PROVENANCE AND TECTONIC SETTING OF THE JACOBSVILLE SANDSTONE, FROM IRONWOOD TO KEWEENAW BAY, MICHIGAN

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Abstract

The Middle Proterozoic Jacobsville Sandstone, located on the upper peninsula, Michigan, is the youngest rift- related sedimentary unit in the 1.1 Ga Midcontinent rift. Although outcrops of the Jacobsville Sandstone along the Lake Superior shoreline and in river gorges are well studied, these outcrops represent stratigraphically only the upper 300-400 feet of the estimated 9,000 feet thick Jacobsville Sandstone. I used drill cores and newly-studied outcrop samples; 1) to characterize stratigraphically continuous sections; 2) to compare the Jacobsville Sandstone in subsurface with the Jacobsville Sandstone in outcrop; 3) to identify lateral and vertical variations in texture and petrographic composition within the Jacobsville Sandstone; and 4) to determine petrographic provenance of the Jacobsville Sandstone.

Results from this study show that subsurface samples of Jacobsville Sandstone are very similar to outcrop samples and that the greatest variation in the Jacobsville Sandstone occurs laterally between samples east and west of Lake Gogebic. The Jacobsville Sandstone east of Lake Gogebic, from Lake Gogebic to Marquette, Michigan, is a relatively flat lying, moderately to well sorted, medium- to fine grained sandstone, containing only local basal conglomerates. The average grain size in thin section is 0.4 mm, and the average composition of the sandstone is 74.2% quartz, 17.6% feldspar, 4.5% rock fragments and 3.7% accessory minerals. Plutonic rock fragments are most abundant, followed by silicic volcanic, metamorphic, and sedimentary rock fragments; no mafic volcanic rock fragments were found.

The Jacobsville Sandstone west of Lake Gogebic, from Ironwood to Bergland, Michigan, is dipping 9-34 degrees to the north, is moderately to poorly sorted, and is dominated by conglomerate and coarse sandstone throughout the stratigraphic section. The average grain size in thin section is 0.9 mm and the average sandstone composition is 55.3% quartz, 21.1% feldspar, 13% rock fragments, and 10.6% accessory minerals. Plutonic rock fragments are again the most abundant, followed by metamorphic, mafic volcanic, silicic volcanic, and sedimentary rock fragments. Iron-formation, vein quartz, and quartzite are the dominant conglomerate clast lithologies.

The Jacobsville Sandstone, both east and west of Lake Gogebic, had a predominantly southern provenance. Iron-formation, quartzite, metasiltstone, vein quartz, and chert conglomerate clasts all had a southerly source. Plutonic and metamorphic sand-sized grains also had a southerly source. Only undeformed sandstone, siltstone and silicic volcanic rock fragments (all relatively minor in abundance) were derived from a northerly source. The source of mafic volcanic clasts is ambiguous.

The lack of basinwide laterally continuous units in the Jacobsville Sandstone, and the strongly contrasting petrology east and west of Lake Gogebic are evidence that Jacobsville Sandstone sedimentation was not a simple basinwide infilling of a slowly subsiding rift in its late thermal stage, as previously thought. Steeper dips and a predominance of conglomerate in the Jacobsville Sandstone west of Lake Gogebic indicates a distinct western basin with a unique depositional history. The areal extent of the conglomerate facies in this western basin coincides with the upper plate of the Marenisco and Pelton Creek thrust faults, suggesting that the southerly source for the conglomerate, indicated by the provenance data, was upthrust basement rocks near the leading edge of the thrust sheet. Northerly dips and northward divergence of dips in the conglomerate facies suggest that deposition occurred during progressive northward rotation of the upper plates of the faults.

Southerly highlands, created by movement along the Marenisco and Pelton Creek faults, shed debris northward to alluvial fans and into local drainage basins. The dominant conglomerate lithology in these "local" drainage basins is iron-formation. However, the dominant lithology from the larger rivers draining the Archean and Early Proterozoic rocks farther to the south is vein quartz and quartzite. These rivers are inferred to have been deflected around the tectonically active southern highlands and turned to the northwest or west once north of the termination of the Marenisco fault near the present Lake Gogebic.

INTRODUCTION

The Jacobsville Sandstone, located on the upper peninsula of Michigan, is the youngest rift-related sediment in the failed, 1.1 Ga Midcontinent rift, a rift that hosts major copper mineralization. Previous work on the Jacobsville Sandstone focused primarily on outcrops along the Lake Superior shoreline and in river gorges, because it is rarely exposed elsewhere. Although geophysical data indicate nearly 9,000 feet of Jacobsville Sandstone, generally only the upper 300-400 feet is exposed, owing to the relatively flat dips of the sandstone units (Kalliokoski, 1982). Furthermore, a lack of stratigraphic markers in the Jacobsville Sandstone makes it difficult to correlate between the discontinuous outcrop areas.

In this study, drill cores, in addition to outcrop samples, were used to: 1) study stratigraphically continuous sections, 2) compare the Jacobsville Sandstone in subsurface with the Jacobsville Sandstone in outcrop, 3) identify lateral and vertical variations, and 4) determine petrographic provenance of the Jacobsville Sandstone.

Previous work

Aside from initial work done by Houghton (1841) and Irving and Chamberlin (1885), the most thorough study of the Jacobsville Sandstone was done by Hamblin from 1955 to 1957 (Hamblin, 1958). At that time the Jacobsville Sandstone was considered Cambrian in age and Hamblin studied it along with the Cambrian Munising and Au Train Formations. Hamblin mapped the outcrop belt along the southern shoreline of Lake Superior, from Bete Grise Bay to Sault St. Marie (Figure 1). In addition to mapping he studied the stratigraphy, sedimentology and paleontology of each sandstone unit.

Kalliokoski (1982) summarized the current knowledge concerning the Jacobsville Sandstone and discussed various problems including the correct stratigraphic position and age of the Jacobsville Sandstone. More recently, Abel (1985) studied outcrops of the Jacobsville Sandstone and Bayfield Group, the equivalent unit in Wisconsin, as possible sources for the mature Cambrian sandstones. He described both the average Jacobsville Sandstone and the average Bayfield Group sandstones as "a medium-grained, well-sorted, subangular, lithic subarkose" (Abel, 1985). He found that, compositionally, the Jacobsville Sandstone contains somewhat less quartz and larger amounts of feldspar and lithics than the Bayfield Group.

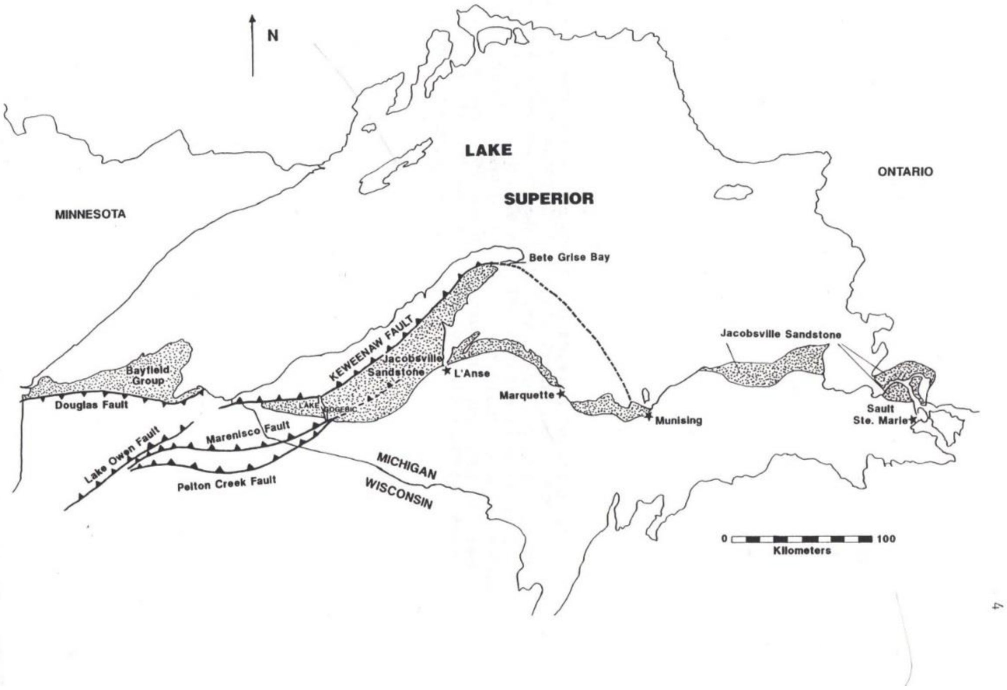


Fig. 1. Map showing location of the Jacobsville Sandstone, equivalent Bayfield Group (both

shown in stippled pattern), place names mentioned in text and major thrust faults.

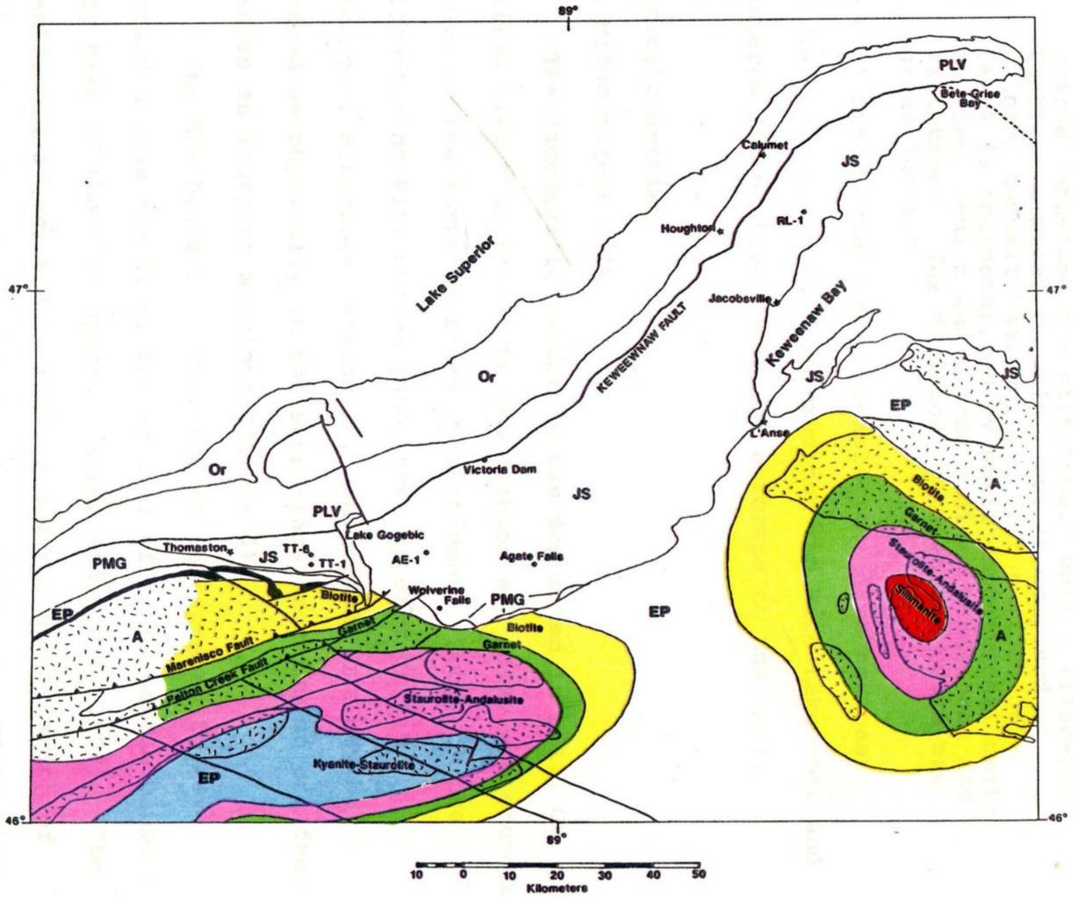


Fig. 2. Generalized geologic map showing location of Archean (A, patterned unit), Early Proterozoic (EP), Jacobsville Sandstone (JS), Portage Lake Volcanics (PLV), and Oronto Group (Or) rocks. The Gogebic Iron Range is shown in black. Sample locations are black dots and towns are black stars. Penokean metamorphic zones are colored. Map modified from Sims 1992. Metamorphic isograds from Geiger and Guidotti, 1989.

