A FIELD AND PETROGRAPHIC STUDY OF THE FREDA FORMATION ALONG THE MONTREAL RIVER, GOGEBIC COUNTY, MICHIGAN

by

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ABSTRACT

The Montreal River provides a geographic boundary between Wisconsin and Michigan on the south shore of Lake Superior.

A geologic study, both field and laboratory, was made of the 12,000 foot thickness of steeply dipping Freda formation exposed along this river. The field study includes mapping of sedimentary structures in an effort to determine the dominant current directions during deposition of the formation. Pebble and quartz grain orientation as well as heavy mineral and rock composition analyses were made in the laboratory to supplement the field work.

The rock composition and heavy minerals indicate the constituents were derived from a relatively close hinterland, probably composed of Keweenawan instrusives and extrusives. Petrofabrics and directional sedimentary structures reconstructed to a pre-tectonic attitude indicate that the prevailing paleo-current direction was northwest.

ACKNOWLEDGMENTS

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INTRODUCTION

The Montreal River provides a geographic boundary between Iron County, Wisconsin and Gogebic County, Michigan. The approximately four square mile area investigated is bounded on the west by the Montreal River, on the north by Lake Superior, on the south by the Freda sandstone-Nonsuch shale contact, and on the east by the section line between Section 2 and Section 3, T47N, R49W (Fig. 1).

The economically important geology of the Upper Peninsula has been studied in great detail; conversely, formations with little apparent economic value have been studied in only a general way. The purpose of this study is to augment the heretofor sparse geologic knowledge of the Freda sandstone.

A fifteen day field investigation was made to determine the gross characteristics of the formation and to obtain samples for laboratory analysis. Sedimentary structures, attitude of the beds, thickness and lithology were recorded.

Laboratory investigations to determine direction of deposition, sediment composition, and provenance supplement the field study.

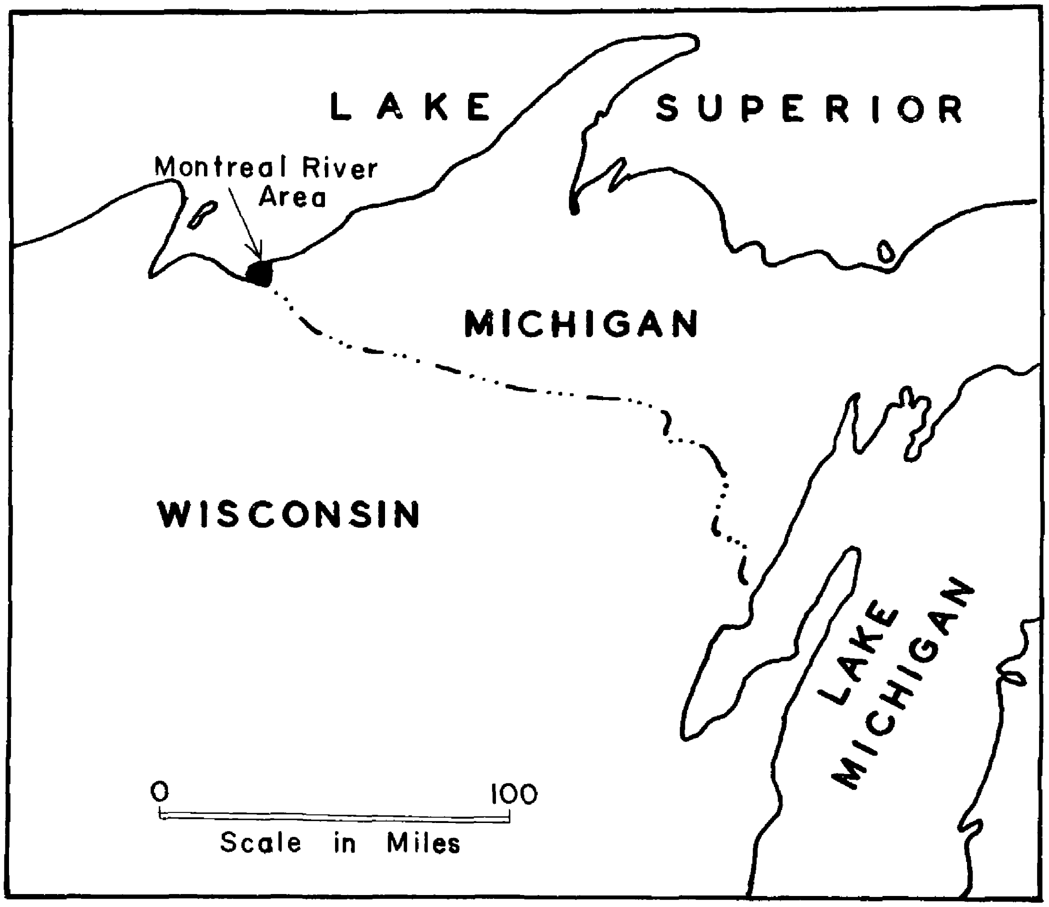


Figure 1. Map showing location of area

GEOGRAPHY

Wisconsin State Highway 122, paralleling the Lake Superior shoreline in the vicinity, provides ready access to the area. Foliage, consisting mainly of second growth woods of birch and aspen covers much of the area. A few unproductive subsistence farms interspersed with summer cottages lie along the highway.

A hydroelectric plant is situated on the Montreal River south of the highway.

The topography is punctuated along the Lake Superior shoreline by impressive Freda sandstone cliffs, 20 to 70 feet high. The cliffs are overlain by a red clay which forms a flat area dissected by intermittent streams. However, to the south, the topography rises to a summit on a ridge formed by the Outer conglomerate. The total relief is in excess of 500 feet. A youthful valley is cut by the Montreal River, the major river of the area.

The average annual rainfall is 33 inches. Proximity to Lake Superior undoubtedly modulates the temperature which achieves an annual average of 10 to 11 degrees for January and 64 to 65 degrees for July.

GEOLOGY

Regional Geologic Setting

The rocks exposed along the Montreal River belong to the upper portion of a series known as Keweenawan. Irving (1883) introduced the term Keweenaw(an), and recognized an unconformity (disconformity) between the Keweenawan and underlying Huronian, as well as an unconformity above, especially with the Mississippi Valley Cambrian sandstones. An estimated 30,000 feet of flows was extruded and 20,000 feet of sediment was deposited in the Lake Superior Region in the Keweenawan period. The Keweenawan Series extends 120 miles northwest of Lake Superior, southwest through Wisconsin to St. Paul, Minnesota, east to the eastern shore of Lake Superior and 12 miles on to the south shore. Three divisions are included in the Keweenawan: (1) the lower sandstones and conglomerates; (2) the middle basic flows, arkoses, conglomerates and acidic and basic intrusives; and (3) the upper conglomerates, shales and sandstones.

The lower Keweenawan sandstone lies stratigraphically below the extrusives; it is most prominently developed in Canada but also crops out to the north of the Upper Huronian sediments on the Penokee-Gogebic range. It is composed of a clean, firmly cemented sandstone underlain by a well-developed conglomerate and ranges in thickness from 50 to

400 feet. The conglomerate contains pebbles of slate, quartzite, graywacke, jasper, chert, iron ore, mica schist, and quartz.

The Middle Keweenawan consists of a thick series of volcanic rocks with some interbedded sedimentary formations, intruded in places by a gabbro, rhyolite porphyry and a late granite. The exact age of the intrusives is conjectural. Aldrich (1929, p. 230-231, 247) considers them to be late Middle or Upper Keweenawan because of their intrusive relation with the Great Conglomerate. The igneous sequence, studied petrographically by Irving (1880, p. 167-207; 1883), includes granite, gabbro, rhyolite, anorthosite, and basic flows.

Conglomerates, arkoses, sandstones and shales comprise the Upper Keweenawan. The following generalized column is modified from Leith, Lund and Leith (1935) by Tyler, Marsden, Grout and Thiel (1940, p. 1436).

Proterzoic	
Algonkian	
Keweenawan	
Upper	Sandstone (Freda) Shale (Nonsuch) Conglomerate (Outer)
Middle	Basic and Acidic flows, some sandstone and conglomerate.
Lower	Sandstone and conglomerate
- - - - - -	unconformity - - - -
Huronian	Granite

The Freda formation is the uppermost formation in the Upper Keweenawan in Michigan. Lane and Seaman (1907, p. 691) named and described the Freda sandstone for its occurrence at Freda, Michigan. The relationship between the Cambrian Jacobsville sandstone (Lake Superior sandstone) and the Freda sandstone was uncertain at that time and because of lithologic and stratigraphic similarity, Lane (1907, 1911) designated the Keweenawan as Cambrian in age. Irving and Van Hise (1911, p. 415-416) discuss the stratigraphic relationships of the Keweenawan in great detail and suggest that Keweenawan is Precambrian in age. Atwater and Clement (1935) found evidence of a profound unconformity between the basal Upper Cambrian of the St. Croix River region and all of the Keweenawan rocks. During this interval the highland areas formed in post Keweenawan time were eroded to form a Precambrian peneplane.

