PETROLOGY AND SEDIMENTATION OF THE FLAMBEAU QUARTZITE

by

Frederick K. Campbell[1]

ABSTRACT

The Early Proterozoic Flambeau Quartzite of northwestern Wisconsin is an outlier in the Penokean Volcanic Belt underlain by felsic volcanic and plutonic rocks. It has a minimum thickness of 800 metres and is folded into a syncline. The Flambeau Quartzite consists of quartz arenite to lithic graywacke. Quartz arenite is by far the most abundant rock type with conglomerate common. The most common framework grains are rounded common quartz, polycrystalline quartz, vein quartz, chert, argillite, magnetite, hematite, and zircon. These components suggest a dominant quartzrich sedimentary source. Paleocurrent data indicate a source terrane to the west and south of the outcrop area.

The poorly sorted pebbly texture, local abundance of clayey fragments and matrix, and unimodal paleocurrent pattern with low variance (2500) strongly support this deposition in a braided stream . Important controls on the sedimentation were the lack of land vegetation, aeolian transport, intense weathering, and a relatively stable tectonic environment.

INTRODUCTION

The Early Proterozoic Flambeau Quartzite is exposed at the surface only on Flambeau Ridge near the confluence of the Flambeau and Chippewa Rivers in northwestern Wisconsin (fig. 1). Flambeau Ridge is an east to west trending erosional remnant composed of well-indurated, cross-bedded sandstone and conglomerate. Contact between the Quartzite and adjacent rock is covered by glacial deposits. Diamond drill holes, water wells and outcrops provide strong evidence that the Flambeau is an outlier in the Penokean Volcanic Belt. Rock units in this belt include intermediate to felsic volcanic and metasedimentary rock (Myers and others, 1974). Model lead ages from volcanogenic massive sulfides near Ladysmith (fig. 1) suggest an age of 1,850 Ma for this belt (Sims, 1976).

The precise age of the Flambeau Quartzite is difficult to determine due to the lack of observable contacts with adjacent rock units. In order to clarify the age of the Flambeau, comparisons with other quartzite exposures in the region (for example, Baraboo, Waterloo, and some others) must be made. The other areas of quartzite have been studied extensively. In some cases there is direct evidence for their relative and absolute ages. It is not within the scope of this paper to make detailed comparisons between the Flambeau and other quartzite units. However, on the basis of lithology, structural and geological relationships, and geographic location, the Flambeau Quartzite is probably correlative with the Baraboo, Sioux, Waterloo, Barron and Rib Mountain Quartzites (Dott and Dalziel, 1972). Radiometric ages and other data indicate deposition of these quartzites after a 1,760 Ma igneous event and prior to a 1,630 Ma metamorphic-deformational event (Smith, 1978).

STRUCTURE AND THICKNESS

The Flambeau Quartzite is exposed in patches along Flambeau Ridge (fig. 2). Outcrop data indicate that the structure of the Quartzite is a steep syncline (fig. 2), although the axis of the syncline is not exposed in outcrop. A stereonet plot (fig. 3) of 80 poles-to-bedding (see Billings, 1972, p. 100-104) indicates that the axis of the syncline trends approximately N. 50° W. and plunges approximately 45° to the northwest. Stratigraphic tops were determined with the aid of cross-bedding, which is visible in nearly every outcrop.

No minor folds or related small-scale structures were observed in the Flambeau, but fractures, joints, slickensides and veins are fairly common in most outcrop. Veins are typically filled with milky quartz. Some veins resemble tension gashes but are not sigmoidal in form.

Due to lack of continuous outcrop the total thickness of the Flambeau Quartzite is unknown. I estimated the exposed thickness of the formation by measuring the stratigraphic distance between outcrop on the southern limb of the syncline (fig. 2). This method yielded approximately 800 metres of section, which will serve as an estimate of the minimum thickness of the Flambeau Quartzite.