Although the Jacobsville Sandstone has been drilled by various companies looking for copper and oil, to date there have been no published studies of Jacobsville Sandstone drill core. A Master's thesis was done by Mark Bowers on the Rice Lake #1 hole (figure 2) (Bowers, 1989). Bowers divided the core into four units, which he described as follows:

> "The uppermost unit (45-400 feet and referred to as the Jacobsville Unit) has the same lithologic characteristics as the surface exposures of Jacobsville Sandstone. Unit 2 (400-1700 feet) is dissimilar to the Jacobsville Sandstone and is characterized by small depositional units

> of coarse sandstone and siltstone. Unit 3 (1700-2500 feet) is similar to Unit 2 but is composed of thinner depositional units. Unit 4 (2500-3630 feet) is characterized by small depositional units of fine, medium and coarse grained sandstones and siltstones. The divisions between the units are gradational."

Several other cores are available, but have not been studied. In my work, I re-examined the Rice Lake core and compared it to other cores and outcrops to the west.

Geologic Setting

Midcontinent Rift. The Jacobsville Sandstone was deposited in a 1.1 Ga, failed rift that transects the Archean and Early Proterozoic crust of the North American midcontinent. Rocks of the Midcontinent Rift System (MRS) are exposed only in Michigan, Minnesota, Wisconsin, and Ontario but can be traced geophysically in the subsurface, forming an arc from Kansas to southern Michigan (figure 3).

The MRS has most recently been interpreted to have formed as the result of the arrival of a new mantle plume at the base of the lithosphere (Cannon and Hinze, 1992). The mantle plume resulted in rifting and the accumulation of volcanic rocks (dominantly basalt) approximately 25 km thick in a central graben. It also generated enough lithospheric extension to nearly separate the crust (Cannon, 1992). Failure of the rift to completely separate the continent has been attributed to compression from the Grenville orogeny (Cannon and Hinze, 1992). After rifting, cooling of the lithosphere allowed the basin to continue to subside and collect sediments (Cannon, 1992).

Initially, a thin layer of mature, fluvial, quartz sandstone (Bessemer Quarztite, figure 4) was deposited unconformably in a basin centered on the site of the future deep rift. The earliest basalt flows covered unconsolidated sands at about 1109 Ma. Volcanism continued for about 15 m.y. (Davis and Paces, 1990) and consisted of large volumes of subaerial flood basalts with lesser amounts of andesite and rhyolite (Powder Mill Group and Bergland Group in Michigan, figure 4) (Green, 1982; Davis and Sutcliffe, 1985; Cannon, 1992).

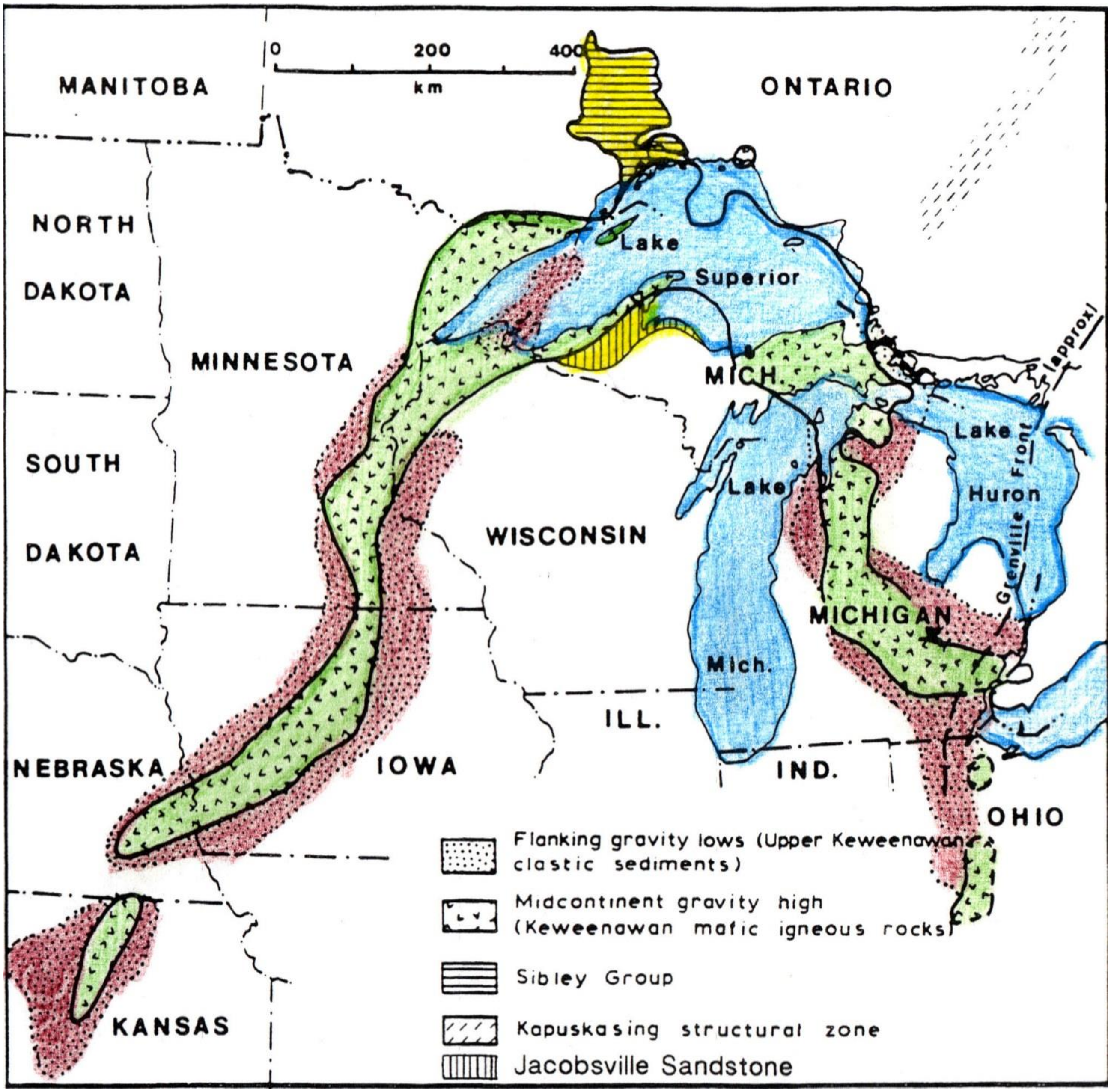


Fig. 3. Map showing location and extent of the Midcontinent gravity high and flanking lows produced by rocks of the midcontinent rift system. Modified from Green (1983).

Sediments are interlayered locally with the volcanic rocks and increase in volume upwards, forming a large wedge of fluvial and lacustrine clastic sediments (Merk and Jirsa, 1982). The exposed part of this wedge is at least 6 km thick and seismic data indicates as much as 8 km of sediments in the deeper parts of the basin (Dickas, 1986; Cannon and others, 1989). The lower part of this sedimentary wedge is the Oronto Group composed of the Copper Harbor Conglomerate, the Nonesuch Shale, and the Freda Sandstone.

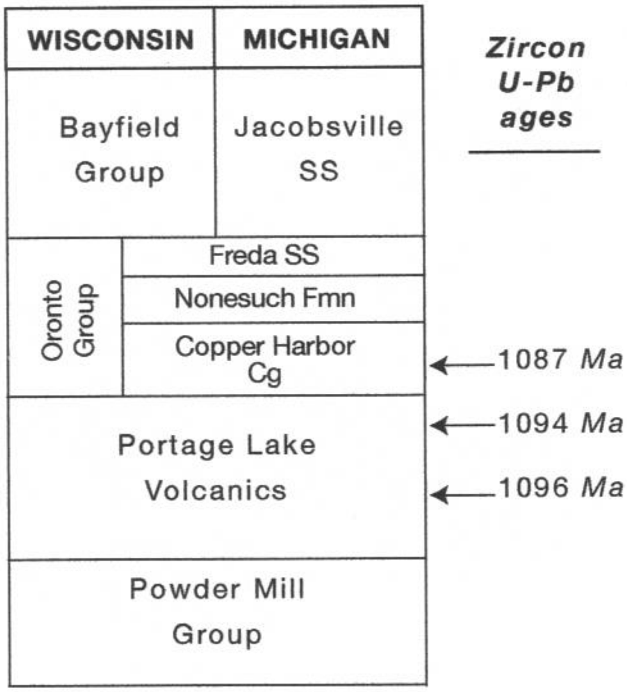


Fig. 4. Stratigraphic nomenclature of the Keweenawan Supergroup rocks. From Cannon and Nicholson (1992).

The Jacobsville Sandstone, and its apparent equivalent the Bayfield Group (figure 1), are believed to represent the upper part of this sedimentary wedge (Kalliokoski, 19B2). This interpretation has long been debated, because neither the Jacobsville nor the Bayfield is seen in direct stratigraphic contact with other rift sediments. A regional post-rifting compressional event probably related to the Grenville orogeny (Cannon and Hinze, 1992) inverted the center of the rift along reverse faults such as the Keweenaw, Douglas and Lake Owen faults (figure 1) (Cannon, 1992? Cannon and Hinze, 1992). In the area of this study, this reversed faulting placed older Portage Lake Volcanics up next to the Jacobsville.

The Jacobsville Sandstone. The Jacobsville Sandstone is an alluvial clastic wedge generally striking east-west and dipping very gently to the north (figure 2). An angular unconformity separates the Jacobsville sandstone from underlying Powder Mill volcanic rocks. To the east, the Jacobsville Sandstone is unconformably overlain by Paleozoic strata. The Jacobsville Sandstone is bounded to the north by the Keweenaw fault, which has thrust older volcanic rocks over it. Kalliokoski (1982) described the Jacobsville Sandstone as "...a thick (+900m) fluvial sequence of feldspathic and quartzose sandstones, conglomerates, siltstones, and shales, completely devoid of lava flows or cross-cutting dikes.'1 with a sandstone composition that "...varies from subarkose to quartz sub-1ithic arenite..."