The most complete section of Upper Keweenawan has been studied in Wisconsin by Thwaites (1912). He gives the following section:

Upper Keweenawan	Feet
Bayfield group (Jacobsville of Michigan	
Chequamegon sandstone	1,000
Devils Island sandstone	300
Orienta sandstone	3,000
Oronto group	
Amnicon formation	5,000
Eileen sandstone	2,000
Freda sandstone	12,000
Nonsuch shale	350
Outer conglomerate	1,200
Total	24,850

Structure

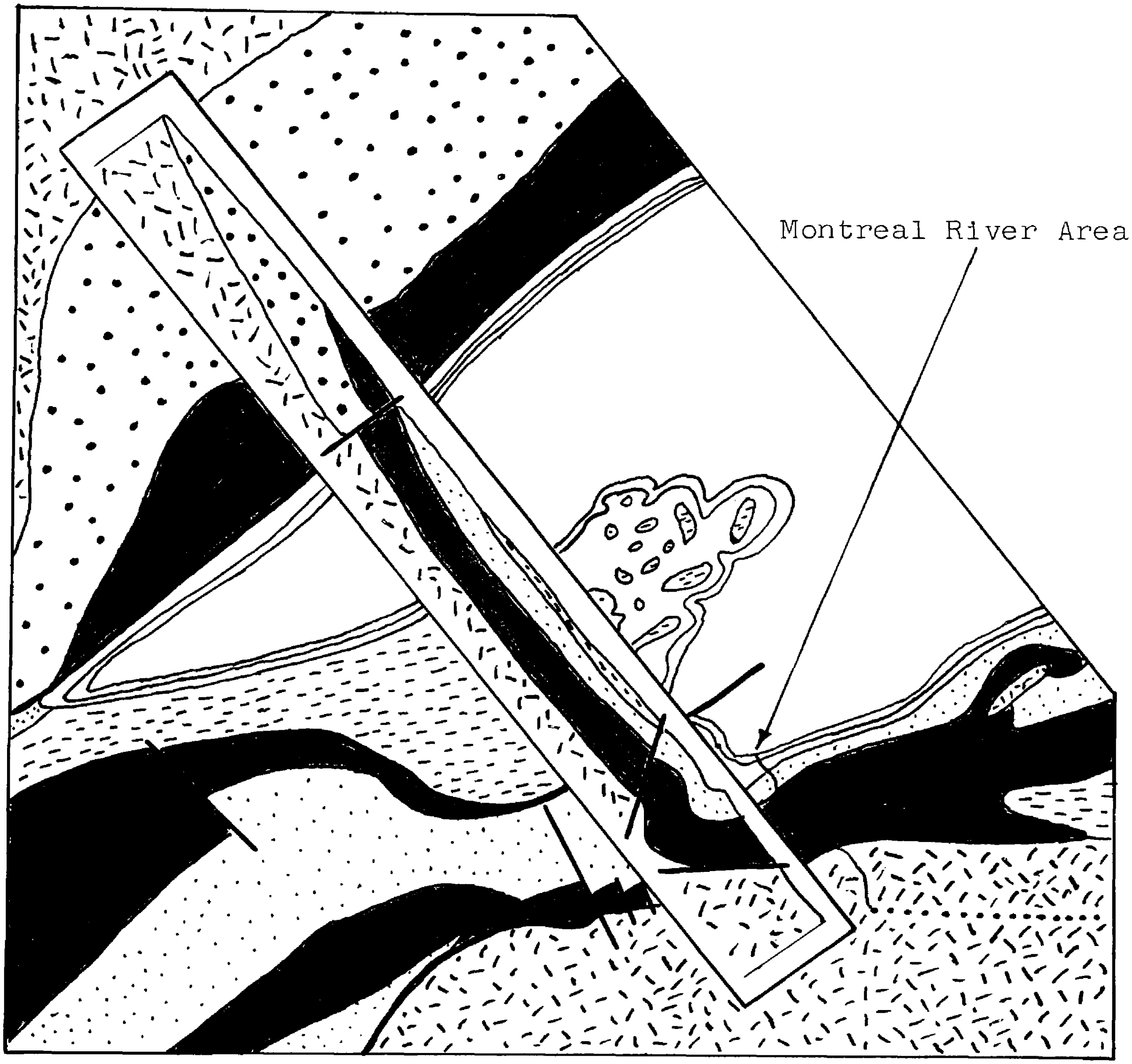
Thwaites map (1935, modified from Irving, 1883) and sections indicate that the Lake Superior topographic basin is also a structural depression (Fig. 2).

Many normal faults of small displacement cut the syncline. Two large thrust faults have been discovered, one on the south side of Keweenaw Point and one south of Duluth. Each fault is associated with a minor basin branching from the main depression.

Stratigraphic correlation problems have caused confusion in determining the origin of the topographic basin. Thwaites (1935) postulates that earth movement occurred simultaneously with late Keweenawan sedimentation. However, the Upper Keweenawan sandstones antedate the great thrusts, folds and the Precambrian peneplane. Since strata of Platteville age rest directly on Precambrian on both sides of the trough, it is believed that subsidence of the Lake Superior syncline continued after deposition of the early Paleozoics. Figure 2 shows that in the Montreal River area the Upper and Middle Keweenawan have been thrust steeply upward along the Keweenaw thrust fault and lowered by a normal fault paralleling the shoreline to the north.

Geology of the Freda Formation along the Montreal River

An initial reconnaisance of the Montreal River area disclosed that the most continuous exposure of Freda



Keweenawan	Upper	Bayfield	
		Oronto	
	Middle	Flows	
		Intrusives	
	Lower	Sediments	
Pre-Keweenawan			
		Faults	

Figure 2. A geologic map and cross-section of western Lake Superior (modified from Thwaites, 1935)

sandstone discovered to date forms the banks of the Montreal River. The Freda formation was measured with a one hundred foot metal tape, sampled and geologically described from the basal contact to Lake Superior. In order to find the Freda-Nonsuch contact it was necessary to wade up the river which flows northwest and cuts through the beds dipping 70° northwest. This facilitated measurement of the strata and provided almost maximum exposure of the formation in a short distance. (See Plate I)

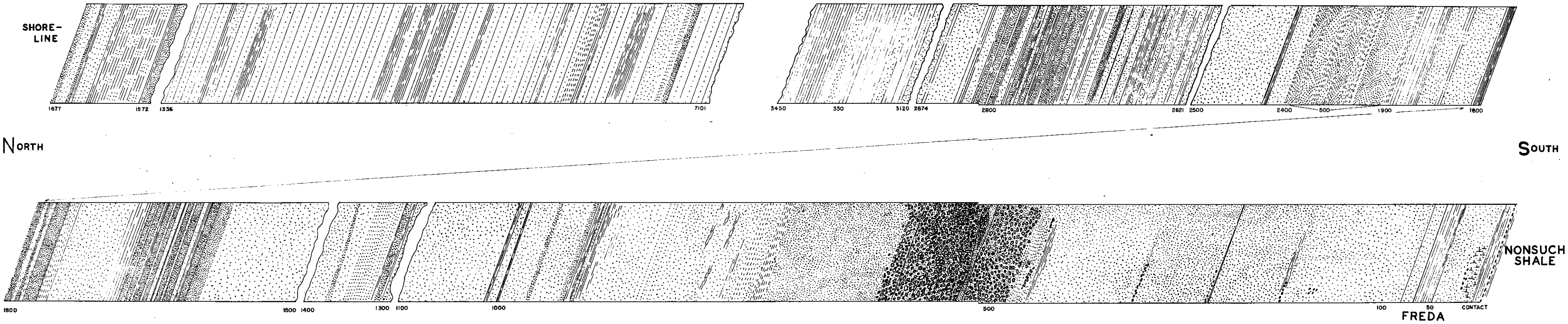
Nonsuch formation

Approximately 300 feet of soft fine grained, highly argillaceous shale to sandstone comprises the Nonsuch Formation along the Montreal River. The shale is predominate, the sandstone being interbedded. In color the shale is dark gray to nearly black and the sandstone dark gray to black. It conformably overlies the Outer conglomerate and underlies the Freda formation. The Freda-Nonsuch contact is gradational. In a 12 foot zone the Upper Nonsuch grades from finely laminated gray shale into a pink fissile shale. A salmon colored intermediate shale is arbitrarily picked as the contact.

Freda Formation

A red, medium to coarse sandstone with calcite-filled cracks, mudballs and pebbles overlies the pink fissile shale and is the basal segment of the Freda formation.

PLATE I



GENERALIZED GEOLOGIC CROSS-SECTION OF FREDA FORMATION AS EXPOSED ALONG THE MONTREAL RIVER

CONGLOMERATE
BEDDED SANDSTONE
MICACEOUS SANDSTONE
CROSS-BEDDED SANDSTONE
SHALY SANDSTONE
HARD SANDSTONE
MASSIVE SANDSTONE
SHALE
SILTSTONE
CALC. SANDSTONE
COVERED INTERVAL

SCALE
0 50 100 FEET

Generally, the lower 500 feet of the Freda formation is characterized by coarse red sandstone, in which there are occasional pebbles, mudballs and shale beds. Some horizons could correctly be called granule, pebble, or grit beds containing a large number of grains from 2 - 4 millimeters in size.

Five hundred feet north of the basal contact a conglomerate marks the first major change in lithology. It is over 100 feet thick and has a 10 foot thick sandstone lense near its center. The pebbles composing the conglomerate are preponderantly rhyolite porphyry and quartzite. They are subangular to round in shape and average approximately 1-3/4 inches in diameter. The largest pebble observed was 7-3/4 inches in diameter. Compositionally the conglomerate is classified as a petromict or the coarse equivalent of the arkosic and lithic sandstone. Petromict conglomerates are thought to be basic-margin accumulations shed from rather sharply elevated highlands (Pettijohn, 1957). It is interesting to note a shale bed is adjacent to and below the conglomerate, recording a rapid lithologic change. Nineteen hundred feet (See Plate 1) north of the basal contact there is a zone of purple to red micaceous sandstone in which there are several stream channels. The channels range from 10 to 20 feet across and average 7 feet in depth. This horizon is followed by several hundred feet of very thinly cross-bedded red to pink hard sandstone.

The cross beds are straight and each set is truncated by a horizontal (pre-folding) bed. The tabular nature of the beds is typical of torrential cross-bedding.

Overlying the cross-bedded zone are beds which are noticeably irregular and suggestive of seasonal or diurnal deposition. Many hard white sandstone beds, sometimes quite calcarous, and ranging in thickness from a few inches to several feet are alternately interbedded with usually thinner beds of red shale and siltstone. A covered interval of a few thousand feet formed by the backwater of the Montreal River dam is next encountered. North of the dam the Freda is typlified by red very hard mudstone and siltstone interbedded with occasional shale beds. In some horizons the mudstones are markedly cross-laminated. The cross-laminations are small scale structures composed of very fine-grained material. The cross laminae, in section, appear as smooth,comparatively long layers which meet the underlying laminae at low angles; a type which McKee refers to as "tangential" (1935).

Following a covered interval of several hundred feet the Freda is exposed continuously to Lake Superior.a distance of 105 feet. The beds in this area are primarily very fine-grained siltstones, mudstones and shales. The mudstones and shales have a typically flaggy jointing pattern and contain zones rich in mica. Every 10 to 20 feet at least one layer of hard white medium to coarse, often calareous, sandstone is encountered.