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1. 4917 Russell Ave. So., Minneapolis, Minnesota 55410

STRATIGRAPHY AND GROSS LITHOLOGY

The northern limb of the syncline is exposed only on the eastern end of Flambeau Ridge, whereas the southern limb is exposed on the central and western parts of the Ridge (fig. 2). The geometry and the structure suggest that the lowermost exposed beds are on the northern limb of the syncline, and the uppermost exposed beds are on the southern limb (fig. 2).

Three main lithologies occur in the Flambeau Quartzite: quartzite, mudchip conglomerate, and quartz-pebble conglomerate. All three lithologies are found in the north limb of the syncline, but mud-chip conglomerate is absent in the south limb. It appears that the mud-chip conglomerate ise the lower-most exposed units in the Flambeau, whereas the uppermost exposed units are mostly quartzite. The three main lithologies all exhibit a poorly sorted fabric, a well-indurated texture

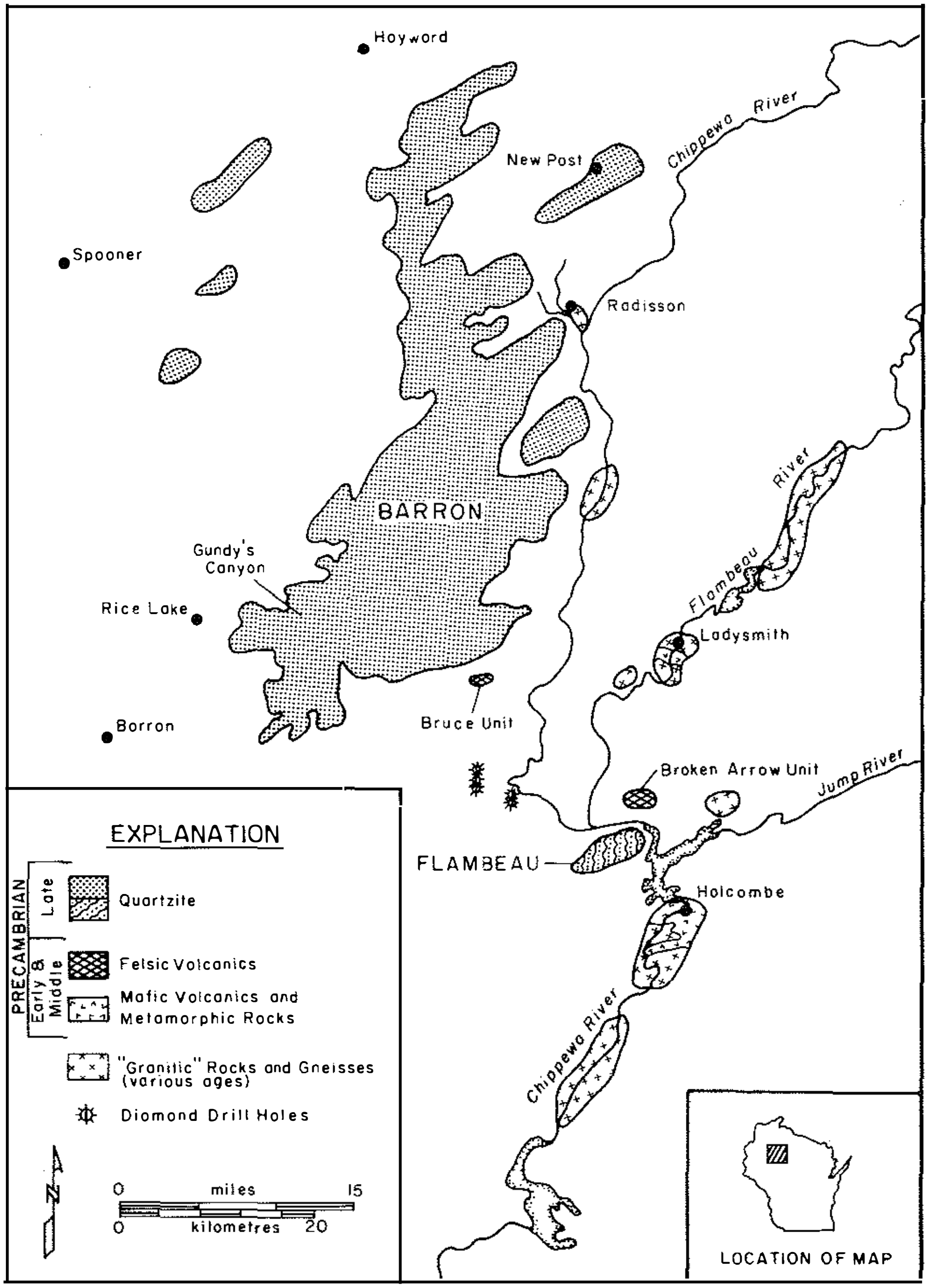

Figure 1. Map of Flambeau and Barron Quartzite Formations, modified from Hotchkiss and others (1915), Dutton and Bradley (1970).

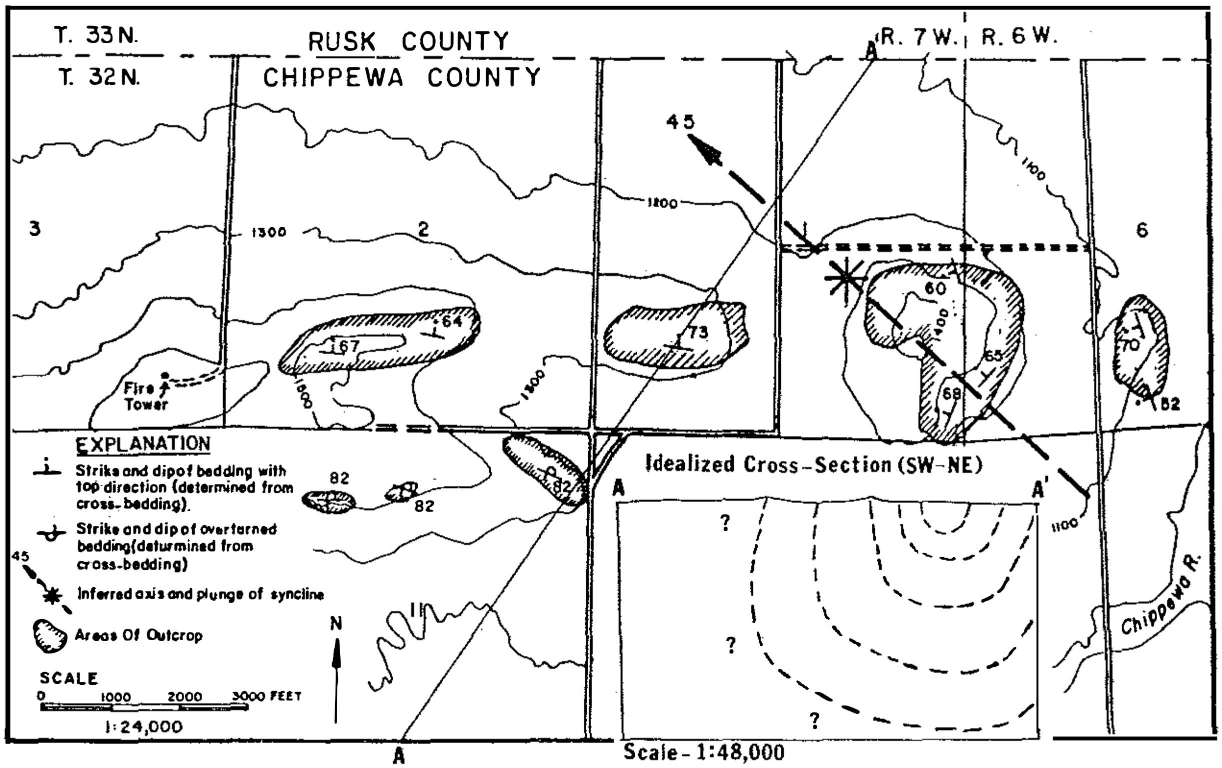

Figure 2.--Map of Flambeau Quartzite.

