaunee Iron-formation, and the Goodrich Quartzite are all possible sources. One other possible source located in Michigan is the Sturgeon Quartzite in Dickinson County. Formations in Minnesota that may have been source rocks are the Pokegama Quartzite, the Biwabik Iron-formation, and the Gunflint Iron-formation.

Part of the Barron may not have a sedimentary provenance. The angularity and size of the quartz pebbles in the basal conglomeratic zone of the Barron point to a local source. The underlying regolith and biotite gneiss in the area may have been sources for these quartz pebbles. The regolith contains abundant quartz grains and the gneiss is full of quartz "eyes" as well as large pods and veins of quartz. However, although local non-sedimentary sources may have made minor contributions to the Barron Quartzite, the primary source was most likely sedimentary.

CHAPTER VI CORRELATION, AGE, AND TECTONIC SETTING

Correlation

The quartzites of the Lake Superior region, due to their lithological similarity, have been correlated by many different authors. However, they have recently been divided into two distinct groups (Fig. 39); the northern "younger" quartzites and the southern older quartzites (Ojakangas, in press, and Ojakangas and Morey, 1983).

The northern quartzites; the Bessemer Quartzite, the Puckwunge and Nopeming Formations, and the lowest part of the Osler Group, are believed to be between 1200 and 1100 m. y. old. The Pass Lake Formation of the Sibley Group may or may not fit into the group of "younger" quartzites, having been dated at 1340 m.y. (Franklin et al., 1980).

Dott (1983) correlated what he calls the Baraboo interval (1750 to 1450 m.y.) quartzites; the Baraboo, Sioux, and Barron Quartzites. The Flambeau, McCaslin, Waterloo, and Rib Mountain Quartzites of Wisconsin probably also fit into this time interval and are lithologically similar. In addition, there is a quartzite encountered only in drill core in Washington County, Iowa that also should be included in this group (Anderson, 1985).

This thesis corroborates the correlation of the Barron Quartzite with the Baraboo interval quartzites. Lithologically, the Barron is almost identical to the Baraboo and Sioux Quartzites. All three are