Traverses were made and samples taken on several small creeks east of the Montreal River as well as along the Lake shoreline wherever possible. The 70° inclination of the beds into the lake makes a shoreline traverse difficult. Several cross-sections of stream channels are found along the shoreline. The channels are 5 - 10 feet across and 3 - 4 feet deep; they are composed of slightly coarser material than the material channelled. Without exception the bottom layer of the channel is a greenish blue clay.

Lane (1909) surmised that the 12,000 feet thickness of the Freda formation at the Montreal River as estimated by Irving (1880) was in error. He suggested that a fault caused repetition of some beds. The strike and dip of the beds is constant (See Plate 2) and aside from a small slickenside on the bedding surface caused by the folding of the beds to their present attitude there is no indication of faulting in the area. The thickness as measured in the field indicates that the Freda formation is at least 12,000 feet thick as estimated by Irving, especially since an unknown thickness of upper portion lies beneath Lake Superior.

Summary

The Freda formation, as shown by rock exposures on the Montreal River and immediate vicinity, is entirely clastic and dominantly red. Coarse clastics are characteristic of the formation but finer-grained materials become more dominant in the higher horizons. Even in the upper part of the formation shale members never achieve significant thickness, most of the beds being mudstone and siltstone.

Sedimentary properties observed in the field indicative of a continental origin are legion. In summary they are:

1. Rapid changes in lithology.
2. Abundant and irregular cross-lamination.
3. Over-all thickness of sediment.
4. Many ripple marks.
5. Lack of gradational bedding.
6. Poor sorting.
7. Lithogic units thin rapidly along strike.
8. Channels in shale beds are filled with sandstone.
9. Red color, apparently due to oxidizing conditions.
10. Clay galls and mudstone balls in sand matrices. (Pettijohn, 1957, 620).

Furthermore, Thwaites (1912) reports the presence of mud cracks and rain prints in the Oronto (Freda) group in Wisconsin.

Slow down warping of the Lake Superior syncline probably caused rapid erosion and consequent deposition of continental alluvial deposits as the Freda formation along the borders of the basin.

MINERALOGY

Heavy Minerals

Seventeen samples for heavy mineral analysis were selected from different stratigraphic horizons within the Freda formation. The compactness and nature of the cementing material of the samples made disaggregation very difficult. After unsuccessful trials with various chemical methods a modification of the method proposed by Rittenhouse (1948) was used, as follows:

1. Sample gently pounded in a mortar to pass through a 4 mm. sieve.
2. Sample split in a Jones type riffle to 90-100 gm. size.
3. Sample weighed to nearest .01 gm.
4. Sample soaked in water for 12 hours.
5. If large aggregates remained (did in all cases) the sample was transferred to a 250 cc. sillmanite evaporating dish and the aggregates crushed.
6. Sample allowed to settle in 800 cc. beaker and excess water siphoned off until the water was clear after one minute of settling.
7. Sample dried at 203 degrees F.
8. Sample weighed.
9. Sample placed in 250 cc. beaker of 3-4 normal hydrochloric acid.
10. Sample washed (as in step 6) dried (as in step 7) and weighed.
11. Samples not disaggregated or still iron-stained were subject to a second acid treatment, washing, drying, and weighing.
12. If aggregates still persisted (they did in almost all cases) the sample was placed in a nest of 8" diameter Tyler screens in which each screen was twice the opening (diameter) of the sub-adjacent screen, e.g. 10, 18, 35, 60, 120, 230.

13. After a minute of shaking the material was removed from each screen and crushed by rolling. The binocular scope was used to check for aggregates.
14. The sample was recomposed and rescreened in a Ro-tap for 10 minutes.
15. Sieves sizes were weighed and packaged.
16. Any samples whose Tyler 150 or 230 size grains were still iron stained were again boiled in hydrochloric 3-4 normal solution for ten minutes.

Two heavy mineral separations were made on each sample, Tyler screen sizes 150 and 230, using bromoform. (Krumbein and Pettijohn, 1938). The heavy mineral fractions were weighed and mounted on glass slides in arochlor (index 1.66). The light fractions were then weighed and compared with the weight of the heavy fraction. A petrographic microscope was used to identify and count the minerals on each slide. Figure 3 summarizes the findings. At least 300 grains were counted on each slide.

Figure 5 shows that the Montreal-Freda heavy mineral suite correlates well with the Tyler Falls-Freda suite. There is a change in emphasis, however, with ilmenite becoming more dominant in the Tyler Falls sand and the percentage of epidote declining. A relatively large percentage of ilmenite also occurs in the Middle Keweenawan arkose.

The heavy minerals found in this study represent several source rock types. The zircon is of the "normal" type described by Tyler, Marsden, Grout and Thiel (1940, p. 465) which is derived from acid igneous rocks. The small brown rounded tourmaline present on almost every slide is

Figure 3

HEAVY MINERALS PERCENTAGES IN THE FREDA SANDSTONE

Sample No.	Weight %	Relative Per Cent									No. of Grains Counted
		Leucoxine	Epidote	Garnet	Ilmenite	Staurolite	Zircon	Tourmaline	Muscovite	Rutile	
2	a .74	14.8	30.4	1.7	32.7	2.5	16.5	X			358
	b 3.11	2.2	39.3	23.3	10.9	X	19.2	2.2			313
4_o	a 1.72	8.2	31.1	X	29.3	4.0	24.0	1.8		X	328
	b 1.50	2.2	36.1	14.4	24.9	1.6	16.6	3.1			313
12	a 10.62	5.6	30.5	22.3	23.5	X	15.7	1.3			305
	b 9.30	3.8	35.0	15.6	8.8	X	17.6	3.2	12.6	X	340
12_a	a 3.73	7.8	39.2	4.5	37.8	X	8.4	1.1			357
	b 3.00	3.2	38.6	10.3	17.8	X	23.9	3.4	X		321
13	a 4.39	4.4	25.4	13.4	45.5		9.8	X			275
	b 6.87	4.7	40.2	24.3	11.2		16.5	3.2			321
15	a 4.29	4.9	45.7	8.5	29.9	X	9.5				328
	b 2.45	2.8	45.8	37.9	3.8	X	8.5	X			319
16	a 3.24	3.2	39.5	4.8	41.7		8.9			X	314
	b 2.99	8.6	46.3	8.1	21.5		12.2	2.7			335
18	a 3.84	1.3	43.7	2.7	48.0	X	2.7	X			302
	b 4.75	3.6	57.2	19.9	9.3		8.4	1.2			332
19	a 6.49	4.3	47.3	X	26.3		21.0				266
	b 10.56	7.6	66.9	9.1	5.6		9.4	1.5			341
20	a 6.48	7.0	55.3	4.3	26.7		6.7			X	319
	b 4.02	5.2	35.0	16.3	16.0		25.5	X	X	X	306
25	a 2.22	5.1	20.0	21.1	38.2	1.9	10.8	X			314
	b 4.91	1.6	35.0	32.5	11.1	X	15.0	3.8		X	314
26	a .81	X	2.7	X	6.1		90.5				410
	b 6.70	5.9	47.7	6.1	17.9		18.6	3.6		X	392

Figure 3 (Continued)

Sample No.		Weight %	Leucoxine	Epidote	Garnet	Ilmenite	Staurolite	Zircon	Tourmaline	Muscovite	Rutile	No. of Grains Counted
			Relative Per Cent									
28	a	.28	2.0	21.1	6.9	25.7	X	42.9				303
	b	.29	2.5	40.4	11.1	22.6	X	19.1	2.9			314
36	a	.05	1.6	44.9	1.9	31.3		15.5	X			316
	b	1.16	4.7	51.0	3.0	21.1		13.6	5.0	1.2		337
40	a	2.44	4.8	27.3	14.2	33.3		17.9	X			330
	b	8.55	1.8	37.8	27.5	13.0	X	12.7	4.2	2.4		331
41	a	.41	5.5	34.5	14.4	22.4	X	15.8	X			361
42	a	6.10	4.9	24.9	23.1	21.3	X	22.8	X			329
	b	15.54	3.8	39.8	23.9	10.0	X	15.9	4.4	1.3	X	389

N.B. a represents heavy minerals from Tyler 150 sieve size.
b represents heavy minerals from Tyler 230 sieve size.
X represents less than 1%

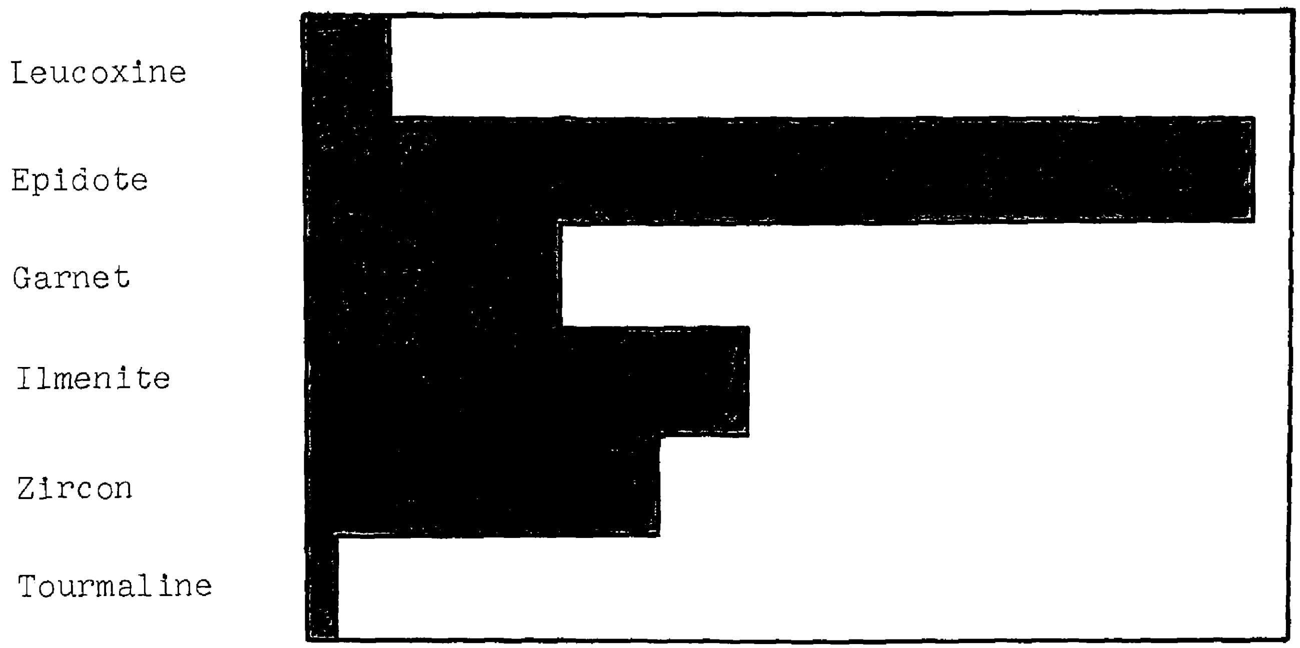


Figure 4. Average percentage of heavy minerals for all samples of Freda sandstone.

indicative of low rank metamorphic rocks. Garnet, epidote, muscovite are derived from high rank metamorphic rocks whereas Ilmenite is of basic igneous rock derivation (Pettijohn, 1957, p. 513). The Freda formation source area, appears to be one of heterogenous rock types as is true for most clastic sediments.