Kalliokoski (1988) noted the abundance of conglomerate and coarse sandstones west of Lake Gogebic and an overall fining eastwards after preliminary work on drill cores TT6 and AE1 and examination of limited outcrops in that area. Clast lithologies and paleocurrent data indicate a southerly source. The sandstone is crossbedded and pebbly beds show both fining upward and coarsening upward sequences (Kalliokoski, 1988).

The thickness of the Jacobsville Sandstone varies considerably owing to the underlying paleotopography along the unconformity on top of the Powder Mill Group (Kalliokoski, 1988; Hamblin, 1958). The Jacobsville Sandstone thickens towards the Keweenaw fault and towards the east. Northward diverging dips within the Jacobsville Sandstone indicate continued subsidence during deposition. East of Lake Gogebic, the Jacobsville Sandstone dips less than 10 degrees to the north. However west of the lake, dips are as high as 35 degrees N. An exception is along the Keweenaw fault where dips are reversed to the south and are nearly vertical.

Brojanigo (1984) studied the sedimentology of the Jacobsville Sandstone along the Keweenaw fault near the tip of the Keweenaw Peninsula. He found clast lithologies and sedimentary structures indicative of small alluvial fans shedding debris to the south from a fault scarp located along the present day Keweenaw fault near Bete Grise Bay. This pattern would indicate movement along the Keweenaw fault before and during Jacobsville Sandstone deposition. However, deformation of Jacobsville Sandstone by the Keweenaw fault is also well documented indicating continued movement along this fault after Jacobsville Sandstone sedimentation (Brojanigo, 1984? KalliokosKi, 1982). In contrast, east of Munising, the Jacobsville Sandstone covers the Keweenaw fault trace seen in geophysical data (Cannon and others, 1989) indicating Jacobsville Sandstone deposition outlived movement on the fault in that area.

The exact age of the Jacobsville Sandstone is not known, but several dates help to constrain the timing of its deposition. A lower age limit comes from basalt flows, dated at 1086 Ma (Davis and Paces, 1990), interlayered in the lower 1000 m of the Copper Harbor Conglomerate (Oronto Group). GLIMPCE seismic reflection data show sedimentary rocks interpreted to be Jacobsville Sandstone, lying unconformably on the Oronto Group (Cannon and others, 1989). If this interpretation is correct then the Jacobsville Sandstone is definitely younger than the Oronto Group. The upper age limit for the Jacobsville Sandstone comes from dates of thrust faulting that is believed to have been concurrent with early Jacobsville Sandstone deposition.

Cannon and others (in press), dated this episode of faulting at 1060 Ma based on closure ages for Rb/Sr in biotites from uplifted fault blocks. Native copper mineralization, believed to be coincident with thrust faulting, has also been dated at 1060 +/-20 m.y. (Bornhorst and others, 1988).

METHODOLOGY

Field Area

This study focused on four drill cores (Figure 2):

West of Lake Gogebic

1) TT1 - NWI/4 Sec. 9, T47N, R43W (1070 feet of Jacobsville Sandstone)
2) TT6 - SW1/4 Sec. 33, T48N, R43W (2693 feet of Jacobsville Sandstone)

East of Lake Gogebic

3) AE1 - WI/4cor. sec. 36, T48N, R40W (2070 feet of Jacobsville Sandstone)
4) RL1 - Center sec. 14, T55, R32 (3550 feet of Jacobsville Sandstone)

Drill cores AE1, TT1 and TT6 are located in Marquette, Michigan, at the Department of Natural Resources Geologic Division core shed. The RL1 drill core is located in Calumet, Michigan, in a shed owned by the Lake Superior Land Company. A partial RL1 core, consisting of samples every 10', is located at Michigan Technological University.

All four cores were drilled through several hundred feet of overburden (glacial till), but only AE1 was drilled completely through the Jacobsville Sandstone and into the underlying basalt. The two eastern drill cores (drilled vertically) contain core footage of Jacobsville Sandstone that approximates the true stratigraphic thickness, because of low dip angles (AE1-2070[1], RL1-3550'). West of Lake Gogebic the Jacobsville Sandstone dips up to 35 degrees. However, core TT1 was drilled at an angle roughly perpendicular to bedding, so that the core footage (1074 feet) is also approximately the true statigraphic thickness. Drill core TT6 was drilled vertically and when corrected for an estimated 25 degree dip, approximately 2423 feet of stratigraphic section is represented.

In addition to the drill cores, six outcrops of conglomerate and sandstone (west of Lake Gogebic) and three outcrops of sandstone (east of Lake Gogebic) were sampled (figures 5 and 6), to supplement drill core data and to help integrate drill core information with previous work.

Field Work

Approximately three weeks during the spring of 1990 were spent sampling the drill cores. Generalized descriptions of bedding, color and grain size intervals were made for each drill core. The RL1 partial core at Michigan Technological University was described in the same way as the other drill cores. Samples from drill cores AE1 and TT1 were taken every 50'.

J. Kalliokoski logged and sampled the TT6 core every 10' in 1978. He kindly loaned his samples (284) and thin sections (27) for this study. Dr. Doug McDowell from Michigan Techological University was also kind enough to loan thin sections (37) from Mark Bowers* MS thesis on the RL1 drill core.

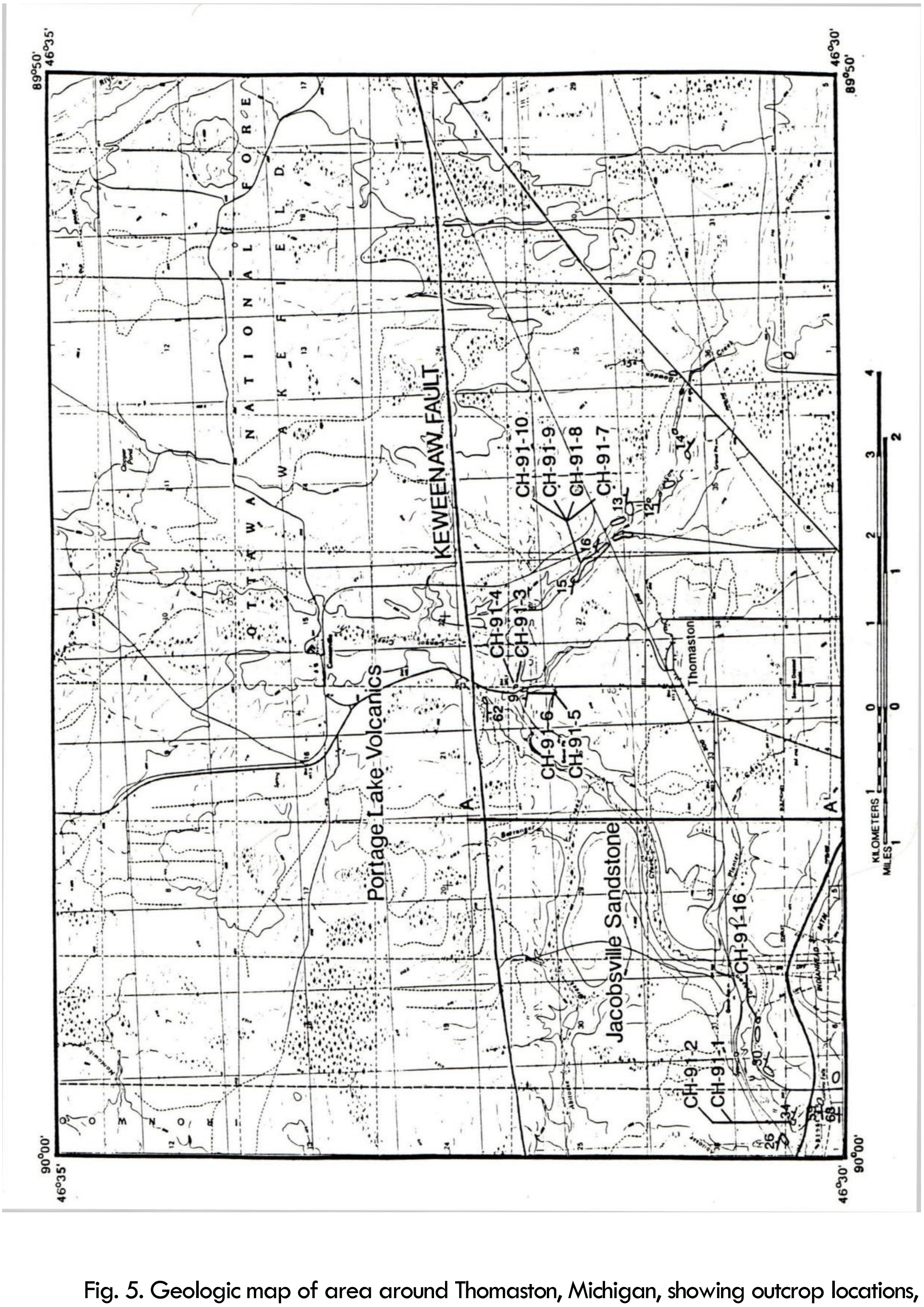


Fig. 5. Geologic map of area around Thomaston, Michigan, showing outcrop locations, strike and dip, cross section A to A' and the location of outcrop samples. Geology generalized from Copper Range Corp./Michigan Geological Survey cooperative mapping (unpublished).

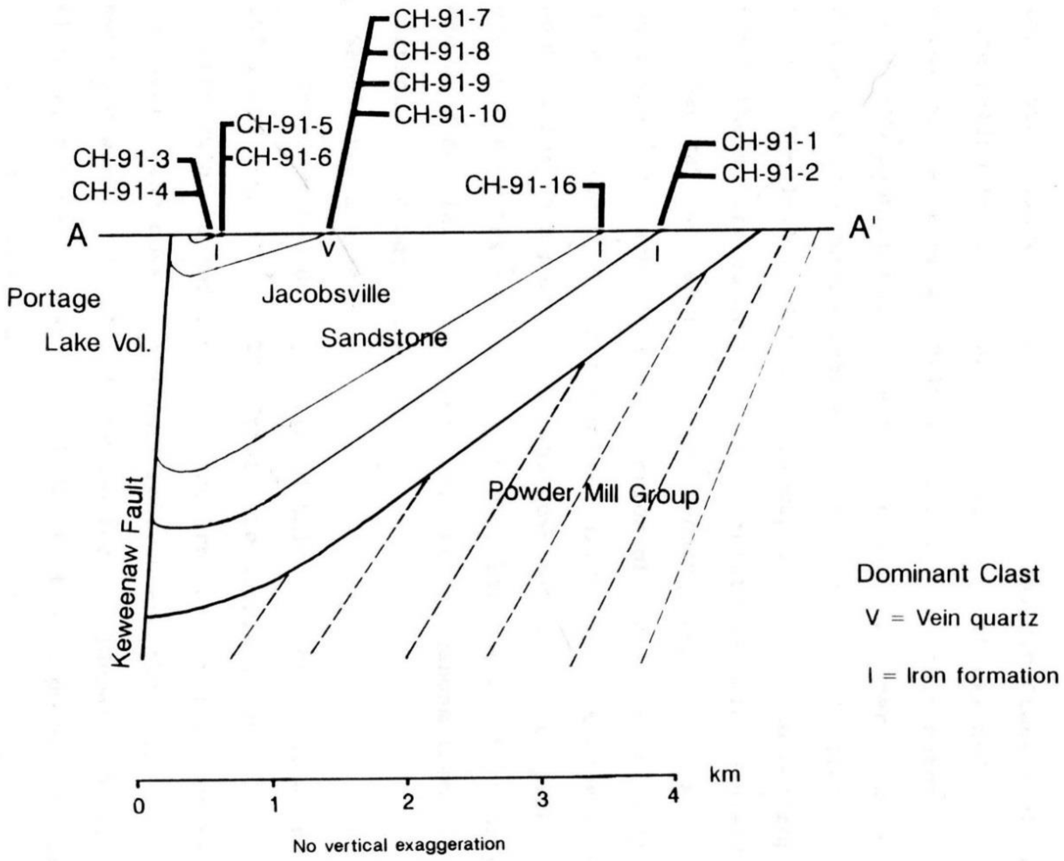


Fig. 6. Cross section A to A^1 showing the Keweenaw fault and the angular unconformity between the Jacobsville Sandstone and the Powder Mill Group. Projected outcrop sample locations are shown. Lines within the Jacobsville Sandstone are internal dips estimated from dip angles measured at the surface. In the fall of 1991 nine outcrops of Jacobsville