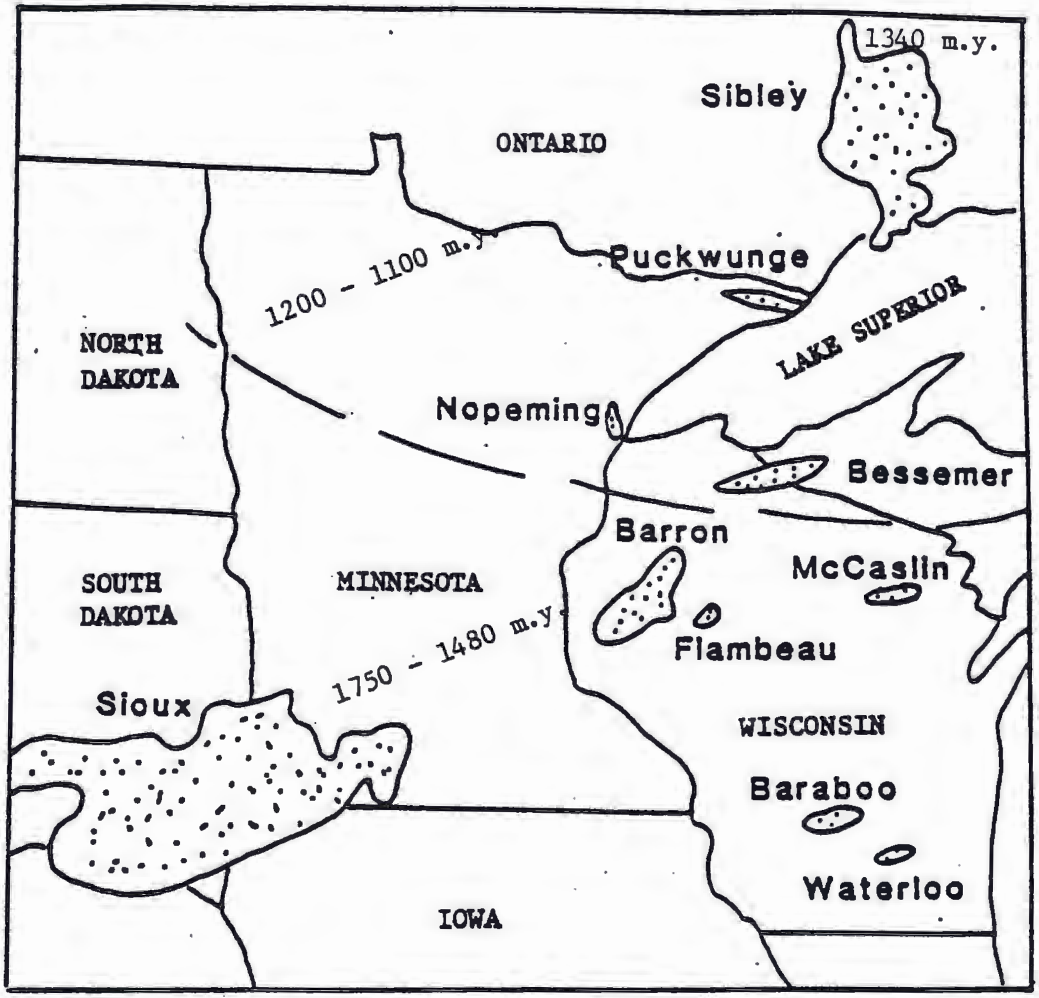


Figure 39. Age groups of the quartzites of the Lake Superior region. (After Ojakangas, in press)

(Note: The Sibley Quartzite may not fit into the group of younger quartzites, having been dated at 1340 m.y.)

composed of quartz-pebble conglomerate, quartz arenite, and red argillite. Texturally, all of the Baraboo interval quartzites are alike. The quartzites are all well-sorted and well-rounded. The proportions of different quartz types present are very similar, with common quartz accounting for approximately 90% of the framework grains in quartzites.

Heavy mineral suites of the Sioux, Baraboo, McCaslin, Flambeau, and Barron Quartzites are virtually indistinguishable. In all cases, rounded zircon is the dominant species with minor rounded tourmaline and rounded rutile also present in small amounts. ZTR indices range from 96 for the Barron to 100 for the Sioux and McCaslin.

Another similarity between the quartzites is the likelihood that they were deposited in similar environments. The presumed depositional environment of the quartzites is either a braided stream system or a combination of braided stream and shallow marine environments. Finally, the available evidence shows that the quartzites were all deposited in a fairly narrow time span.

Table 4 illustrates the similarities between the quartzites but also reveals some dissimilarities. The Barron Quartzite is unmetamorphosed while the Flambeau, McCaslin, and Waterloo are all at least somewhat metamorphosed. Furthermore, the Barron is almost untouched structurally while the Baraboo, Flambeau, McCaslin, and Waterloo have all been folded to some degree. The clay minerals present in the quartzites differ also. A final incongruity between the Barron and the other Baraboo interval quartzites is the difference in thickness. The

Table 4. CHARACTERISTICS OF BARABOO-INTERVAL QUARTZITES

	BARRON	FLAMBEAU	BARABOO	SIOUX	McCASLIN	WATERLOO
PEBBLES	spc quartz rpc quartz vein quartz chert jasper	vein quartz quartzite chert iron-fm. rhyolite argillite	vein quartz chert jasper	vein quartz quartzite chert iron fm. rhyolite jasper	vein quartz iron-fm. chert quartzite jasper	unknown
% QUARTZ	100	90 +	100	95 - 100	100	100
DETRITAL (<1%) NON-OPAQUE HEAVY MINERALS (ZTR INDEX)	zircon tourmaline rutile apatite clinopyroxene orthopyroxene sphene hornblende (96%)	zircon tourmaline rutile augite apatite garnet sphene (97%)	zircon rutile (100%)	zircon tourmaline (100%)	zircon rutile (100%)	zircon (100%)
PHYLLOSILICATES	kaolinite muscovite	illite muscovite kaolinite	muscovite pyrophyllite kaolinite	pyrophyllite muscovite illite	muscovite kaolinite	muscovite
LITHOLOGIES PRESENT	qtz arenite qtz-pebble conglomerate argillite	qtz arenite sub-lith arenite lithic arenite qtz wacke lithic graywacke conglomerate	quartzite phyllite breccia	qtz arenite conglomerate conglomeratic quartzite mudstone	quartzite meta-conglomerate	quartzite
PALEOCURRENT TREND	southeast southwest	northeast	south southeast	south	east northeast	unknown

spc - stretched polycrystalline
rpc - recrystallized polycrystalline
iron-fm. - iron-formation
qtz - quartz

(Modified after Campbell, 1981; Dott, 1983; Dott and Dalziel, 1972; Ojakangas, in press; Olson, 1984; Utzig, 1972; and Weber, 1981)

Barron is only 200 m (possibly up to 400 m) thick. The other quartzites are quite a bit thicker, but this difference may be meaningless if what remains of the Barron is just an erosional remnant of a much thicker original sequence. Furthermore, it could represent the thinner northern edge of the basin of deposition.