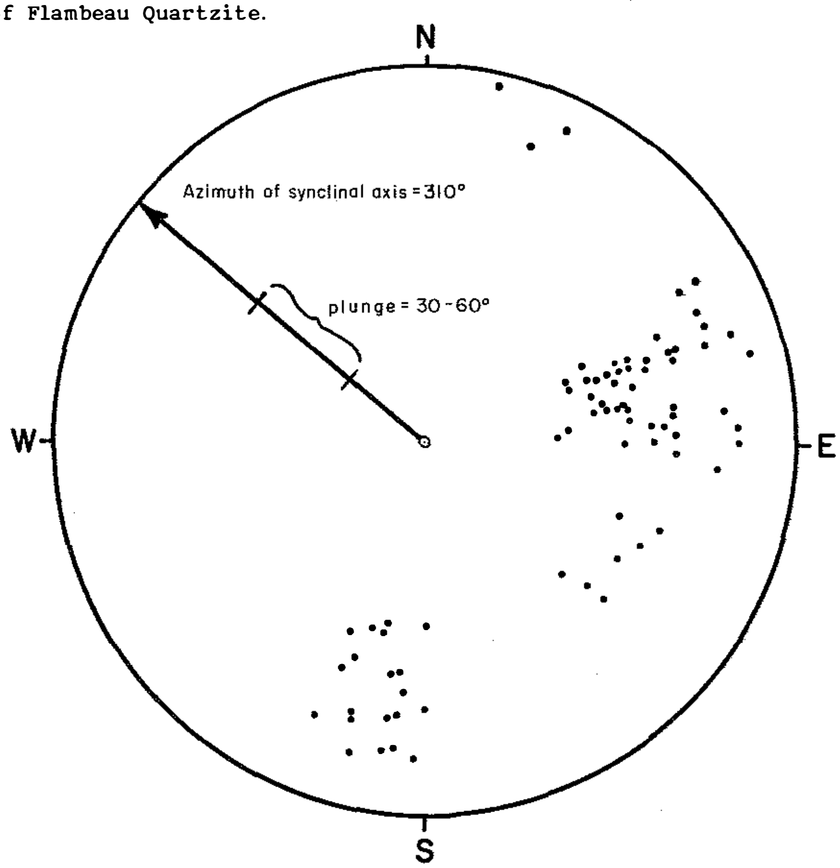

Figure 3.--Poles to bedding plotted with inferred axis and plunge of syncline (80 measurements).

texture, and stratification or cross-bedding or both. Pebbles occur in varying proportions in all three lithologies. Quartzite typically contains less than five percent pebbles, whereas the mud-chip conglomerate contains up to thirty percent pebbles, and the quartz-pebble conglomerate contains more than twenty-five percent pebbles. Pebble counts indicate that vein quartz is the most common pebble lithology (75 percent), followed by argillite (19 percent), chert and iron-formation (4 percent), rhyolite (1.5 percent) and quartzite (0.5 percent). These clasts are generally well-rounded except for the argillite pebbles, and are concentrated in stringers at the tops and bottoms of beds. Pebbles are also scattered randomly in the fine to coarse sand-sized matrix. The clasts range in size from a few millimetres to ten centimetres.

Bedding in the Flambeau Quartzite is visible in nearly every outcrop, although joints, fractures, and liesegang bands may be mistaken for bedding or may obscure it. The average thickness of bedding is 60 cm and ranges from 2 to 180 cm. Most beds are of consistent thickness in outcrop, however some beds are lensoidal or wedge-like. No bed could be traced to other outcrop areas.

In addition to bedding, cross-bedding is another common primary sedimentary structure. It is present in all lithologies. Tabular (planar) cross-bedding appears to be much more common than trough cross-bedding. The average thickness of foreset beds is approximately 30 cm, whereas the average dip of foreset beds is about 20°.

Ripple marks or possible pseudo-ripple marks are visible in a few outcrops. The form of the ripple-like features is irregular and the lateral extent is limited. The ripples are symmetrical with rounded crests and range from 7 to 15 mm in amplitude and from 5 to 15 cm in wavelength. These ripple-like features may be of sedimentary origin or they may be pseudo-ripple marks, the result of post-depositional deformation.