Figure 5

HEAVY MINERALS OF OTHER UPPER KEWEENAWAN SEDIMENTS

Tyler Falls	Weight %	Relative Per Cent					
		Zircon	Tourmaline	Leucoxene	Ilmenite	Epidote	Garnet
Freda	3.1	1	x	1	78	18	1
	18.6	x	...	6	73	19	1
	17.0	x	...	4	82	13	x
	16.4	1	x	8	84	6	1
	10.8	x	...	...	88	12	x
	9.3	1	...	...	80	18	1
	11.7	2	x	...	86	11	x
	7.5	7	x	3	58	27	..
Middle Keweenawan arkose Montreal River	16.1	x	...	2	98	...	..

(x less than 1 per cent)

(Modified from Tyler, Marsden, Grout, and Thiel, 1940)

The angular nature of the heavy minerals, if not entirely due to the somewhat rigorous disaggregation process, denies the probability of a sedimentary rock source: one criterion for the recognition of reworked sedimentation being the roundness of the grains. Although chert is found in all thin sections it is the metamorphic variety not the cryptocrystalline sedimentary type (see petrography).

Granites, called Huronian by Tyler, Marsden, Grout and Thiel (1940), may have had orogenic significance in post Huronian and pre-Keweenawan time. These granites occur in Gogebic, Marenisco, Turtle, Vieux Desert, and Conover districts which are generally 50 - 70 miles south of the Keweenawan deposits.

However, significantly, these Huronian granites contain "malacon" zircon and not the "normal" zircon prevalent in the Freda formation. Since the Middle Keweenawan igneous rocks (basic and acidic) contain normal zircons they are logically suspect as providers of clastic material for later formations (Tyler, Marsden, Grout, Thiel, 1946). The other accessory heavy minerals are not diagnostic since they are also characteristic of older granite. Furthermore, the large amount of heavy minerals and their angularity infer that the sediments were not transported far. Figure 6 shows the close similarity of the Keweenawan igneous rocks and the Freda sandstone.

Figure 6

COMPARISON OF KEWEENAWAN IGNEOUS ROCKS
WITH THE FREDA SANDSTONE
(adapted from Tyler, Marsden, Grout, Thiel)

Minerals	Igneous Rocks	Freda Sandstone
Apatite	rare	dissolved in HCl
Biotite	common	very rare
Chlorite	common	very rare
Epidote	common	common
Fluorite	rare	none
Garnet	none	common
Hornblende	rare	none
Ilmenite	common	common
Leucoxene	common	common
Magnetite	common	rare
Olivine	very common	none
Pyroxene	very common	none
Quartz	common	abundant
Rutile	very rare	rare
Sphene	rare	none
Staurolite	none	rare
Tourmaline	very rare	common
Zircon	rare	common
Zoisite	common	included with epidote

The evidence certainly indicates that a large proportion of the Upper Keweenawan sediments derived their heavy minerals from the erosion of Middle-Lower Keweenawan intrusives. An anomalous case is indicated in garnet and tourmaline (see Fig. 3); they are not found in Keweenawan igneous rocks and were probably derived from metamorphosed Huronian sediments. Boswell (1933) claims that garnet is so resistant that it can survive several cycles of sedimentation. The tourmaline was noticeably rounder than other heavy mineral grains suggesting that it might have been derived from pre-existing sediments or derived from igneous rocks and then transported a relatively long distance.

Petography

Five samples representing major variations within the Freda "sandstone" were subjected to compositional study. A thin section of each sample was studied with a petrographic microscope. An ocular containing a grid was employed to determine the percentage of rock constituents on the basis of relative grid area occupied by each constituent. Several grid traverses were made on each slide.

Sample 20, Calcareous Lithic arenite

Megascopic description: A fine to medium grained, dark red to grey, hard sandstone. A few basic detrital grains can be observed with a hand lens. Calcite crystals reflect light causing the rock surface to sparkle in places. The calcite reacts with dilute hydrochloric acid.

Microscopic description:

Rock fragments		Cement	
Basic	41.29	Calcite	16.33
Acidic	5.17		
Chert	15.30		
Chalcedony	2.07		
Quartz	17.14		
Feldspar	2.53		

The sorting is poor; grains range from minute to 1 millimeter in size. Microcline and plagioclase are both present. There are several excellent examples of biotite bent around other grains during compaction. The calcite cement occurs in both large crystals, which surround other grains, and in groups of very small crystals. The quartz grains are quite angular.

Sample 15, Arkosic arenite

Megascopic description: A coarse grained white-speckled red sandstone. Dispersed spots react to dilute hydrochloric acid. Some basic detrital fragments can be discerned with the naked eye. A 3/4 inch clay gall can be seen.

Microscopic description:

Rock fragments	
Basic	17.60
Acidic	11.09
Chert	3.46
Chalcedony	1.30
Quartz	38.15
Feldspar	19.63

Cement	
Calcite	2.95
Rock paste	2.08
Zeolite	2.74

The quartz grains, averaging .3 millimeters in size, are angular and usually have undulatory extinction. Several instances of calcite cement replacing the zeolite cement occur. The feldspars, microcline and orthoclase, are much altered; generally seritization and perthitic replacement. A few basic rock fragments contain microliths of plagioclase. The sorting is poor and the grains are stained with iron oxide. Some rock fragments are 1 millimeter by 1-1/2 millimeter in size.

Sample 12, Feldspathic arenite

Megascopic description: A white, medium-grained, friable arenite. Evidently this sample has been leached of iron oxide. Some red isolated patches of ferric oxide can be seen.

Microscopic description:

Rock fragments		Cement	
Basic	4.49	Zeolite	3.56
Acidic	6.64		
Chert	2.05		
Chalcedony			
Quartz	65.26		
Feldspar	20.85		

A very "clean" slide because of the lack of iron oxide. No calcite is present. The grains range from .2 millimeters to .7 millimeters in size with the quartz grains generally the largest. The small number of basic rock fragments are round to subangular as opposed to angular quartz grains. There are several occurrences of bent biotite grains.

Sample 36, Lithic arenite

Megascopic description: A very compact, uniformly red sandy siltstone. The individual grains in many instances are barely visible with a hand lense.

Microscopic description:

Rock fragments		Cement	
Basic	18.39	?	
Acidic	.95		
Chert	.31		
Chacedony	--		
Quartz	64.23		
Feldspar	15.62		

A rather well-sorted arenite containing rock fragments and feldspar in equal amounts. Microcline and plagioclase both occur. The quartz grains are angular whereas the rock fragments are subangular. The cement is undiscernable because of the compactness of the grains. The grain sizes range from .08 millimeters to .12 millimeters.

Sample b (oriented), Lithic arenite

Megascopic description: A medium grained, hard red sandstone. Some grains, basic rock fragments and quartz, are as large a 1 millimeter.

Microscopic description:

Rock fragments		Cement	
Basic	18.39	Calcite	1.19
Acidic	.95	Rock paste	.81
Chert	.31		
Quartz	64.23		
Feldspar	15.62		
Magnetite and Hematite			

A heavily iron-stained, poorly sorted, arenite. Large crystals of calcite engulf many smaller grains. The quartz grains are noticeably angular and average approximately .27 millimeters in size. Magnetite and hematite grains are prevalent; some of the magnetite seems to be altering to hematite. Microcline is the dominant feldspar. The cement in come cases seems to approach that of a wacke (Williams, Turner, Gilbert, 1954) or rock paste. In other areas twinned calcite is the cementing agent. This sample could conceivably be called a lithic wacke. A few quartzite and biotite grains are in evidence.

The rock types are named according to the classification of Williams Turner, and Gilbert (1954). Most previous literature refers to the Freda as an arkose. Percentages of the detrital fraction plotted in a compositional triangle indicates, assuming the sampling is indeed representative, that the Freda could be correctly called a lithic arenite (see Fig. 7).

Pettijohn (1954) defines an arkose as: "A rock characterized by 25 per cent or more labile constituents (feldspar and rock fragments) of which feldspar forms half or more." Using the percentage of detrital fraction, only sample 15 would qualify as an arkose as defined by either Pettijohn or Williams, Turner, and Gilbert.

Pettijohn (1957, p. 322) states furthermore:

> Most difficulty is encountered with those sandstones which, though highly feldspathic, are neither arkose or subarkose. Many of these have been designated arkose, more commonly they are impure arkose, or dirty arkose. Very probably many of these rocks are graywackes; others may be lithic arenites.

Cement

A problem in determination of cementing material was encountered in the petrographic study. The prevalence of calcite cement was notable in several slides; however, another cement often occurred in slides which did and did not contain calcite. The writer believes this cement is a zeolite. Gilbert and McAndrews (1948) identified a cement possessing similar optical properties as heulandite.