Overall, the Barron shares many characteristics with the Sioux, Baraboo, Flambeau, McCaslin, and Waterloo Quartzites and is considered to be correlative with them.

Age

The age of the Barron Quartzite cannot be precisely determined but an age range can be inferred by correlations with the Baraboo Quartzite. Rhyolites which underlie the Baraboo have been dated at approximately 1750 m.y. (Van Schmus, 1975, 1980). One upper age constraint on the Baraboo is a date of 1440 m.y. on a pegmatite dike which cuts a quartzite near Waterloo, Wisconsin (Bass in Aldrich et al., 1959). A mafic dike (or sill) does cut the Barron in drill core. This dike is as yet undated but it is likely to be found to be Keweenawan (approximately 1100 m.y.) in age. Another upper age constraint is the dating of a metamorphic event in northern Wisconsin which deformed and metamorphosed the Baraboo Quartzite around 1630 m.y. (Van Schmus, 1980). Thus, if the Barron is indeed correlative with the Baraboo Quartzite, its age is between 1750 and 1630 m.y.

Tectonic Setting

The textural and mineralogical maturity of the Barron Quartzite implies that deposition took place on a very stable, low-lying, and deeply weathered craton or continental margin.

The mineralogy of a sandstone can be used to classify what type of tectonic environment the rock was deposited in. Dickinson (1985) used a quartz-feldspar-lithics triangle for plate tectonic classification (Fig. 40). Since the framework mineralogy of the Barron is 100% quartz, the Barron would plot in the craton interior region of the diagram. Sands with high quartz contents reflect intense weathering, prolonged transport, and intense weathering on cratons with low relief (Dickinson and Suczek, 1979).

Greenberg and Brown (1983) proposed three tectonic-sedimentary environments for Baraboo interval sediments (Fig. 41).

1) Marine Transgression Model

   Simple marine transgression model with a source to the north and subsidence to the south.

2) Complex Basin Model

   In this model, many subenvironments exist within one basin. The quartzites are interpreted as derivatives from local basement sources.

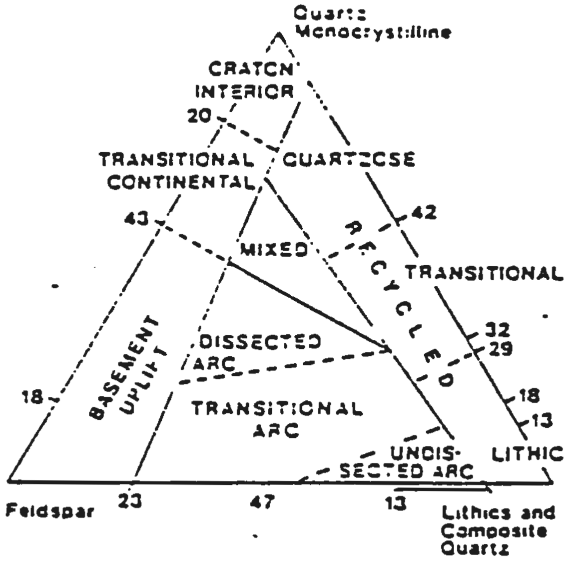


Figure 40. Tectonic classification of sandstones using QFL triangle. (From Dickinson, 1985)