Sandstone were examined and sampled. Outcrops varied in height from 5 to approximately 30 feet and only one sample outcrop, with two exceptions. One exception was a steep cut bank (approximately 8 meters high) in Jackson Creek that had alternating layers of sandstone (15-30 cm thick) and conglomerate (approximately 1 m thick). At this outcrop only, two samples each of sandstone and conglomerate were collected (one sample from each layer, samples CH-91-7 through CH-91-10). The second exception was at an outcrop where the entire outcrop was conglomerate (sample CH-91-16).

Generalized descriptions of bedding, color, and sorting were made for each outcrop. Samples of conglomerate clasts were collected by filling two one-gallon zip lock bags with pebbles for each sample. It was possible simply to pick clasts out of the face of the outcrop because of the poorly cemented matrix. Pebbles were selected at random from a portion of the outcrop surface.

Sample Preparation

Thirty-three doubly-polished thin sections (one every 100 feet) from AE1 and TT1 drill core samples, cut perpendicular to bedding, were prepared and stained for K-feldspar. The cover slips were removed and the thin sections were polished and stained for K-feldspar. Cover slips were removed only from slides that were point counted.

Many sandstone samples were extremely friable and had to be epoxy impregnated before the samples could be cut into thin section chips. Even with impregnation the clay cement tended to wash out leaving pits and holes in the surface of the thin section chips. Porosity seen in the thin sections during counting was therefore considered suspect.

Seven sandstone samples from outcrops were selected for heavy mineral separation. The samples were gently disaggregated using a mortar and pestle and sieved into two size fractions, 40-100 and 100-170 mesh. The smaller size fraction was chosen for study because there were fewer lithic fragments and more monomineralic grains. A polished grain mount was made from a portion of each sample. A Franz magnetic separator was used to separate the remaining sample into three splits (mag @ .30, mag @ .80 and non-mag @ .80), Heavy minerals were indentified using both loose grain splits and the polished mounts. Ultra-violet light was used to confirm the presence of zircon and monazite. As a double check, powder X-ray diffraction was used to confirm the presence of visually identified minerals in one sample.

Petrographic Analysis

Sixty-two thin sections, covering 9390 feet of Jacobsville sandstone from drill core, were counted. The average interval between thin sections from drill cores was 150 feet. The maximum interval was 255 feet and the minimum interval was 92 feet. A total of nine thin sections from Jacobsville Sandstone outcrops were also counted.

Up to 400 counts were made from each thin section using a 1 mm point spacing. Six thin sections were too small to count 400 points. The minimum number of counts per thin section was 213 counts, the average was 393. Grain size from thin sections was determined by taking the average of 20 grains measured along a traverse perpendicular to bedding. A number of thin sections contained grains coarser than sand size, while a few grains up to 4 mm were included in the point counts, the coarser grains (up to 1.5 cm) were excluded. Only the grains included in point counting were measured for grain size. This was done to determine if compositional variations were caused by grain size variations.

RESULTS

Textural Characteristics of Conglomerates

Typical conglomerate of the Jacobsville Sandstone is very poorly sorted, clast-supported and contains a coarse sandy matrix. Where interlayered with sandstone, the conglomerate layers range in thickness from 0.6-4.5 meters. Where weathered, it is generally unconsolidated and weathers to a material that superficially resembles glacial till or outwash, but on fresher surfaces it is fairly well cemented. The conglomerate is usually muddy brown to brick red with white reduction spots or irregular shaped zones. Clay fills most interstices and coats all grains.

Clasts are subrounded to well rounded, and range in size from 3-15 cm. Rarely, clasts appear to be imbricated but otherwise bedding within the conglomerate layers is not apparent. Many clasts have a highly shiny surface or patina that looks remarkably like desert varnish and some have distinctly striated surfaces of unknown origin. A few clasts have been found that have shapes and surface textures resembling ventifacts (at sample location CH-91-5).

Petrographic Composition of Conglomerates

Six samples of conglomerate pebbles were examined to determine pebble lithologies (Table 1). Coatings of iron and clay necessitated breaking the pebbles open for positive identification. A variety of clast lithologies were found. However, the dominant clast lithologies were iron-formation, vein quartz, and quartzite. Table 1 lists the percentage of each clast lithology counted. In this table the clasts have been grouped according to general rock types (i.e. sedimentary, metamorphic, volcanic, etc.). The metamorphic category included quartzite and siltstone with a metamorphic fabric, and other metamorphics. Other metamorphics were clasts with a highly sheared fabric but of an uncertain composition, and were a minor component (0-2%).

Table 1. Pebble Counts

	CH-91-4	CH-91-5	CH-91-9	CH-91-7	CH-91-16	CH-91-1
	%	%	%	%	%	%
VOLCANIC	0.0	0.4	0.7	0.0	0.0	4.7
Altered Rhyolite	0.0	0.0	0.7	0.0	0.0	0.8
Weathered basalt	0.0	0.4	0.0	0.0	0.0	3.9
PLUTONIC	0.0	0.4	0.0	0.0	0.0	1.6
Weathered Granite	0.0	0.0	0.0	0.0	0.0	0.8
Granophyre	0.0	0.0	0.0	0.0	0.0	0.6
Monomineralic Grains	0.0	0.4	0.0	0.0	0.0	0.0
SEDIMENTARY	69.0	79.5	12.8	5.2	74.7	50.4
Chert	1.0	0.9	0.0	0.0	2.4	5.5
Sandstone	2.1	0.9	0.7	0.7	3.6	0.0
Siltstone	3.1	0.4	0.0	0.0	0.0	3.1
Iron formation	62.9	77.2	12.2	4.6	68.7	41.7
METAMORPHIC	21.6	8.9	13.5	13.1	21.7	33.1
Quartzite	20.6	8.5	13.5	11.1	9.6	31.5
Meta-siltstone	0.0	0.0	0.0	0.0	12.0	0.0
Other Metamorphic	1.0	0.4	0.0	2.0	0.0	1.6
VEIN QUARTZ	9.3	10.3	73.0	81.7	3.6	9.4
INTERMEDIATE	0	0.45	0	0	Q	0.79
TOTAL PEBBLES	97	224	148	153	83	127

A bar graph (figure 7) illustrates the distribution and trends of the clast lithologies through a cross section of the Jacobsville Sandstone. Clast lithologies from the two samples lowest in the section (CH-91-1 and CH-91-16) and the two samples highest in the section (CH-91-4 and CH-91-5) are dominated by sedimentary clasts (mostly iron-formation) and metamorphic clasts (quartzite) similar to that now exposed in the Early Proterozoic Marquette Range supergroup along the Gogebic Iron Range. In contrast, clast lithologies from the two samples (CH-91-9 and CH-91-7) located in the middle of the section are dominated by metamorphic vein quartz. Figure 8 best illustrates the inverse relationship between the two dominant clasts (iron-formation and vein quartz).

The sample locations were projected onto a cross section to emphasize the sample distribution vertically through the section, but it is important to note that, in map view, the two samples located in the middle of the section are also located to the east of the other samples (see figures 5 and 6).

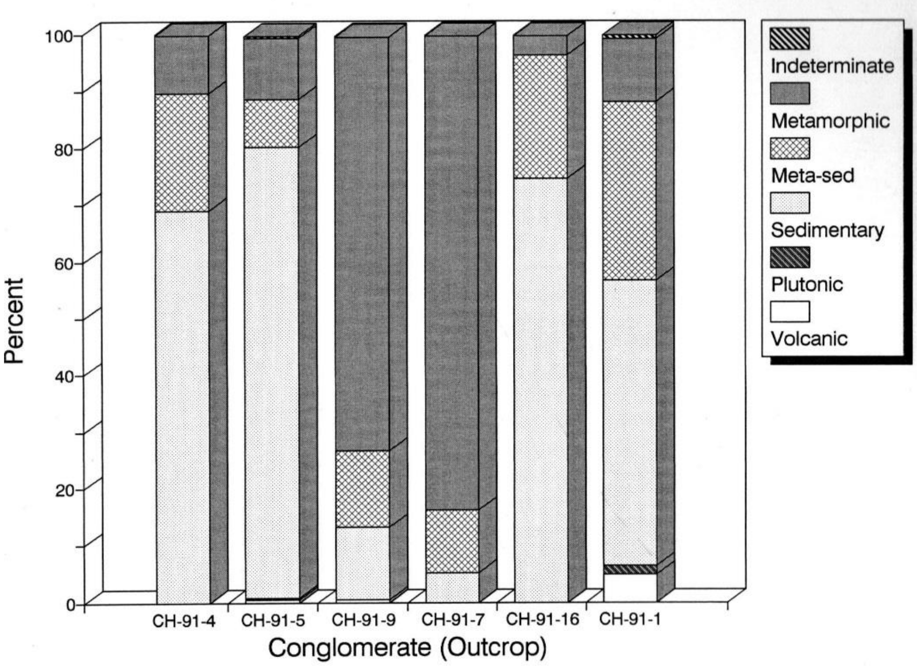


Fig. 7. Stacked bar graph illustrating the composition of the conglomerate samples in percent of volcanic, plutonic, sedimentary, metamorphic, vein quartz and indeterminate clasts. Samples are listed in decreasing stratigraphic position from left to right.