MINERALOGY AND PETROLOGY

The Flambeau Quartzite is a mature quartz sandstone composed mostly of sand-sized quartz with lesser but varying amounts of rock fragments and matrix material and minor accessory minerals (table 1). Four varieties of quartz were distinguished by the author: common, polycrystalline, stretched polycrystalline, and recrystallized quartz. Rock fragments in the formation include argillite, dacite to rhyolite, iron-formation and quartzite (see above). Matrix material is mostly sericite with minor kaolinite. Both quartz and hematite cement are present. The accessory minerals hematite, magnetite, leucoxene, zircon and tourmaline occur in trace amounts throughout the formation.

Rock types in the Flambeau range from quartz arenite to lithic graywacke (fig. 4). Most of the exposed sequence is quartz arenite and many units are conglomeratic. Most of the variation in composition can be seen in a few outcrops on the north limb of the syncline (fig. 2). The lithologic change from lithic arenite to quartz arenite (fig. 4) occurs over a 90 to 120 metre interval. This localized change is probably due to a local change in the environment of deposition. Muddy layers which accumulated during low energy conditions were probably the local source of the argillite fragments comprising the mud chips which formed during high energy conditions. Argillite fragments in the Flambeau are up to ten centimetres across. A fairly high energy, perhaps fluvial, environment is necessary to transport clasts of this size. Experimental studies by Smith (1972) showed that mud chips are broken down in fluvial environments within a few tens or hundreds of metres of their source. Thus, the argillite clasts were probably transported a short distance and were locally derived.

The sand-sized quartz grains which form most of the framework in the Flambeau appear to have been transported from distant sources. These grains show evidence of much abrasion since they are subrounded to well rounded in shape. Substantial abrasion of sand-sized quartz implies that the sediments were well worked and possibly wind transported to some extent. Double (abraded?) overgrowths on quartz grains, although extremely rare in the Flambeau indicate a multicycle origin for at least some of the grains. Multicyclicity is also indicated by the presence of quartzite clasts. The sand-sized rock fragments and heavy-mineral grains are mostly subrounded to well rounded in shape, suggesting substantial transport.

It is apparent from petrographic and petrologic considerations that the Flambeau Quartzite is comprised of both locally-derived (intrabasinal) and transported (extrabasinal) material. The framework grains in most lithologies exhibit fair to poor sorting and subrounded to rounded shapes. The abundance of matrix material, mostly sericite, in some Flambeau lithologies (table 1, fig. 4) is probably due to diagenesis of clays such as illite, montmorillonite, or both.

TABLE 1.--Modal Composition of the Flambeau Quartzite (figures in percent, x = less than 1%)

Sample Number	Common Quartz	Polycrystalline Quartz	Plag.	Rock Fragments	Opaques	Total Matrix	Total Cement
FR-1a	76	7	x	1	2	4	10
FR-1b	76	9	x	1	1	7	6
FR-2a*	48	34	-	5	2	10	3
FR-2b*	59	28	-	2	2	5	4
FR-2c*	55	26	-	11	2	4	5
FR-2e	52	6	2	7	2	25	8
FR-2s	52	34	x	1	1	6	5
FR-3a	69	14	1	2	x	7	6
FR-4a	73	10	1	3	3	3	8
FR-4d	71	11	-	3	2	5	7
FR-5c-1*	42	47	-	2	1	4	3
FR-5c-4*	53	32	-	4	x	7	5
FR-5c-6*	54	26	-	4	5	7	3
FR-5c-8*	29	50	1	4	6	8	3
FR-6b	62	24	-	2	x	8	4
FR-6d	73	16	-	1	1	4	5
FR-6e	71	17	-	1	x	4	7
FR-6f	70	22	-	1	x	3	4
FR-6g	72	11	x	3	1	7	6
FR-7a-1	72	14	x	3	1	7	4
FR-8a-1	60	17	-	11	1	2	7
FR-9c	63	15	-	6	x	12	4
FR-10a-3*	43	10	-	36	x	6	5
FR-11a-1	58	9	-	3	2	24	2
FR-12b*	52	13	-	13	4	11	7
FR-15b*	45	10	-	27	x	11	2
FR-17b*	49	8	x	27	1	9	2
FR-19b	71	14	x	2	1	3	8
FR-20a-1	75	13	-	1	2	4	7
FR-21a	75	12	1	2	1	3	5
FR-22a-2	72	14	x	2	x	8	3
FR-26a	71	12	x	5	1	6	5
FR-26b*	55	27	1	1	1	4	2
FR-26c*	38	50	-	8	x	2	x
FR-27	78	10	x	2	x	2	4