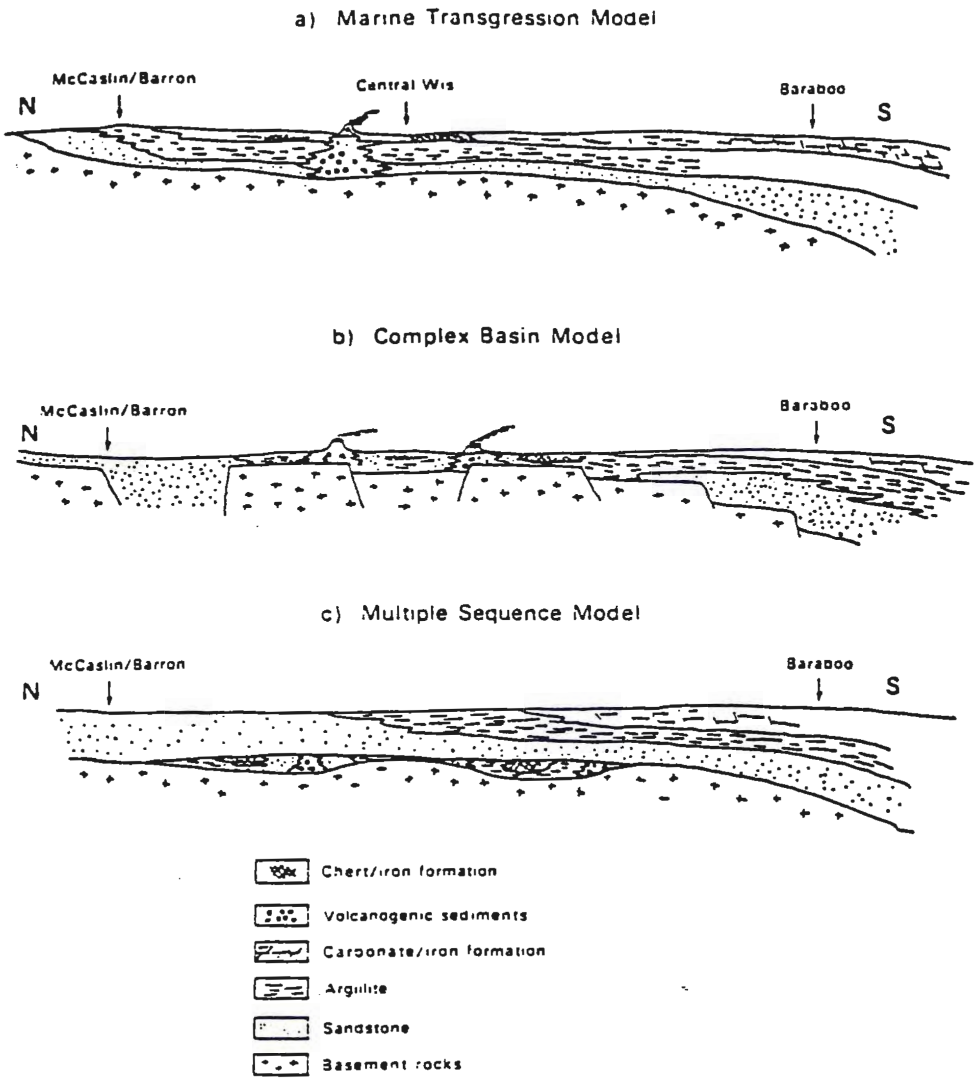


Figure 41. Possible tectonic-sedimentary environments of Baraboo-Interval sediments. (From Greenberg and Brown, 1983)

3) Multiple Sequence Model

This model involves multiple sequences separated by major unconformities.

Greenberg and Brown believe that the tectonic setting for deposition of the Baraboo interval sediments can best be explained by models 2 and 3 or some combination of these two models.

Dott (1983) proposed a tectonically stable continental margin for the deposition of the Baraboo interval sediments based on the unconformable basal contacts, great compositional maturity, and widespread distribution of the quartzites. According to Dott, the quartzites are probably remnants of a vast sedimentary wedge that covered at least the southern margin of the post-Penokean craton of Proto-North America. On this passive continental margin, the sediments which formed the quartzites may have been dispersed by some combination of braided rivers in a humid climate and shallow marine processes (Dott, 1983). Further evidence Dott uses as substantiation for deposition on a continental margin is the great thickness of the Baraboo interval sediments (in particular the Baraboo and the Sioux), and the marine units which conformably overlie the Baraboo Quartzite.

In summary, the tectonic setting of the Barron Quartzite was most likely a subsiding basin on or adjacent to a stable, low-lying, and deeply-weathered craton mantled by braided fluvial systems and later covered by an epicontinental sea.

CHAPTER VII SUMMARY AND CONCLUSIONS

1. The Barron Quartzite is at least 200 m thick and may be up to 400 m thick. It is comprised primarily of quartz arenite with minor interbedded argillite and a thin basal quartz-pebble conglomerate.

2. Framework grains are predominantly common quartz (95%) with minor polycrystalline stretched quartz (3%), vein quartz (1%), and polycrystalline recrystallized quartz (1%).

3. The Barron detrital, non-opaque heavy mineral suite consists almost entirely of rounded zircon. Rounded rutile and rounded tourmaline are present in small amounts. The ZTR index is 96.