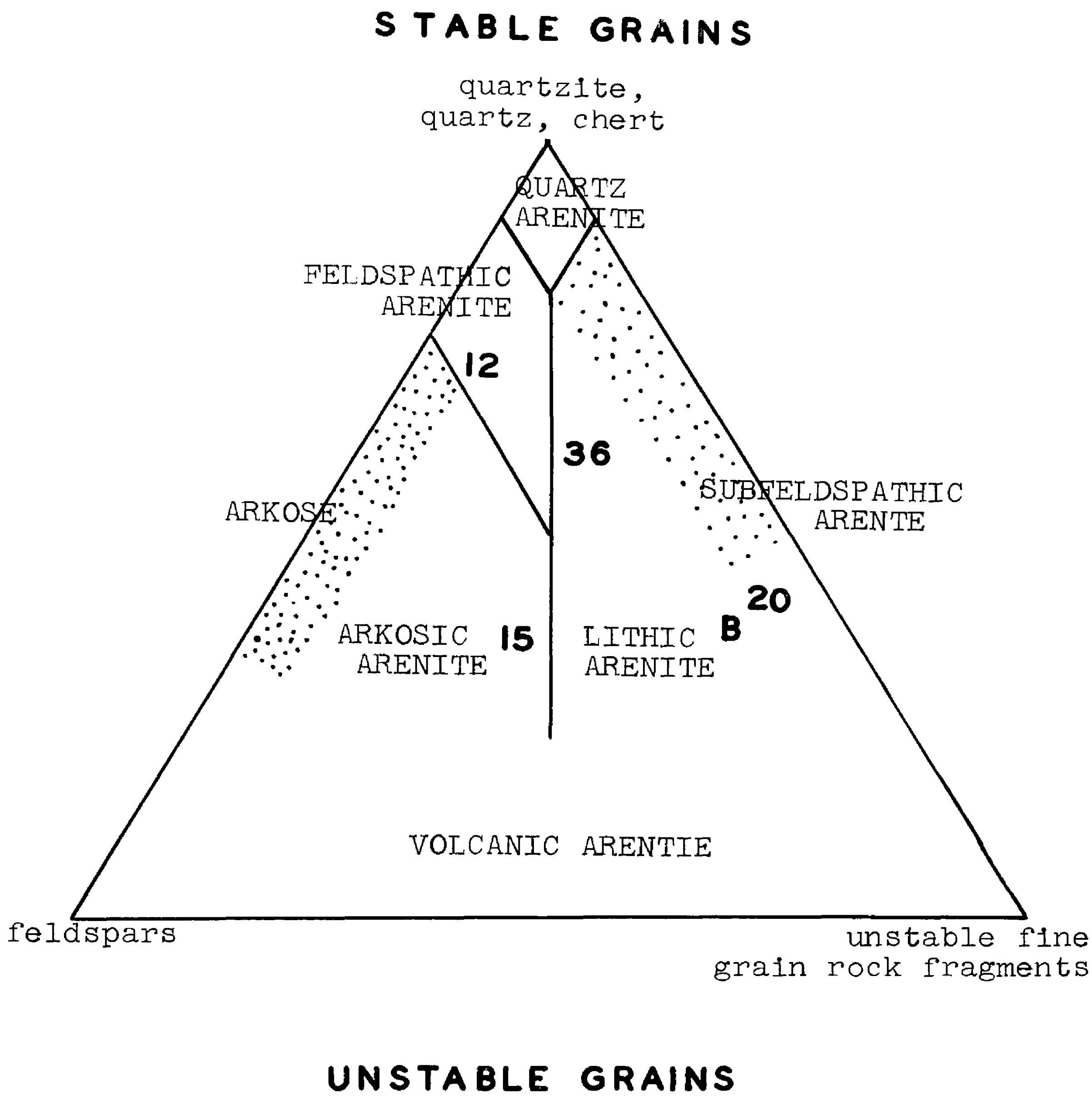


Figure 7. Sandstone compositional classification triangle. (after Williams, Turner, and Gilbert, 1954, p. 293)

The mineral possesses tabular habit parallel to the side pinacoid, low relief, perfect 010 clevage and a refractive index 1.496 - 1.505. Neither the index found in this study (approx. 1.500-1.525) or that found by Gilbert and McAndrews are the same. Dana points out, however, that even the heating necessary to melt the Canada balsam changes the properties of the mineral.

Some of the samples have cement which can only be identified as a rock paste. Iron oxide undoubtedly acts as a cement in some specimens as do overgrowths of authigenic quartz. The paragenesis of the cement is unclear but in one instance calcite appears to have replaced the zeolite (?).

PETROFABRICS

A primary fabric records a response of linear elements (long axes of sand grains and pebbles) to reach an equilibrium in a force field. The field is normally constituted by the flow of the fluid from which the sediment is deposited. Interest has arisen in sedimentary fabrics from their usefulness in determining direction of current flow, as well as their correlation with directional permiability and the determination of the direction of sand bodies.

With all indurated post-tectonic fabrics a problem of interpretation is involved. Is the orientation pattern a result of primary (sedimentary) or secondary (tectonic) forces. The Freda formation along the Montreal River dips 70° northwest. The tectonic force causing such an attitude was undeniably substantial, but its effect on the rock fabric is negligible. No fabrics studies, quartz grain c-crystallographic or pebble axes and maximum projection areas showed patterns diagnostic of tectonic forces (Figures 9, 13, and 15). Therefore, all fabrics were considered a result of flow forces during deposition (Figures 10, 14, and 17).

Pebble Orientation

As early as 1893 Becker (1893, pp. 53-54) recognized and described preferred orientation of pebbles in gravel accumulations. Contemporary geologists (Cailleux, 1938; Krumbein, 1940, 1942; White, 1953) have also studied pebble fabrics. However, only White deals with indurated conglomerate fabric.

A conglomerate represents a problem in methodology since it is often hard to remove pebbles to be reoriented in the laboratory. Therefore, in some instances the orientation measurements must be made in the field.

The study of the Freda conglomerate fabric (see Plate 1) was eased considerably because the pebbles were readily removed from the conglomerate matrix. A technique based on that described by Karlstrom (1952) was used in orienting the 70 pebbles from the one conglomerate horizon. The method briefly described is: (1) The pebbles are marked in outcrop so that their spatial attitudes can be duplicated; (2) after removal from outcrop, the particles are reoriented, and the long axes and/or face poles to the maximum projection areas are measured; (3) a contour diagram (representing the parameters measured) is plotted using methods described by Knopf and Ingerson (1938).

Long Axis Orientation

Krumbein (1940) has found that the long axes of pebbles generally plunge upstream and align themselves in the direction of stream flow. Holmes (1941) noted that in till fabrics there tends to be a lesser concentration of long axes transverse to the direction of ice movement.

Figure 8 shows the long axes orientation of the pebbles sampled, in relation to the Freda conglomerate as it now exists.(post folding). Figure 9 is a generalized diagram of Figure 8. Figure 10 represents the pebble orientation when returned to a pre-folding attitude. The pre-folding attitude represents the sedimentary fabric as opposed to the post-folding fabric.

Figure 11 exhibits a striking monoclinic fabric. Circles 1 and 2 show long axis concentration lying on southeast-northwest line, and dipping southeast. Smaller concentrations 3 and 4 lie transverse to the maximum concentrations, northeast-southwest. The evidence is strongly in favor of a current coming from the southeast.

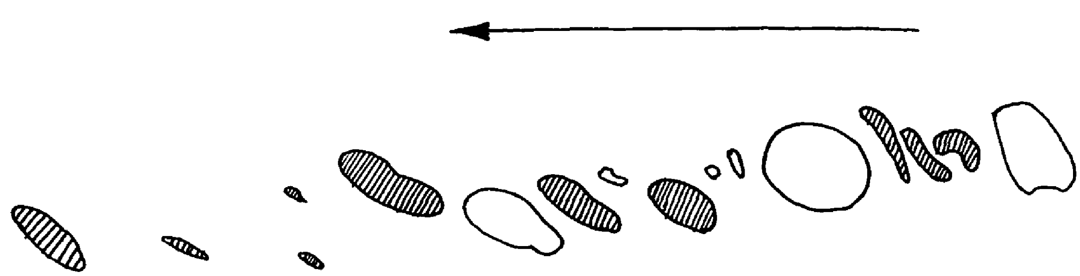


Figure 11. Imbrication of pebbles in relation to current direction (adapted from Pettijohn, 1957).