(*indicates conglomeratic sample)

PROVENANCE AND SEDIMENTATION

Thin section and heavy mineral data from the Flambeau strongly suggest a dominant quartz-rich sedimentary source for the Quartzite. Subrounded to well rounded chert, iron-formation and quartzite fragments are present in most of the formation and are direct evidence of siliceous sedimentary rock in the source area. The preponderance of rounded, sand-sized, common quartz grains, some with double overgrowths, is also indicative of sedimentary derivation. The dominant heavy-mineral assemblage consists of rounded zircon, tourmaline, magnetite, hematite, ilmenite and leucoxene. This mature assemblage implies a dominantly reworked sedimentary source (Pettijohn and others, 1972, p. 304).

Petrographic data indicate important igneous and metamorphic sources for the Flambeau sediments. Volcanic rock fragments and volcanic quartz grains are present and are direct evidence of igneous rock in the source area of the Flambeau. The heavy-mineral assemblage of augite, apatite, biotite and sphene is not common, but does imply an igneous source terrane. The presence of abundant vein-quartz, mostly in the form of pebbles, suggests an important igneous or metamorphic source or both. Polycrystalline quartz comprises up to 50 percent of some Flambeau samples (table 1). The ratio of polycrystalline quartz to total quartz is an indicator of provenance; a high ratio suggests a metamorphic source (Pettijohn and others, 1972, p. 300). This ratio may be as high as 5:8 in some conglomeratic samples of the Flambeau Quartzite (table 1); a metamorphic source for the formation seems likely. The presence of rare schistose rock fragments supports this conclusion.

An interpretation of cross-bedding orientation suggests that the source terrane for the Flambeau Quartzite was probably located to the west and southwest of the present outcrop area. A total of 101 measurements of cross-bedding were taken and were plotted on a stereonet. The azimuths of cross-beds were corrected for the plunge of the syncline (usually 30° to 60°) and for the dip of bedding (50° to 90°) (Ramsay, 1961). A unimodal pattern was obtained for all 101 measurements and also for 68 measurements which were less biased towards the better exposed outcrops (fig. 5).