4. Paleocurrent indicators shown an overall sediment transport direction toward the southwest and southeast.

5. The suggested depositional environment of the Barron Quartzite is a braided fluvial system superseded by a tidally-influenced marine shelf environment.

6. A dominantly sedimentary source is indicated for the Barron by its texture and mineralogical maturity, limited heavy mineral suite, "multicycle" quartz grains, and the presence of chert and jasper rock fragments.

7. The Barron Quartzite is most likely correlative with the Baraboo, Sioux, Flambeau, McCaslin, and Waterloo Quartzites and is approximately 1750 to 1630 m.y. old.

8. The tectonic setting of the Barron was probably a subsiding basin on or adjacent to a stable, low-lying, and deeply-weathered craton.

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APPENDIX A

DESCRIPTIONS OF OUTCROP LOCATIONS

Outcrop Number	Location
1	Strickland Quadrangle: SE 1/4, SE 1/4, Section 22, T35N, R10W (Along county road C.)
2	Strickland Quadrangle: center of N 1/2, Section 28, T35N, R10W
4	Raddison Quadrangle: SE 1/4, SE 1/4, Section 16, T39N, R7W (Along Pipestone Creek.)
5	Becky Creek Quadrangle: On S 1/2 of section line dividing Section 8 and Section 9, T36N, R7W (From Rice Lake: 48 to C to O to Old Blue Hills Trail (north), to Meadow Dam, to H (east). Go 1 mile east on H then turn north. Go 2.3 mi. north - outcrop is at bend of road.)
6	Bucks Lake Quadrangle: NW 1/4, NW 1/4, Section 18, T36N, R9W (C (west), turns into Old Blue Hills Trail, turn right on Dejung, go 0.45 mi. past the path shown on map - outcrop is to the south of Dejung.)
7	Bucks Lake Quadrangle: W 1/2, NW 1/4, Section 18, T36N, R8W
8	Weyerhauser Quadrangle: SW 1/4, NW 1/4, Section 33, T35N, R9W
10	Strickland Quadrangle:

	NE 1/4, SE 1/4, Section 29, T35N, R9W
11	Strickland Quadrangle: Center of N 1/2 of Sec 30 (Gundy Canyon on Rock Creek)
12	Bucks Lake Quadrangle: NW 1/4, NW 1/4, Section 18, T36N, R8W
14	Couderay Quadrangle: NW 1/4, SW 1/4, Section 16, T38N, R8W (On shores of Beverly Lake.)
15	Edgewater Quadrangle: S 1/2 of Section 30, T37N, R9W (Southern 1/2 of Section 36 along the western 1/2 of Sucker Creek in Section 36.)
16	Hauer Quadrangle: SE 1/4, SW 1/4, Section 5, T38N, R8W (On section line between Section 5 and Section 8 and also north into Section 5 along the SOO Line.)
17	Strickland Quadrangle: NW 1/4, Section 29, T35N, R9W (On southern side of Rock Creek.)
18	Rice Lake South Quadrangle: S 1/2, Section 32, T35N, R10W (Center of the southern 1/2 of Section 32.)

21	Weirgor Quadrangle: NE 1/4, Section 10, and W 1/2, NW 1/2, Section 11, T37N,R8W (Along Maple Creek.)
22	Becky Creek Quadrangle: N 1/2, NW 1/4, Section 15, T36N, R8W
23	Becky Creek Quadrangle: E 1/2, SW 1/4, Section 11, T36N, R8W
24	Bucks Lake Quadrangle: NW 1/4, NE 1/2, Section 20 and SW 1/4, SE 1/2, Section 17, T35N, R8W (At top of ski hill under chair lift.)
25	Couderay Quadrangle: NW 1/4, SW 1/4, Section 16, T38N, R8W (On shores of Beverly Lake.)
26	New Post Quadrangle: On section line between Section 31 of T40N, R6W, and Section 6 of T39N, R6W (On edge of Granite Bay.)
27	Hauer Quadrangle: SW 1/4, SW 1/4, Section 19, T38N, R8W
30	Strickland Quadrangle: NW 1/4, SW 1/4, Section 30, T35N, R9W (Gundy Canyon along Rock Creek.)
31	Rice Lake South Quadrangle:

W 1/2, Section 31, T35N, R10W
(Center of the W 1/2 of Section 31,
along the road.)

33 Mikana Quadrangle:
NW 1/4, NE 1/4, Section 15, T35N, R10W