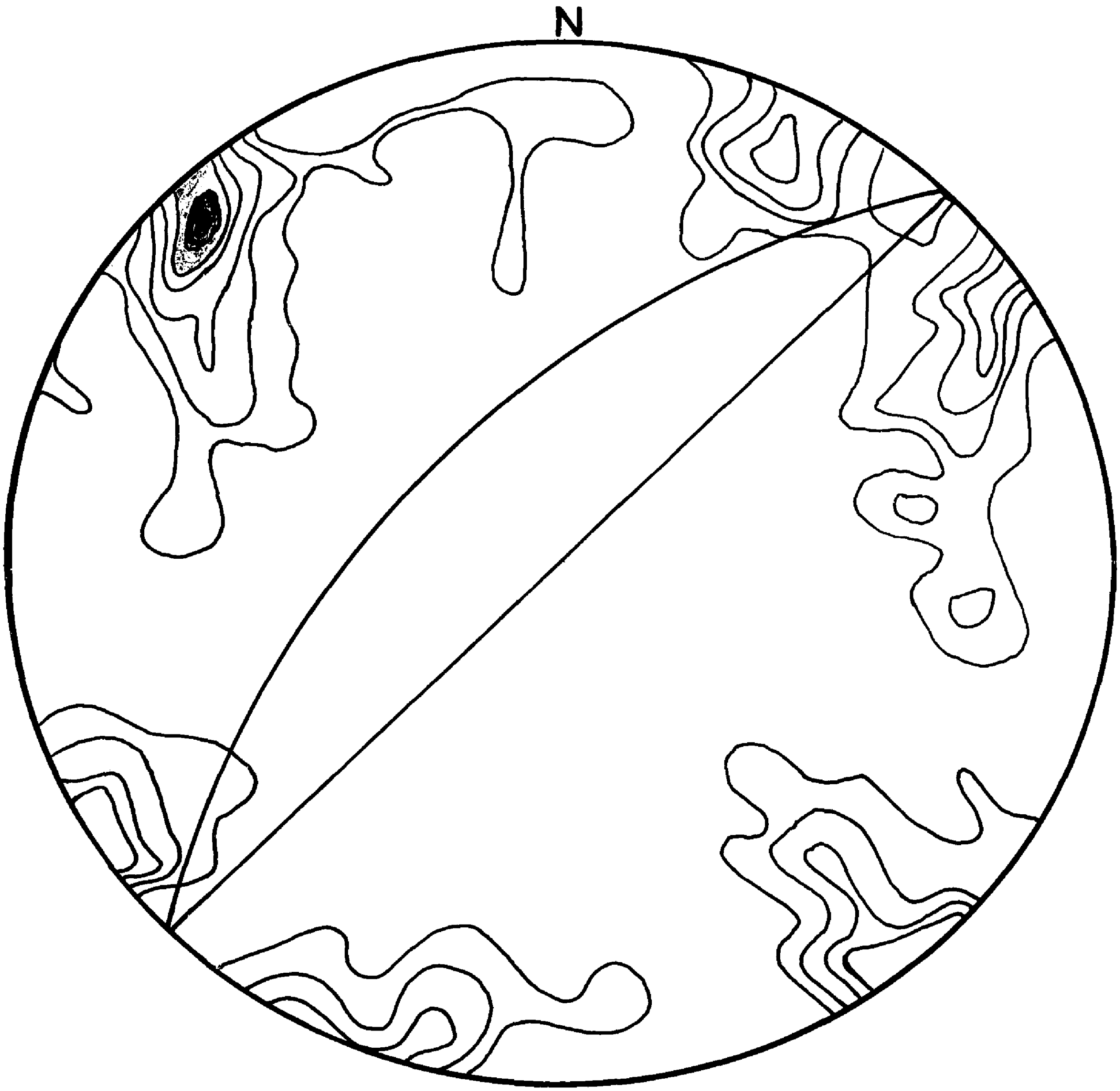


Figure 8. Seventy pebble long axes from the Freda conglomerate.
Contours 1-2-3-4-5-6-7 per cent.

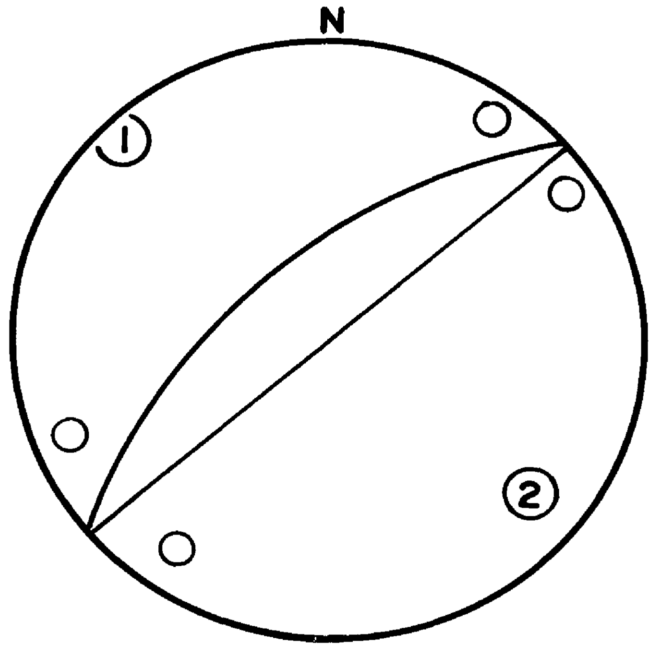


Figure 9. Generalized diagram of Figure 8 (post-tectonic, dip 70° N.W.).

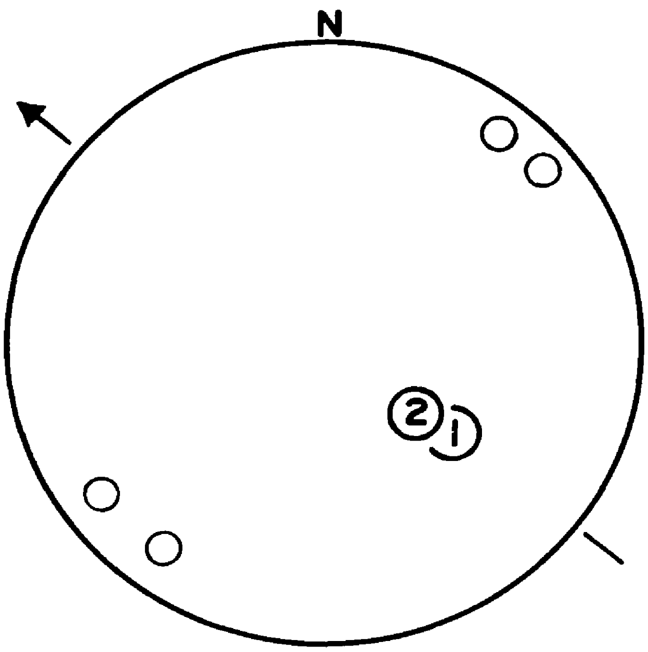


Figure 10. Generalized diagram showing Figure 9 reoriented to pre-tectonic attitude, 0° dip.

Maximum Projection Area Orientation

The long axes of a pebble may not show a preferred orientation especially for pebbles approaching a disk. In such cases the orientation may be controlled by large flat faces. The position of the faces is best approximated by giving the azimuth and angle of dip of the normal (face pole) of the maximum projection area. Cailleux (1945) found in his study of 4000 pebbles that fluvial deposits showed a mean upstream pebble imbrication of 15 to 20 degrees.

Figure 12 illustrates the post-folding concentrations of maximum projection area poles. Figure 13 is a generalized diagram of Figure 12; Figure 14 is a diagrammatic reconstruction of the pre-folding pebble maximum projection area pole orientation. In the primary fabric the greatest percentage of poles disclose imbrication inclined southwest.

Summary of Pebble Orientation

The continuity between the pre-folding maximum projection area poles and the long axes of the pebbles is extremely good. A northwest-southeast linear trend is well defined; the imbrication in both studies dips southeast. Therefore, the prevailing current at the time of deposition in all likelihood came from the southeast.

The conglomerate undoubtedly had primary dip, but since this would have no effect on the determination of current direction and only slightly alter the angle of imbrication it was discounted as negligible in this study.

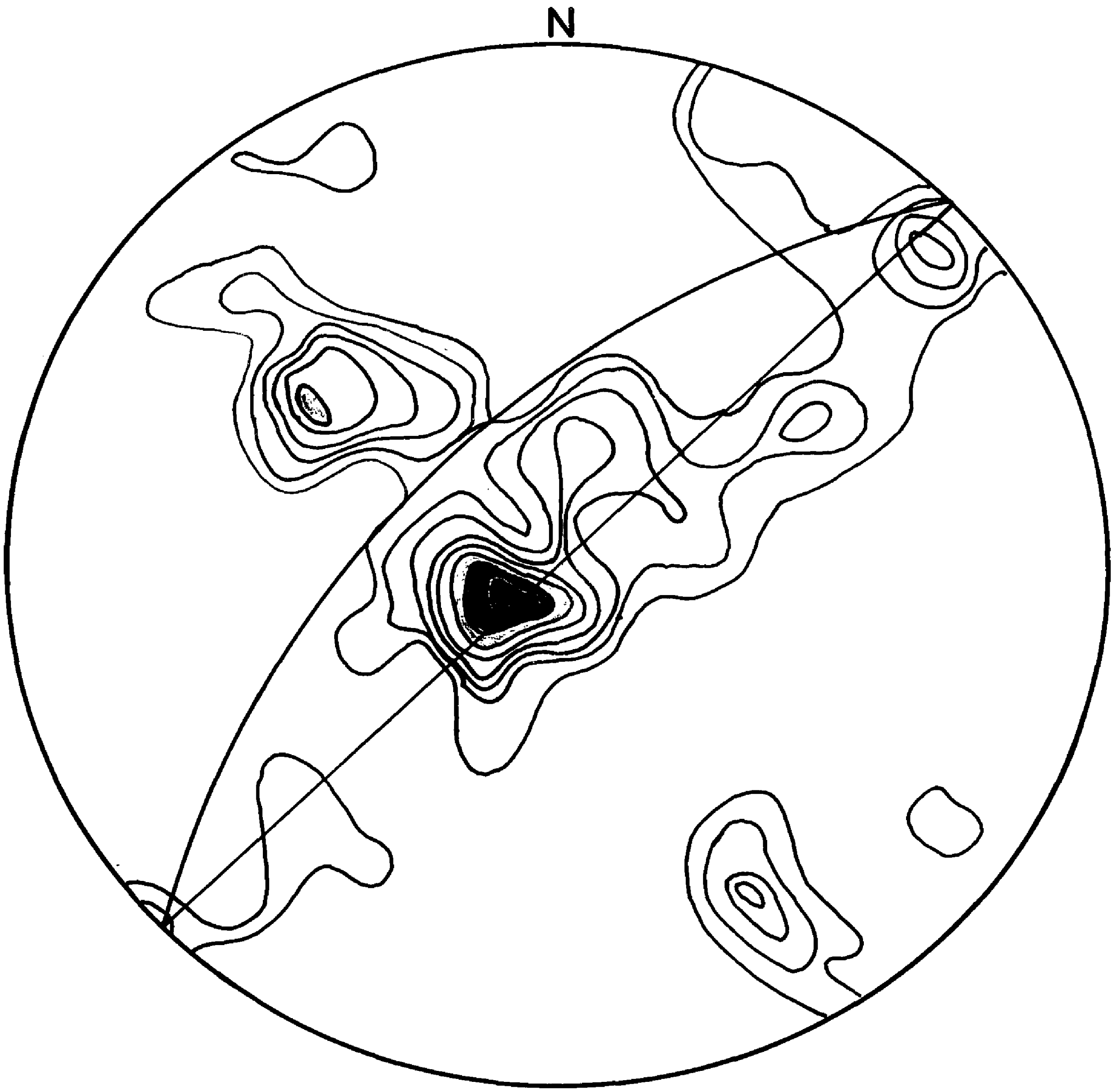


Figure 12. Seventy pebble maximum projection area poles from the Freda conglomerate. Contours 1-2-3-4-5-6-7-8 per cent.