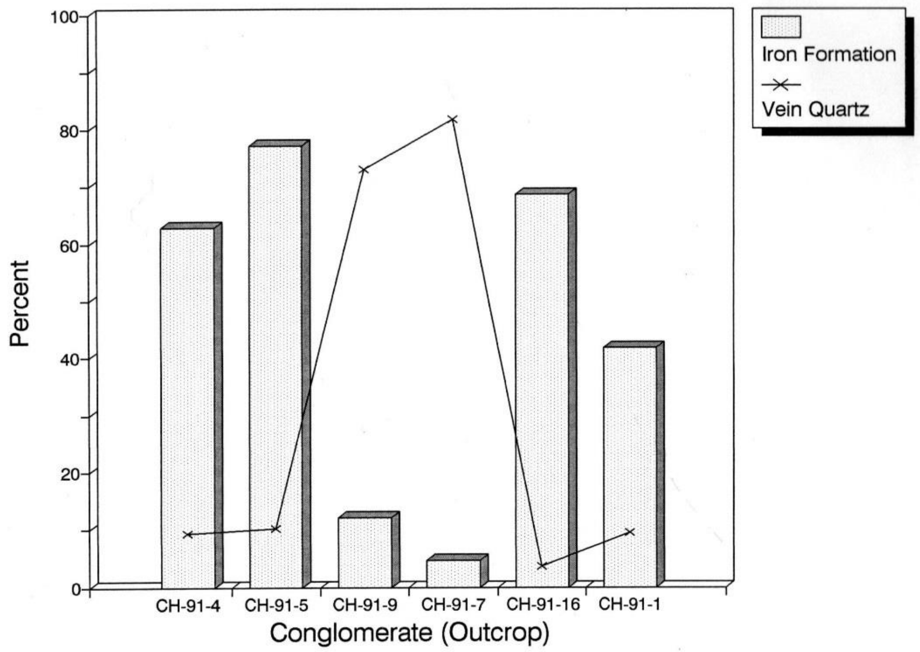


Fig. 8. Graph illustrating the inverse relationship between iron-formation and vein quartz clasts from conglomerate samples. Samples are listed in decreasing stratigraphic position from left to right.

Textural Characteristics of Sandstones

The average grain size (as measured from thin sections) of Jacobsville Sandstone from samples west of Lake Gogebic is 0.9 mm and from samples east of the lake is 0.4 mm. Table 2 shows the average grain size for each drill core and the east and west outcrop samples.

Table 2. Average Grain Size (in mm)

WEST		EAST	
Outcrops	0.9	Outcrops	0.2
Core TT1	1.0	Core AEI	0.4
Core TT6	0.9	Core RLI	0.5
Average	0.9	Average	0.4

Grain size estimates for each sample can be found in appendix I. Graphs of grain size versus depth for each drill core are shown in figure 9. Grain sizes measured in the western drill cores TT1 and TT6 range from 0.5 to 1.4 mm, however, the cores contain numerous clasts from 0.5 to 3 cm and some clasts up to 6 cm are present. Grain sizes in the eastern drill cores AE1 and RL1 range in size from 0.1 to 1.2 mm. While coarser grains (up to 3 cm) can be found in the eastern drill cores AE1 and RLI, they are much less common than in the western cores TT6 and TT1. Drill core RLI has the greatest variation in grain size (0.1 to 1.2 mm). RL1, with the exception of one sample, has the same grain size range as AE1 (0.1 to 0.8 mm). No trends of grain size changing with depth are evident.

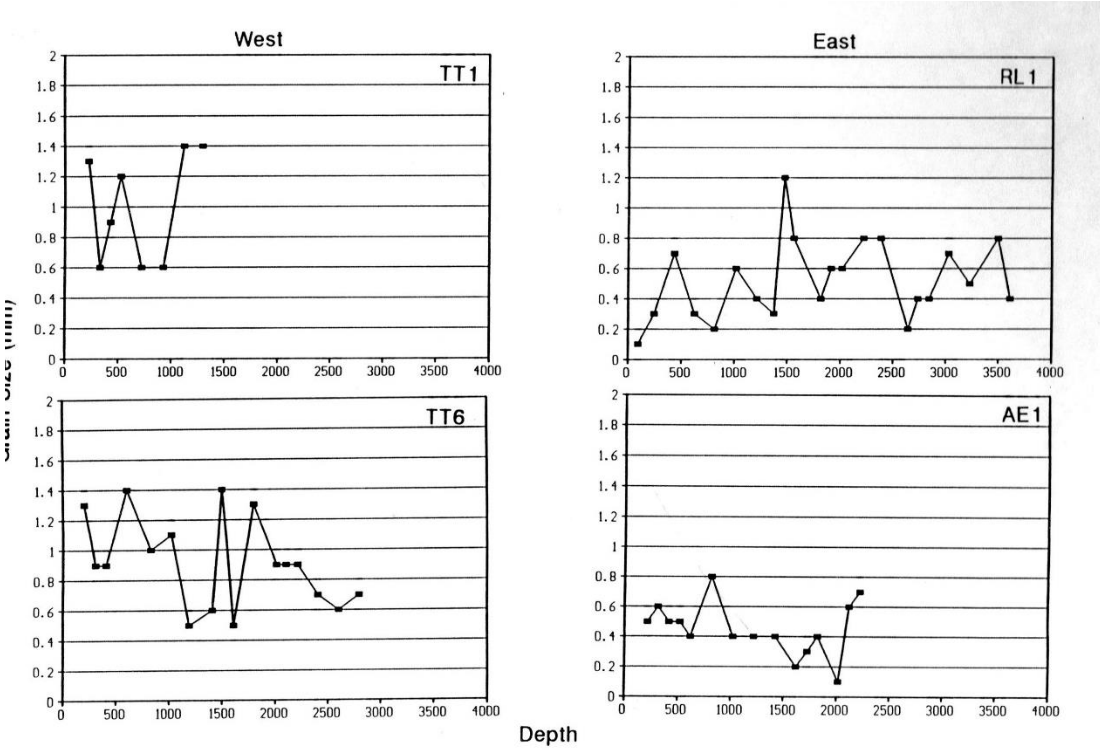


Fig. 9. Graphs illustrating Jacobsville Sandstone grain size (mm) versus depth for the four drill cores. Overall the western cores TT1 and TT6 are coarser grained than the two eastern cores AE1 and RL1.

Graphs of grain size versus stratigraphic position for each sample (in relative descending stratigraphic order) for the six outcrop samples west of Lake Gogebic and the three outcrop samples east of the lake are shown in figure 10.The six western outcrop samples range in size from 0.6 to 1.2 TOT, while the three eastern samples are finer grained, ranging in size from 0.1 to 0.4 mm. No trends of changing grain size are seen in the western samples. However, the eastern samples decrease in grain size downward in the stratigraphic section. This trend could be a reflection of sampling rather than a true trend of grain size in the stratigraphic section. When these grain size graphs are compared with similar graphs of composition versus depth (figures 14-21), it is apparent that a change in grain size does not correlate with changes in composition.

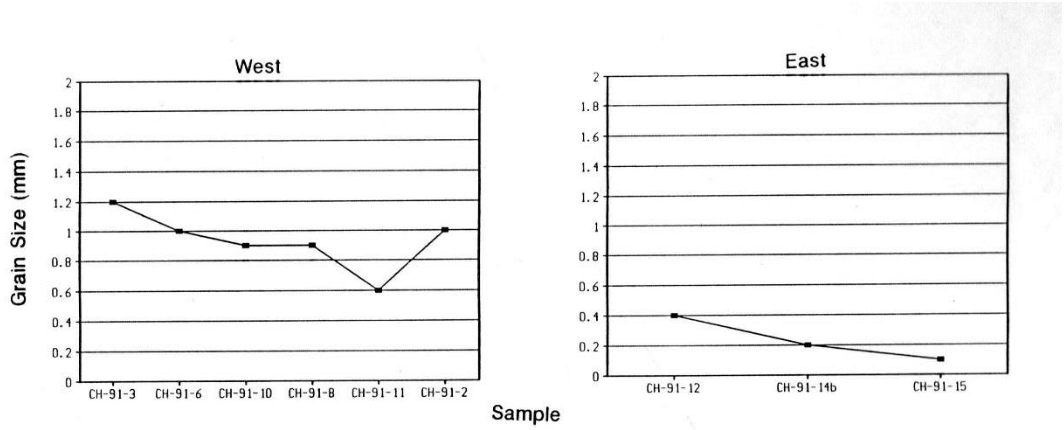


Fig. 10. Graphs illustrating Jacobsville Sandstone grain size (mm) for the outcrop samples. Overall the western outcrop samples are coarser grained than the eastern outcrop samples.

Petrographic Composition of Sandstone

After an initial inspection of the petrologic data it became apparent that the greatest variation in the composition of the Jacobsville Sandstone was lateral (from west to east). It will be shown that the Jacobsville Sandstone west of Lake Gogebic is compositionally distinct from the Jacobsville Sandstone east of the lake and that there is comparatively little vertical variation within any one section. The difference between samples west and east of Lake Gogebic and can be seen in Table 3 showing (in percent) the average composition of the framework grains (total quartz, total feldspar, rock fragments and accessory minerals) for drill cores TT1, TT6, AE1, RLI. Compositional data for individual samples may be found in Appendix XI. Table 3 also shows the averages of six outcrop samples west of Lake Gogebic, three outcrop samples east of Lake Gogebic and the grand averages for all samples west and east. It can be seen that the Jacobsville Sandstone west of Lake Gogebic is less quartzose, more feldspathic, more lithic and contains more accessory minerals than Jacobsville Sandstone east of the lake.

When the data are plotted on a QFR triangular diagram (figure 11), the Jacobsville Sandstone east of Lake Gogebic plots primarily as subarkose with a few samples plotting as arkose, sublitharenite, or quartzite. In contrast, the Jacobsville Sandstone west of Lake Gogebic plots more towards the center of the triangle and ranges from subarkose and sublitharenite to arkosic and lithic arenite.

When the data are plotted on a QtFL triangular diagram (Qt=Qm+Qp, L=aphanitic rock fragments) (figure 12), the Jacobsville Sandstone east of Lake Gogebic plots entirely on the arkosic side and again primarily as a subarkose.