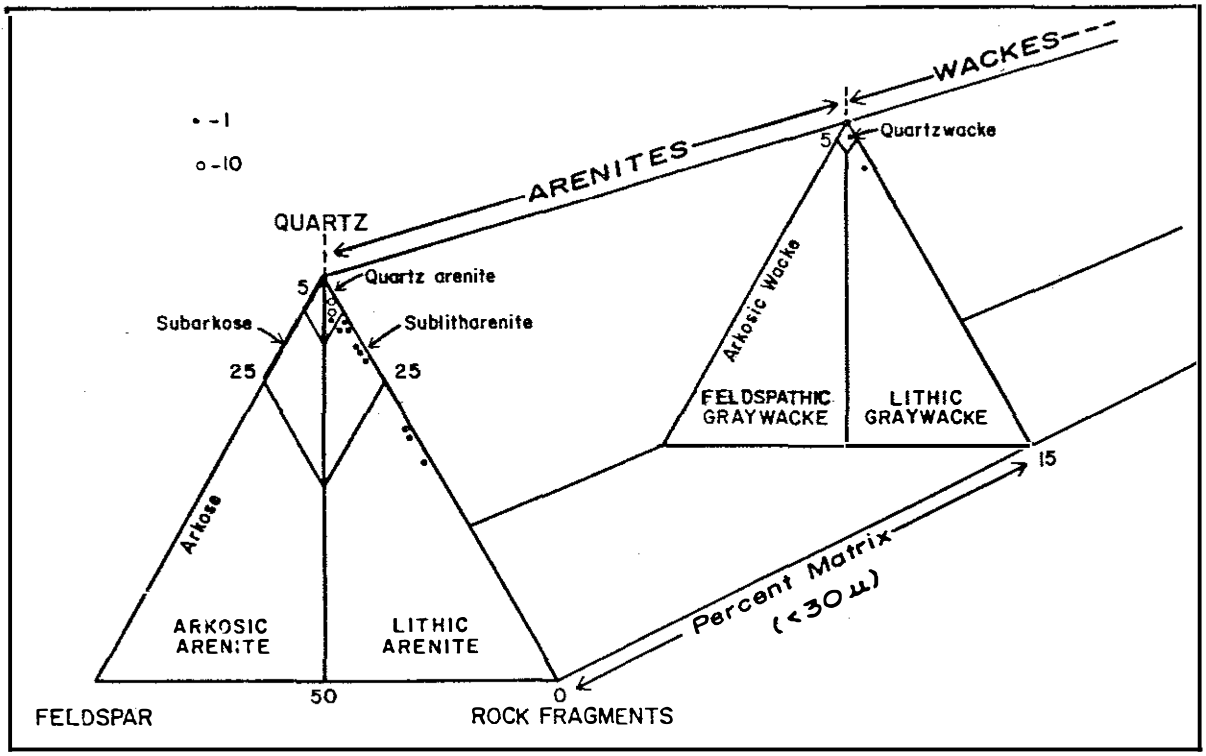

Figure 4.--Thirty-five samples of Flambeau Quartzite plotted diagrammatically to show compositional range.

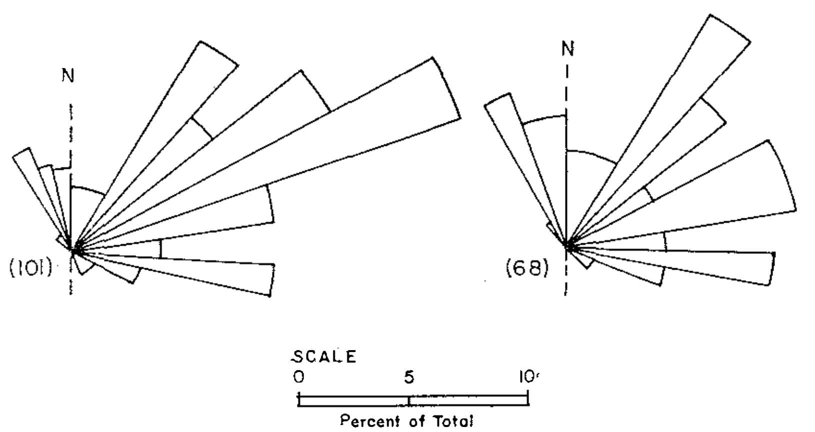

Figure 5.--Paleocurrent directions in Flambeau Quartzite based on doubly rotated cross-beds. Number in parentheses indicates number of measurements.

The variance of cross-bed azimuths in the Flambeau is fairly low (2500). A low variance is typical of a fluvial environment (Long and Young, 1978). The unimodal paleocurrent pattern for the Flambeau (fig. 5) also suggests fluvial deposition. The generally poorly sorted framework, the pebbly and conglomeratic texture, the local abundance of clayey fragments and matrix and unimodal paleocurrent pattern with low variance of cross-bed azimuths is strong evidence that the Flambeau was deposited in a braided fluvial environment (Rust, 1978).