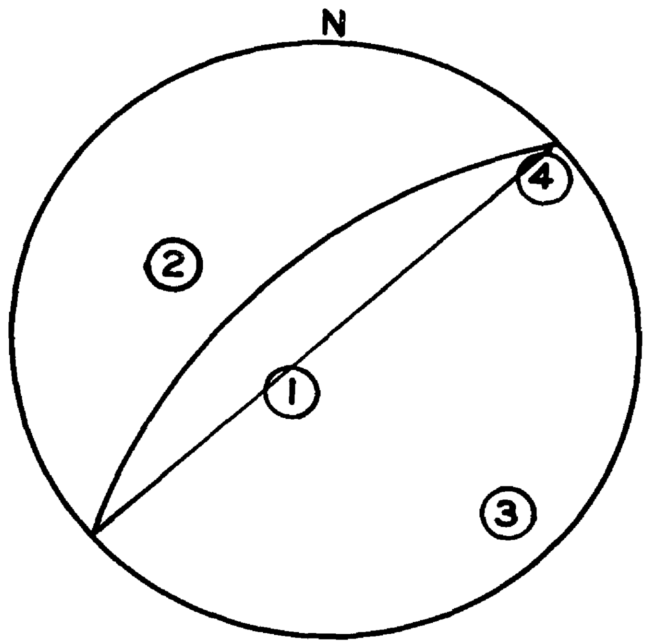


Figure 13. Generalized diagram of Figure 12 (post-tectonic, dip 70° N.W.).

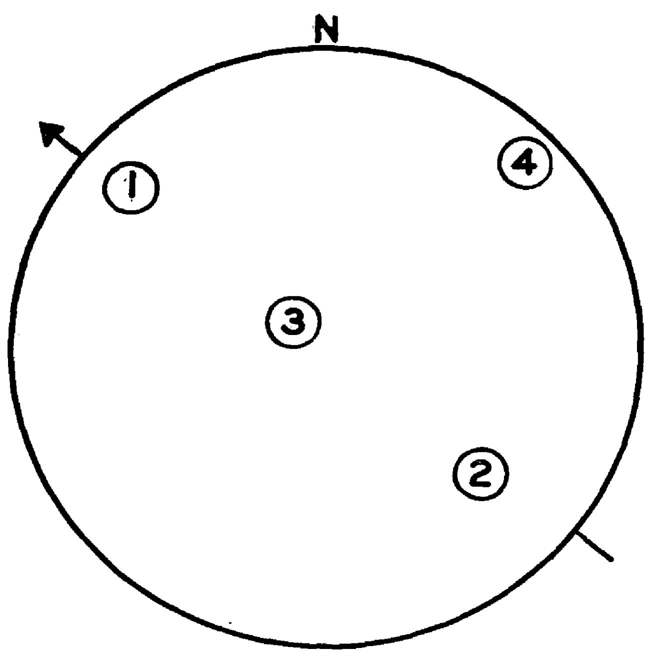


Figure 14. Generalized diagram showing Figure 13 reoriented to pre-tectonic attitude, 0° dip.

Quartz Grain Orientation

Difficulties encountered in the study of fine-grained materials have caused the fabric of sandstones to be less understood than that of gravels.

Observation of fabrics made experimentally in consolidated sandstones disclosed that the long axes are concentrated in the direction of current flow and tend to dip upstream (Schwarzacher, 1951). A lesser concentration of long axes was observed to lie transverse to the current flow. In other sandstones studies by Schwarzacher a "double maximum" tendency was noted, the bisectrix of which was parallel to the current direction. Three slides were made of an oriented sample of Freda sandstone. One section was taken from the bedding plane, and two from sections in planes normal to each other and both normal to the bedding plane. The c-crystallographic axis orientation of 200 quartz grains on each slide were found by using a Lietz four-axis universal stage mounted on a petrographic microscope (Fairbairn, 1949). The orientations of each slide were then plotted on a Schmidt equal area net and subsequently re-oriented to a horizontal plane. Figure 15 is a contoured representation of the orientation of the three slides compounded.

A primary consideration in interpretation is whether the c- crystallographic axes of clastic quartz grains

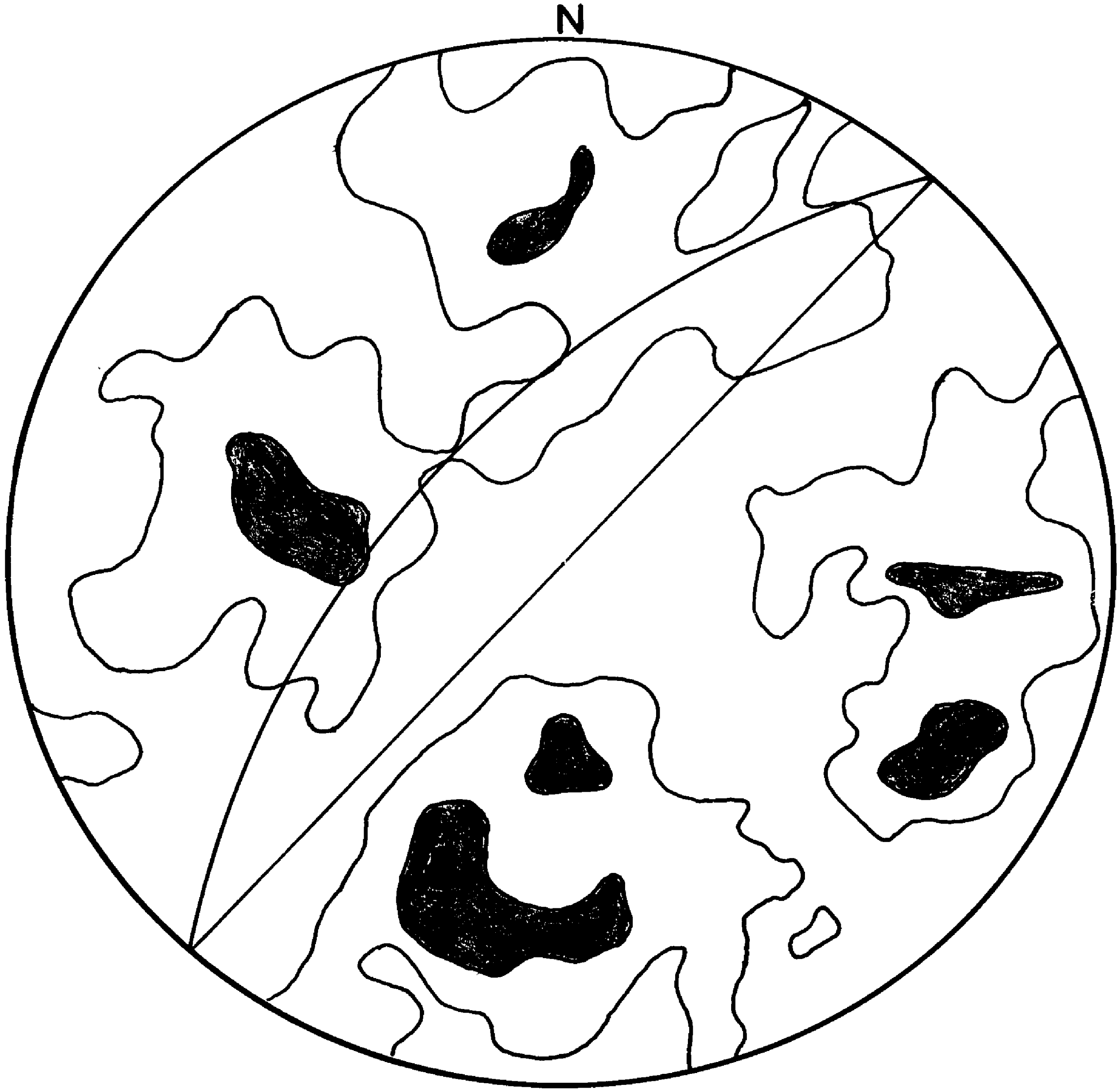


Figure 15. Orientation of 600 quartz grain c-crystallographic axes from the Freda sandstone. Contours 1-2-3 per cent.

correspond with the long dimension of the grains. For the purposes of this study, the author assumed that Wayland's (1939) finding (that c-crystallographic axis and the long axis of quartz grains tend to be the same) is valid. However, Rowland's (1940) studies showed that a large percentage of quartz grains are elongate parallel to the unit rhombohedron and therefore are at some angle near 40° from the c-crystallographic axis.

Figure 16 is a generalized diagram of Figure 15, whereas Figure 17 is a pre-folding generalized diagram. The sedimentary orientation of the long axes of the quartz grains show a double maximum with axes plunging generally southwest. A pattern which Swarzacher's studies found to indicate a current in the direction of the bisectrix, in this case northwest-southeast. The inclination of the axes to the southwest is surmised as evidence that the current came from that quadrant.

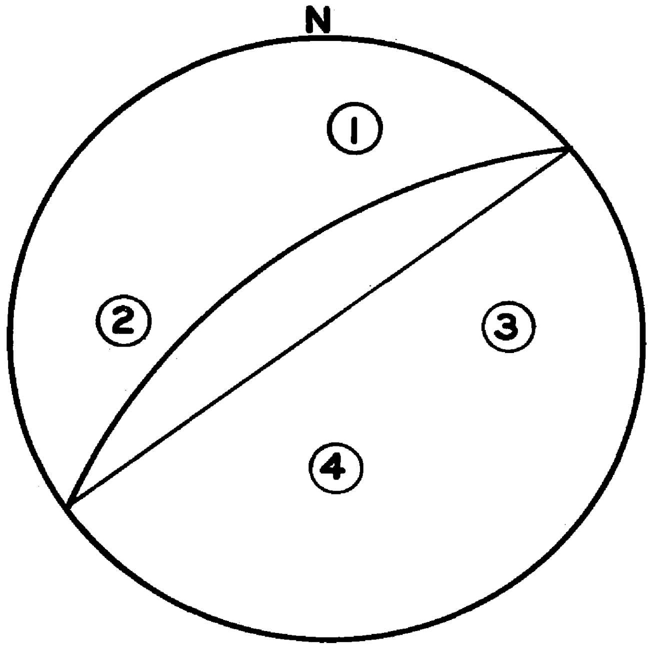


Figure 16. Generalized diagram of Figure 15 (post-tectonic, dip 70° N.W.).