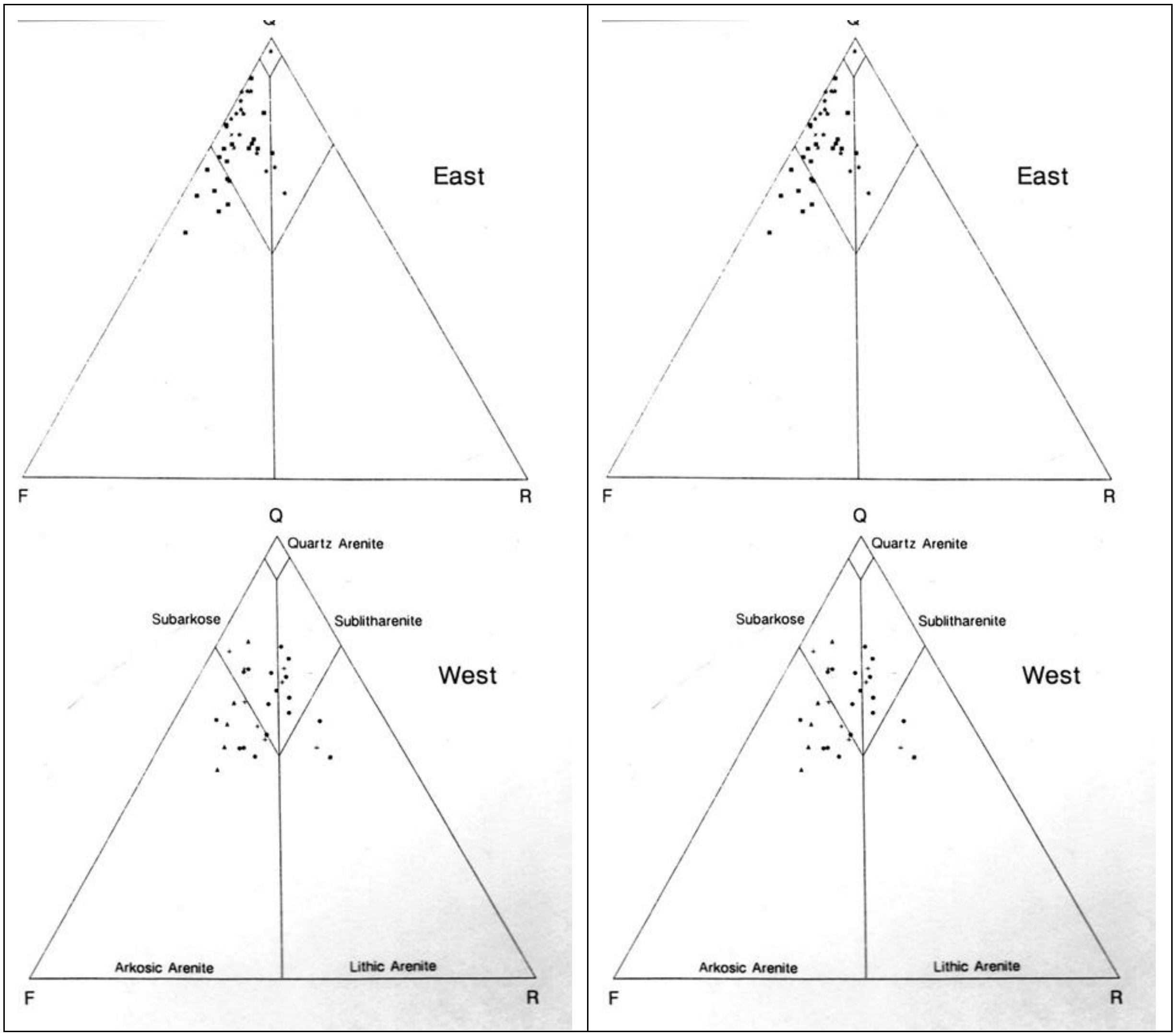
Table 3. Framework Grains (volume %)

	Q	F	R	A	*Number of samples*
Outcrops west	57.9	26.9	10.9	4.3	6
Core TT1	54.2	18.5	12.8	14.4	8
Core TT6	53.7	17.9	15.4	13.0	17
Average - west	55.3	21.1	13.0	10.6	31
Core AE1	79.6	13.4	5.1	1.9	15
Outcrops east	75.0	18.8	2.7	3.5	3
Core RL1	68.1	20.5	5.6	5.8	22
Average - east	74.2	17.6	4.5	3.7	40

The Jacobsville Sandstone west of the lake also plots in the subarkose region, however, when compared to the eastern samples the data has shifted towards the feldspathic and lithic end points.

When the data are plotted on a QmFLt triangular diagram suggested by Dickinson (1970) (Qm=monocrystalline quartz and tt=R+Qp, Qp=polycrystalline quartz, to emphasize unstable clasts) (figure 13), the Jacobsville Sandstone east of Lake Gogebic plots more in the center of the diagram and ranges from a subarkose, sublitharenite to an arkosic or lithic arenite. Whereas the Jacobsville Sandstone west of Lake Gogebic plots primarily as a lithic arenite with some samples plotting as arkosic arenite. The data from west of the lake, when compared to the data from east of the lake, shifts away from monocrystalline quartz.

Modes (monocrystalline quartz, polycrystalline quartz, feldspar and lithics) were plotted as percent versus depth for the drill cores and as percent versus descending stratigraphic order for the outcrop samples. These graphs of composition versus depth were used to illustrate both vertical changes in composition within each core and for lateral changes in composition between cores.



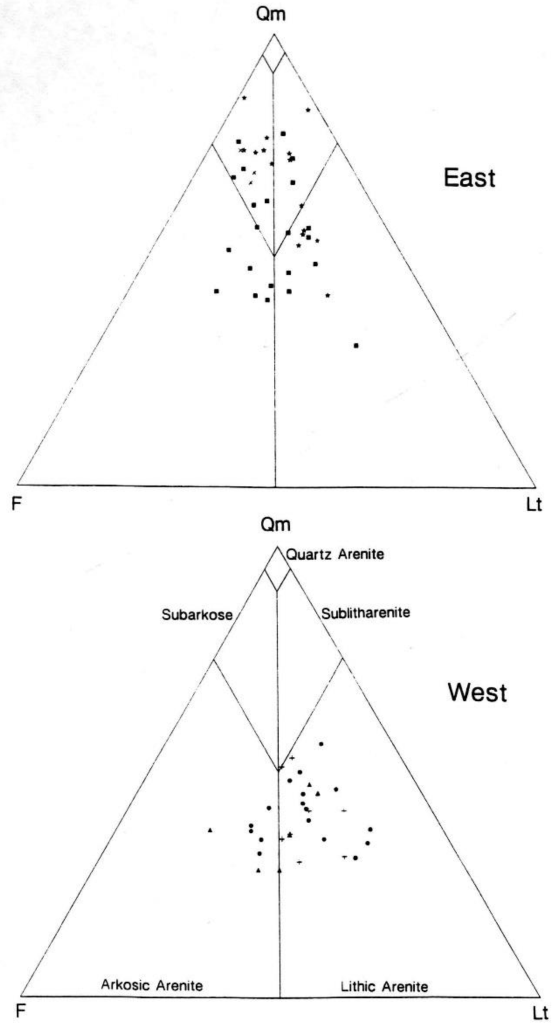


Fig. 13. QmFLt ternary plots of all samples east and west of Lake Gogebic. Samples east of the lake plot more in the center of the diagram, samples west of the lake plot mostly as lithic arenites.

Quartz

Two categories of quartz grains were counted, monocrystalline and polycrystalline. Grains composed of two or more sand-sized component grains were counted as polycrystalline quartz. Although chert and chalcedony grains were present in some samples (up to 2% in several samples) most contained negligible amounts (0 - 0.5%).These grain types were included with the polycrystalline quartz grains.

The graphs of percent monocrystalline quartz (Qm) versus depth for the four drill cores are shown in figure 14. The two drill cores west of Lake Gogebic (TT1 and TT6) contain <50% Qm. No trends of composition changing with depth are evident. The two drill cores east of Lake Gogebic (AE1 and RLI) overall contain more Qm. AE1, with the exception of one sample, is composed of >50% Qm and nine samples are >70% Qm. RLI contains 11 samples with >50% Qm and nine samples that range from 28% to 45% Qm. These define an upper and lower high quartz zone separated by a middle low quartz zone, no vertical trends of composition changing with depth are evident in AE1, all of which, except the lowest sample is similar to the high quartz zones of RLI.

The graphs of percent monocrystalline quartz (Qm) versus stratigraphic position for each sample (in relative descending stratigraphic order) for the six outcrop samples west of Lake Gogebic and the three outcrop samples east of Lake Gogebic are shown in figure 15. Again the samples east of Lake Gogebic contain higher percentages of monocrystalline quartz. The samples west of Lake Gogebic contain consistently <43% Qm and the samples east of the lake contain consistently >65% Qm. No vertical trends of composition changing with stratigraphic position can be seen. It should be noted that the two sandstone samples west of the lake (CH-91-10 and CH-91-8) with the highest percentages of Qm were interbedded with the conglomerate samples (CH-91-7 and CH-91-9) containing the high percentages of vein quartz clasts.

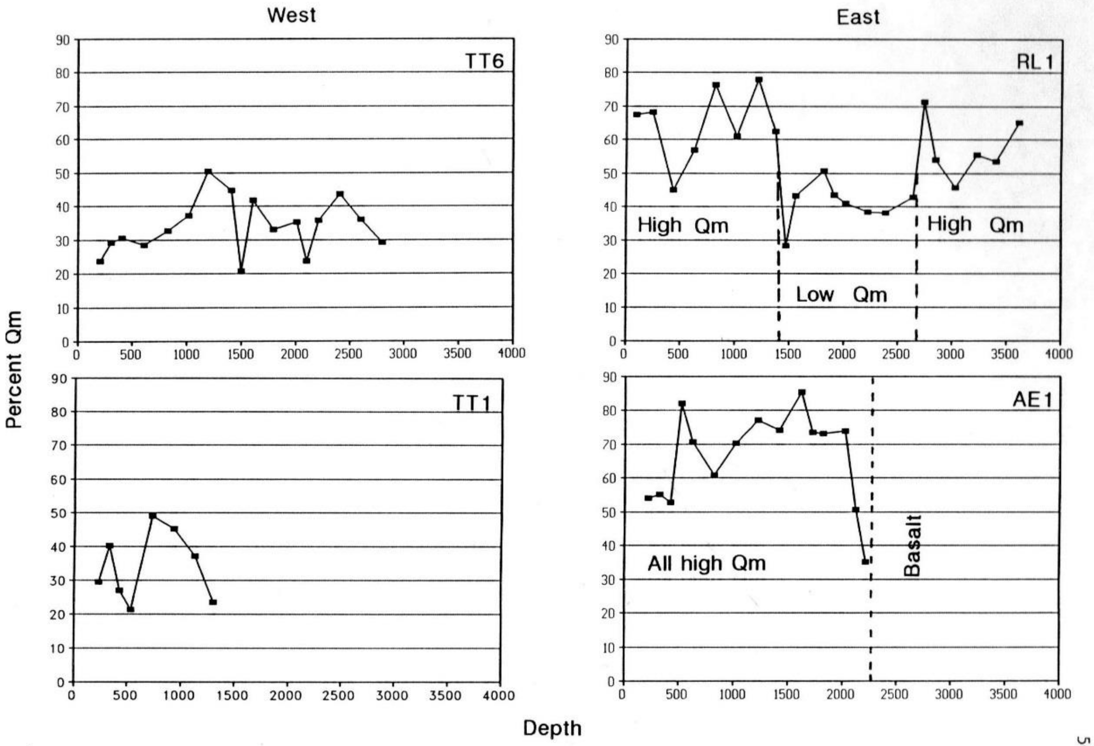


Fig. 14. Graphs illustrating percent monocrystalline quartz versus depth for the four drill cores east and west of Lake Gogebic. Overall, samples west of the lake contain less monocrystalline quartz than the samples east of the lake.