Modern braided alluvial deposits exhibit various facies types which are based upon grain size and sedimentary structures (Rust, 1978). The Flambeau Quartzite exhibits many of the facies types which are recognized in modern environments. The facies types that are well-represented include Sp (planar cross-stratified sand), Sh (horizontally stratified sand), Gp (planar cross-stratified gravel), Gm (massive or horizontally bedded gravel) and Se erosional scours with muddy intra-clasts). These facies types are typically the result of longitudinal and transverse bars and their related alluvial features (Miall, 1978). A representative, composite vertical profile of the Flambeau Quartzite (fig. 6) shows the relationship between stratigraphy and facies types.

The braided stream system which probably deposited the Flambeau sediments may have resembled an alluvial plain due to the lack of vegetation-stabilized river banks. This type of environment permitted the rapid erosion and removal of the finer clastic material. Wind transport of sand, silt and clay was probably characteristic of the environment and is strongly suggested by the well-rounded, sand-sized material. Clay and silt probably accumulated during low-energy stages of sedimentation. Later current action destroyed the muddy layers and produced the observed mud-chip conglomerate (facies type Se) in the lower Flambeau.

Important controls on the sedimentation of the Flambeau Quartzite include the nature of source materials, the depositional environment, tectonics and climate. Tectonics is probably the primary factor and has a large influence on the other variables (Pettijohn and others, 1972, p. 243). However, sedimentation in the Precambrian may have been quite different from that in post-Devonian time (Long, 1978). Intense weathering, the lack of land vegetation and a quartz-rich source terrane (see above) may have been major factors in the sedimentation of the Flambeau. The possible large effect of these three factors on the compositional uniformity of the Proterozoic Athabasca Formation of northwestern Canada is postulated by Ramaekers and Dunn (1976).

The tectonic environment in which the Flambeau was deposited is implied by the lithology thickness and structure of the Quartzite. It seems likely that the formation was deposited at or near the edge of a craton. The sediment was well-worked and probably became mature in a tectonically stable area before reaching a more rapidly subsiding basin. The mature quartzite could have accumulated to a significant thickness in a rapidly subsiding basin. After deposition and fairly deep burial the Flambeau was probably deformed in a zone of mild tectonic activity.

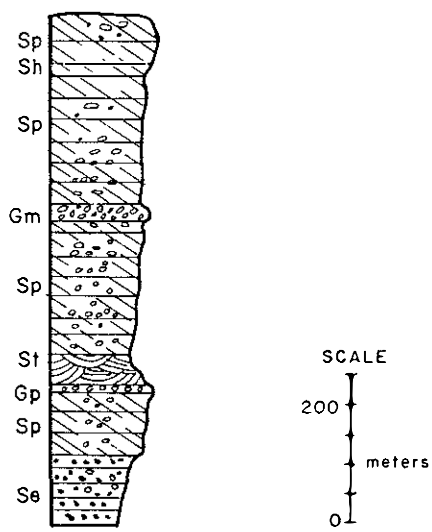

Figure 6.--Vertical profile of facies types in Flambeau Quartzite.

GEOLOGIC HISTORY

Based on lithology, structure, and stratigraphic relationships, the Flambeau Quartzite appears to be correlative with other early Proterozoic quartzites in the region including the Baraboo, Waterloo, Sioux, and Barron Quartzites. If this correlation is valid, then these quartz- ites probably had a similar geologic history. The available data suggest that the following se- quence of events led to the present condition of the Flambeau Quartzite: (1) syn or post-Penokean (1,760 Ma) felsic volcanic and intrusive activity in the source area; (2) erosion of an Archean or early Proterozoic source terrane; (3) intense chemical weathering of the source terrane, producing large volumes of quartz-rich sediment; (4) braided fluvial and aeolian transport of sediment; (5) slow but continuous subsidence of the depositional basin; (6) sheet-like sedimentation of sand- sized material with local lag deposits of gravel and pebbles; (7) burial and diagenesis of the sediment; (8) folding and metamorphism during a 1,630 Ma event; (9) fracturing; (10) uplift and erosion; (11) marine transgression and regression; deposition of sandstone during late Cambrian, later transgression and regression; (12) uplift and erosion; and (13) erosion and deposition of glacial material by the Chippewa Lobe during late Pleistocene time.

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