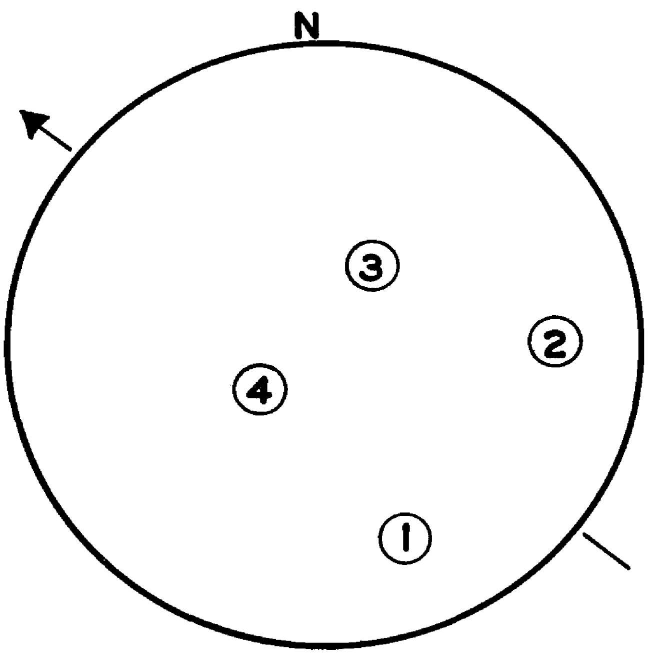


Figure 17. Generalized diagram showing Figure 16 reoriented to pre-tectonic attitude, 0° dip.

SEDIMENTARY STRUCTURES

Cross-bedding and Ripple Marks

In recent years geologists have become interested in vector properties of clastic sedimentary deposits as an aid in the determination of paleogeography. Pettijohn (1957) states, "Geological field work involving the coarser clastic sediments can now be considered acceptable only if it includes mapping of the primary sedimentary structures of these rocks."

Cross-bedding and ripple marks are two sedimentary structures which show vectorial properties. These fossil records of the current system prevailing at the time of deposition are common in clastic sediments.

Systematic mapping of primary structures enables the reconstruction of the areal paleocurrents. Pettijohn (1957) states,

> The significance of such studies is obvious, for paleocurrents flowed down the regional slope within the area of sediment accumulation and the determination and mapping of regional slopes is of paramount importance in any paleogeographic construction.

It is not entirely clear that all cross-bedding represents down slope direction: abberrant long shore currents can cause cross-bedding (McKee 1940). McKee (1945) concluded that although cross-bedding can record a long shore current direction it generally represents source direction and may indicate regional slope.

The Freda formation displays cross-bedding in many horizons throughout its entire thickness in the Montreal River area. However, the cross-bedding was usually exposed in a way which does not lend itself to directional measurements. Usually only one surface could be observed at some acute angle to the strike of the cross-beds; furthermore, the hardness of the sandstone does not allow exhumation of cross-bedding surfaces. Despite the difficulties involved, one hundred measurements were made of a thick series of tabular type cross-beds found 2100 feet north of the Freda-Nonsuch contact approximately 1780 feet above the base of the formation (see Plate 1).

Each measurement recorded the angle of dip of the cross-bed and the azimuth of the plane in which this angle was measured. The maximum angle of dip in the series of measurements was assumed to be the true dip. All of the cross-bed dip measurements were rotated on a steronet to correct them to true dip and the reoriented azimuth of dip direction tabulated. The corrected dip direction figures range from 302° to 341° with a mean direction 318° or north 38°W, indicating the current which formed the cross-beds came from the southeast.

The validity of assuming that the maximum dip measured is the true dip and that other dips measured are apparent dips is questionable. The assumption is based on the hypothesis that tabular type cross-beds in adjacent horizons of identical composition and presumably very similar environmental conditions have approximately the same amount of dip, and that measured dips less than this are apparent dips.

Occurrences of ripple marks were studied and mapped in the field (see Plate 2). They were mainly symmetrical and trended east-west. Near Flick Creek, however, a few trended north-south. Van Bertsbergh (1940) found oscillation (symmetrical) ripples oriented normal to the current flow. Hyde (1911) concluded that ripple marks parallel the shoreline.

The ripple marks observed indicate paleocurrents trended north-south near the Montreal River and east-west near Flinck Creek. However, a regional study is necessary to substantiate conclusions drawn in so small an area.

CONCLUSIONS

Although the study of the Freda formation was limited in its areal scope, certain conclusions may be readily drawn from the individual phases of the investigation.

The heavy minerals, especially normal zircon, strongly indicate the source area was primarily composed of igneous rocks assumed to be of Keweenawan age.

The mineral associations and properties in thin section, notably angularity of quartz grains and large amounts of detrital minerals, infer that the sediments were rapidly deposited but not transported far.

Studies of both directional structures and petrofabrics implied that the dominant downslope direction during deposition was toward the northwest. The striking parallelism of the orientation of pebble long axes and maximum projection areas to each other and both to the results of other investigators of pebble orientation phenomena emphasizes the validity of their inferences.

These conclusions are based on the investigation of a relatively small area. Therefore, they may or may not be compatible with similar studies regional in extent.

SUGGESTIONS FOR FURTHER STUDY

As this investigation proceeded, other problems occurring in this area where research would be rewarding became apparent. They are:

1. A micro paleontological study of the Nonsuch formation might disclose the existence of fossil micro-organisms within its black shale beds.

2. A study of the fabric of the Outer conglomerate with emphasis on sedimentary vectorial indicators would aid in defining the source area and direction of sedimentation of the Upper Keweenawan sediments.

3. A study of known types of cementing agents in sedimentary rocks describing such things as:

   a. characteristics

   b. occurrences

   c. paragenesis

4. A study of practical methods of breaking down cementing materials in sedimentary rocks, especially older sediments, would be of great value in dissaggregation processes.

5. A similar study of other exposures of Freda sandstone would help in the understanding of the regional geologic genesis of this formation.

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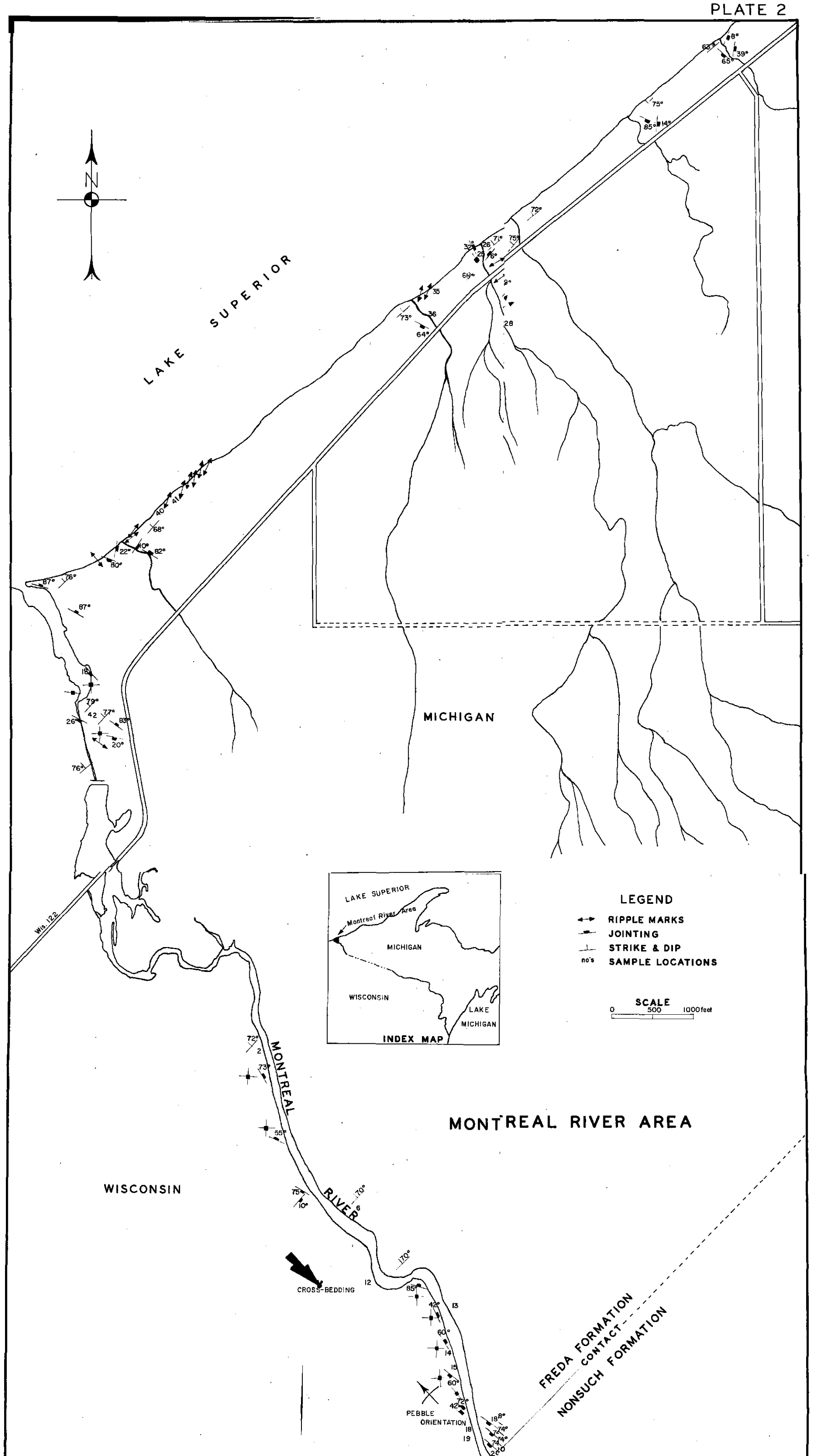
LAKE SUPERIOR
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MICHIGAN
Wis 122
MONTREAL RIVER
WISCONSIN
MONTREAL RIVER AREA
CROSS-BEDDING
PEBBLE ORIENTATION
FREDA FORMATION
CONTACT
NONSUCH FORMATION
LAKE SUPERIOR
Montreal River Area
MICHIGAN
WISCONSIN
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