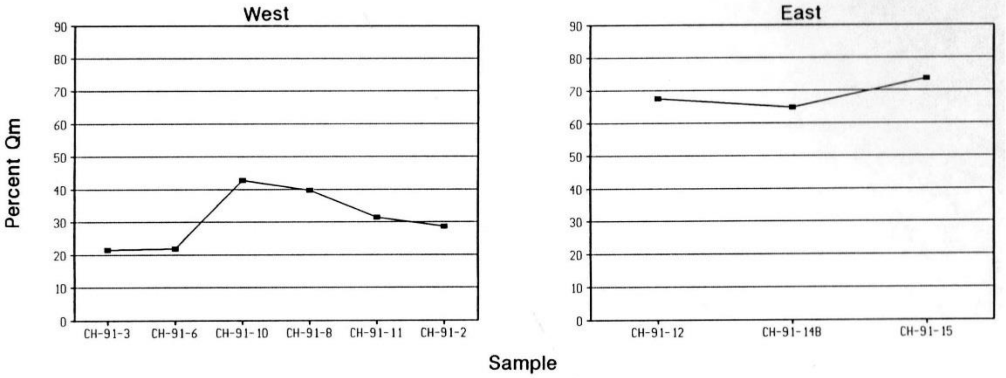


Fig. 15. Graphs illustrating percent monocrystalline quartz versus stratigraphic position (in relative descending stratigraphic order) for the outcrop samples east and west of Lake Gogebic. Samples west of the lake uniformly contain less monocrystalline quartz than the samples east of the lake.

The graphs of percent polycrystalline quartz (Qp) versus depth for the four drill cores are shown in figure 16. The two drill cores (TT1 and TT6) west of Lake Gogebic contain slightly more Qp and have less variation between samples (20-40%) compared to the cores east of the lake. No trends of composition changing with depth are evident. The two drill cores east of the lake (AE1 and RLI) contain somewhat less Qp overall and have a wider range in percentages (1-47%). Again no trends of composition changing with depth are evident.

A similar pattern is seen for the outcrop samples (figure 17). The six samples west of Lake Gogebic contain consistently more Qp (18-35%), than the three samples east of the lake (6-11%). No trends of composition changing with depth are seen in either sample set.

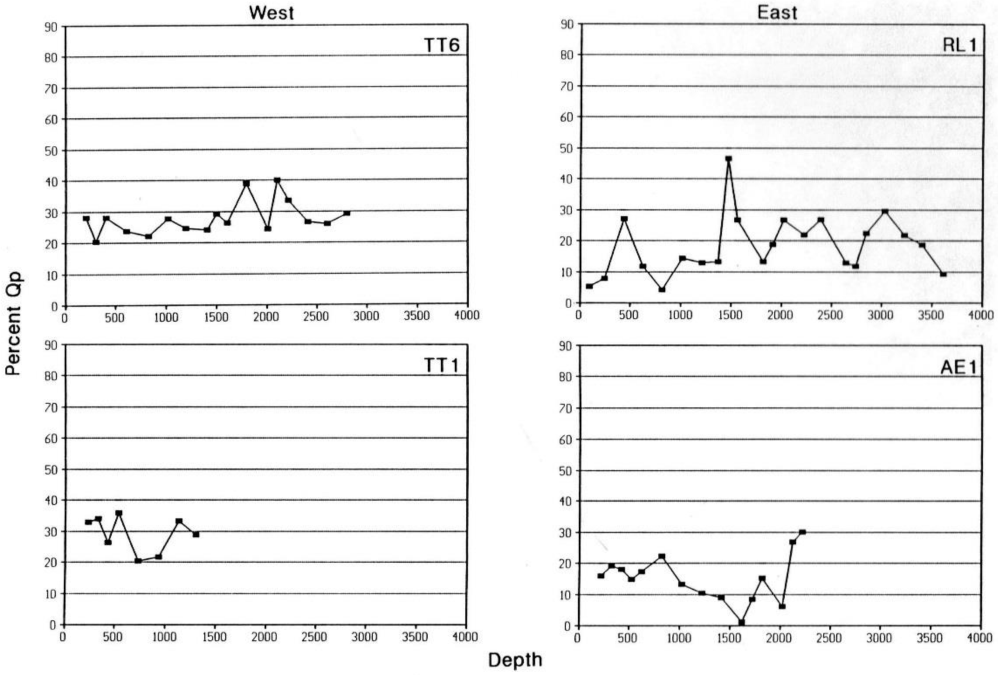


Fig. 16. Graphs illustrating percent polycrystalline quartz versus depth for the four drill cores east and west of Lake Gogebic. Samples west of the lake for the most part contain more polycrystalline quartz than the samples east of the lake.

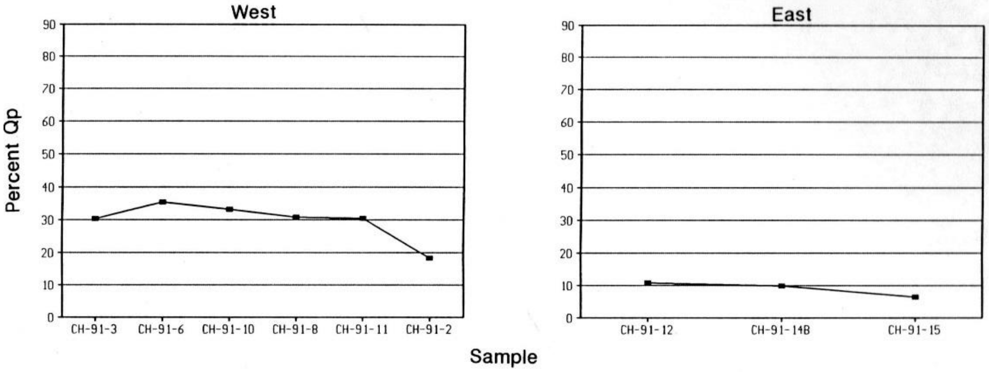


Fig. 17. Graphs illustrating percent polycrystalline quartz versus stratigraphic position

(in relative descending stratigraphic order) for the outcrop samples east and west of Lake Gogebic. The samples west of the lake contain more polycrystalline quartz than the samples east of the lake.

Feldspar

Thin sections were stained for potassium feldspar and point count categories included total feldspar, potassium feldspar, plagioclase feldspar and indeterminate feldspar. The process of staining for potassium feldspar enhanced the feldspar cleavages, thus making positive identification of feldspars very easy. However enough of the thin sections took the yellow potassium feldspar stain so poorly or inconsistently that discrimination of plagioclase from potassium feldspar was difficult and the resulting data must be regarded as less reliable than for the other petrographic variables. Only total feldspar will be discussed here, but the proportions of feldspar types for each sample is given in appendix II.

The graphs of percent feldspar versus depth for the four drill cores are shown in figure 18, The two drill cores west of Lake Gogebic (TT1 and TT6) contain on average slightly more feldspar (12-33%) than the AE1 core (2-19%) and on average slightly less feldspar than the RL1 core (9- 40%). In general the samples from the western cores TT1 and TT6 have less scatter in the data and a slight vertical trend indicating a decrease in percent feldspar with depth. The samples from the eastern core AE1, with the exception of one sample, plot consistently between 10 and 20% feldspar and have no trend. The samples from the eastern core RL1 range from 9 to 40% feldspar with more scatter in the data than any other drill core and with no trend.

The graphs of percent feldspar versus stratigraphic position (in relative descending stratigraphic order) for the six outcrop samples west of Lake Gogebic and the three samples east of the lake (figure 19) show that samples west of Lake Gogebic contain from 16 to 39% feldspar. No trends of composition changing with stratigraphic position are evident. However, the two western samples (CH-91-8 and CH- 91- 10) lowest in feldspar were from a sandstone interbedded with the conglomerate (samples CH-91-7 and CH-91-9) containing the high percentages of vein quartz clasts. The three eastern samples contain from 19 to 21% feldspar and no trends of composition changing with stratigraphic position are evident.

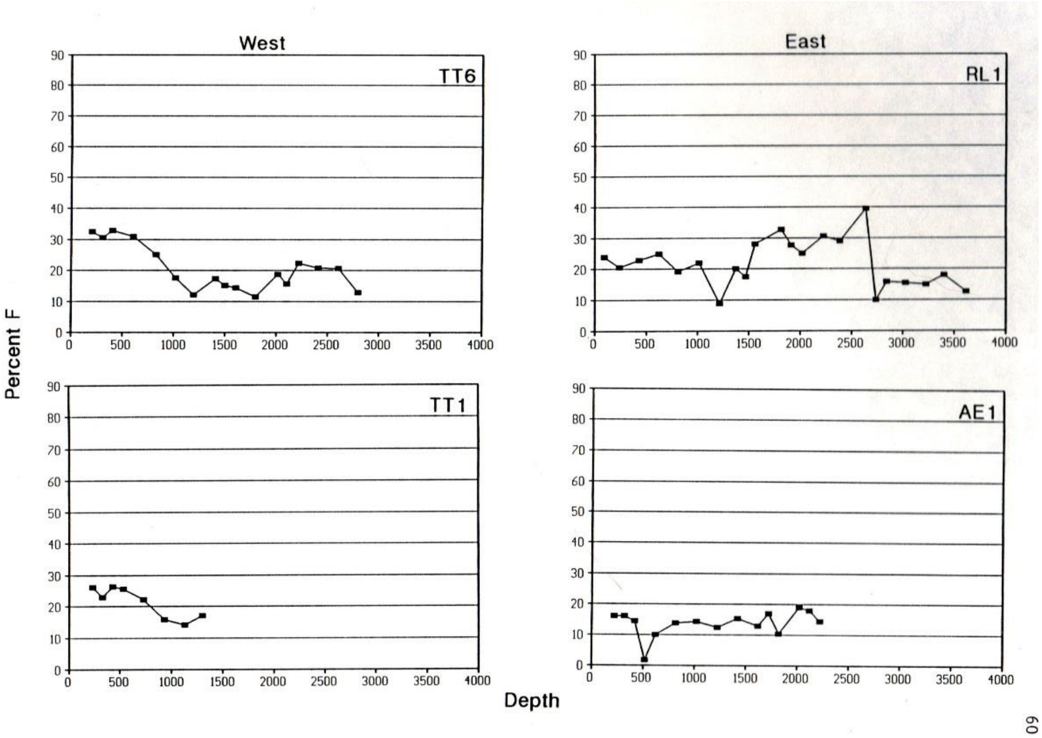


Fig. 18. Graphs illustrating percent feldspar versus depth for the four drill cores east and west of Lake Gogebic. The two western (TT1 and TT6) drill cores contain on average slightly more feldspar than the AE1 core and slightly less than the RL1 core.

Rock Fragments

The graphs of percent of total rock fragments (R) versus depth for the four drill cores are shown in figure 20. Overall the two drill cores west of Lake Gogebic (TT1 and TT6) contain more rock fragments than the two drill cores east of Lake Gogebic (AE1 and RL1). Drill core TT6 contains from 8-35% total rock fragments and drill core TT1 contains from 3-31% total rock fragments. No trends of composition changing with depth are evident. Whereas drill cores AE1 and RL1 contain, with the exception of four samples, consistently <10% total rock fragments. No trends are seen in RL1 or AE1* However, AE1 contains more rock fragments in the upper and lower most samples and almost no appreciable rock fragments in the middle of the core. All four drill cores show a sharp trend towards increasing total rock fragments in the very bottom of the drill cores.

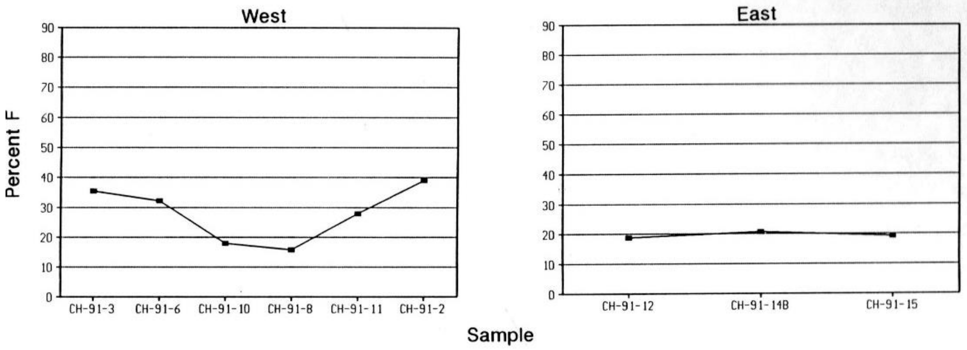


Fig. 19. Graphs illustrating percent feldspar versus stratigraphic position (in relative descending stratigraphic order) for the outcrop samples east and west of Lake Gogebic. The western samples tend to contain more feldspar than the eastern samples.

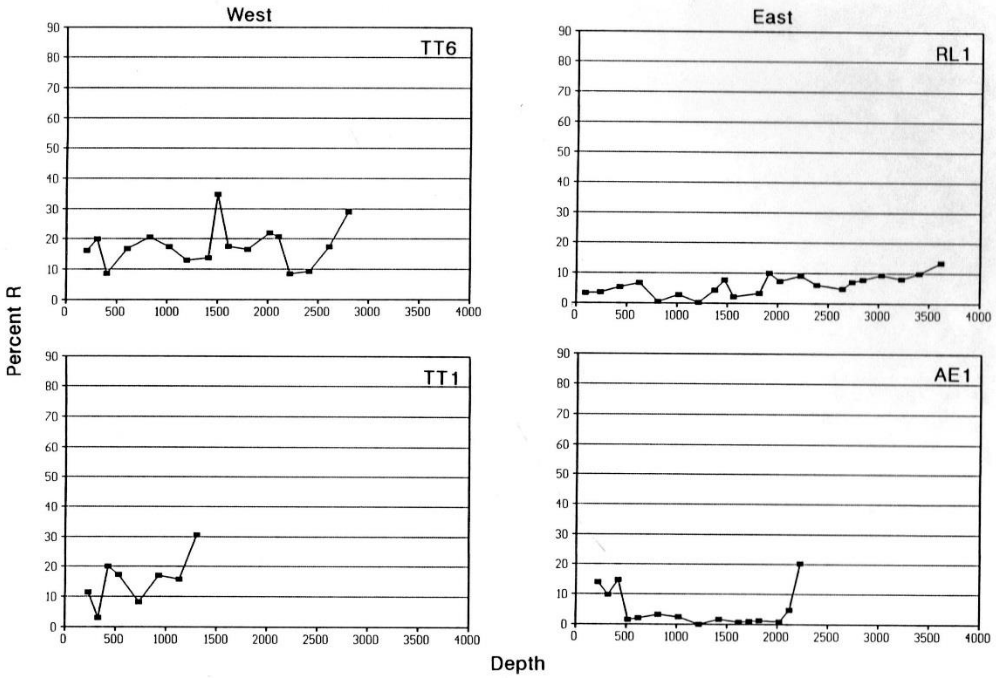


Fig. 20. Graphs illustrating percent rock fragments versus depth for the four drill cores east and west of Lake Gogebic. The western drill cores typically contain more rock clasts than the eastern samples.

The graphs of percent total rock fragments versus stratigraphic position (in relative descending stratigraphic order) for the six outcrop samples west of Lake Gogebic and the three samples east of the lake are shown in figure 21. Overall the western six samples contain more total rock fragments than the eastern three samples. No trends of composition changing with position are evident.

Individual rock types were grouped into five categories: plutonic, metamorphic, volcanic-silicic, volcanic-mafic and sedimentary. The percentages of the individual rock types counted for each sample can be found in appendix II. Only samples with greater than 5% rock fragments were included in the following more detailed analysis of rock fragments. One sample from core TT1, 10 samples from AE1 and 8 samples from RLI had less than 5% rock fragments and were not included in this analysis. None of the western outcrop samples contained less than 5% rock fragments, however two of the three eastern samples contained less than 5% rock fragments and were not included in this analysis. To better compare the various percentages of rock types for each sample, the data for the five categories of rock types were recalculated to 100%.

Plutonic Rock Fragments. Grains consisting of coarse grained quartz and feldspar were counted as plutonic rock fragments. The graphs of percent plutonic rock fragments versus depth for the four drill cores is shown in figure 22. Overall the two drill cores west of Lake Gogebic contain more plutonic rock fragments than the two drill cores east of the lake. Drill core TT6 contains from 18-90% plutonic rock fragments and drill core TT1 contains from 30-90% plutonic rock fragments. No trends of composition changing with depth are evident. Drill core RL1 contains from 0-81% plutonic rock fragments and drill core AEI contains from 4-71% plutonic rock fragments. No trends of composition changing with depth are evident in RL1, but AEI contains more plutonic rock fragments at the base of the stratigraphic section than at the top of the section.

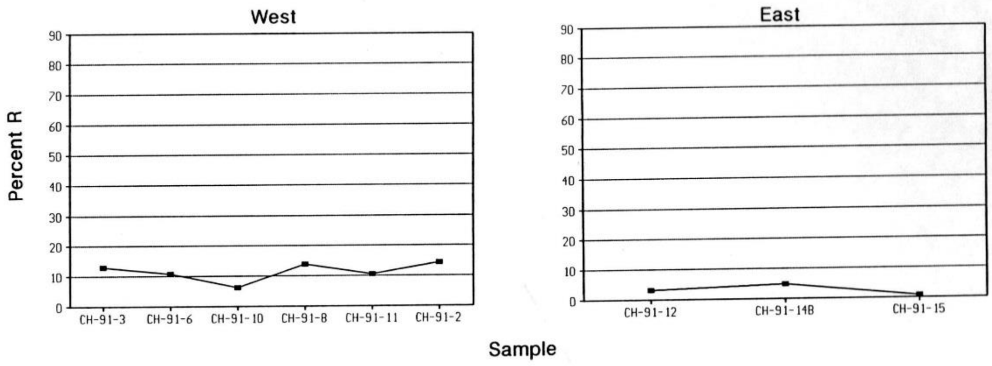


Fig. 21. Graphs illustrating percent rock fragments versus stratigraphic position (in relative descending stratigraphic order) for the outcrop samples east and west of Lake Gogebic. The western samples have a higher rock fragment abundance than the eastern samples.

The graphs of percent plutonic rock fragments versus stratigraphic position (in relative descending order) for the six outcrop samples west of Lake Gogebic and the three samples east of the lake are shown in figure 23. The six western outcrop samples contain significantly more plutonic rock fragments (65-98%) than the eastern sample (21% plutonic rock fragments). No trends of composition changing with stratigraphic position are evident.

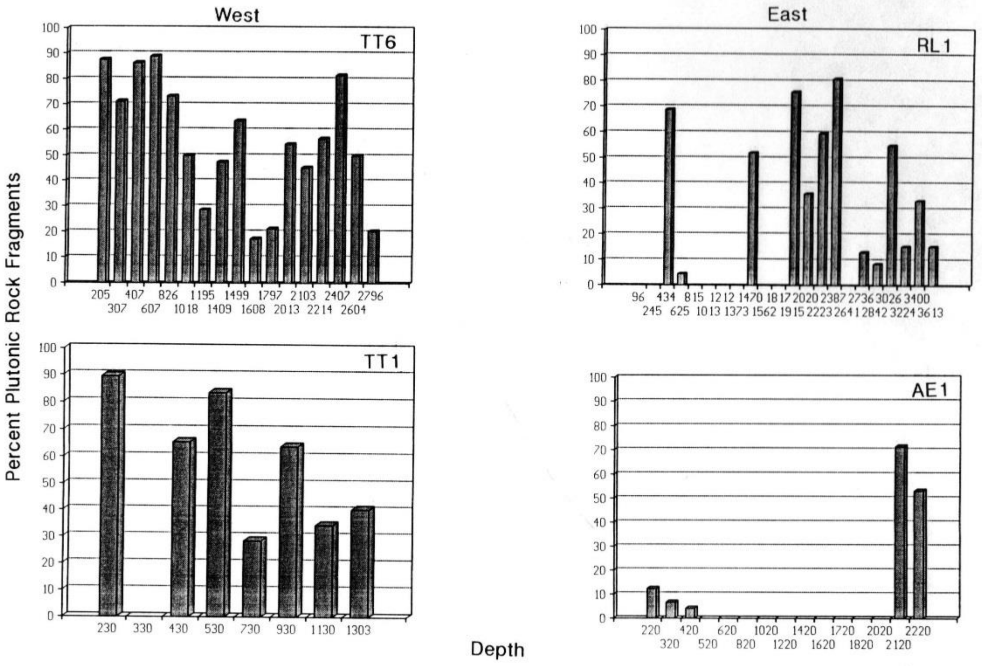


Fig. 22. Graphs illustrating percent plutonic rock fragments versus depth for the four drill cores east and west of Lake Gogebic. The western cores contain more plutonic fragments than the eastern cores.

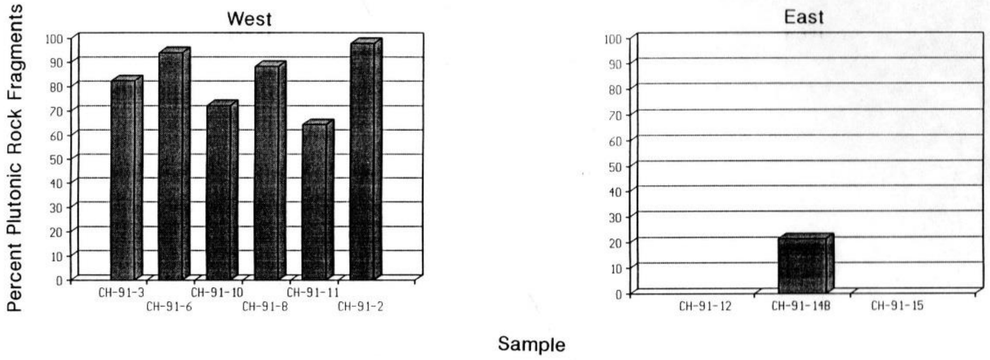


Fig. 23. Graphs illustrating percent plutonic rock fragments versus stratigraphic position (in relative descending stratigraphic order) for the outcrop samples east and west of Lake Gogebic. The western samples contain more plutonic rock fragments than the eastern samples.

Metamorphic Rock Fragments. Grains consisting of monocrystalline quartz and/or polycrystalline quartz and mica, with or without a metamorphic fabric were counted as metamorphic fragments. Overall the two drill cores west of Lake Gogebic contain more metamorphic rock fragments than the two eastern drill cores as shown in figure 24. The western cores TTI and TT6 contain 5-56% metamorphic rock fragments, whereas the eastern cores AE1 and RLI contain 3-44% metamorphic rock fragments. A trend of decreasing metamorphic rock fragments upsection is seen in both AE1 and TTI cores.

The graphs of percent metamorphic rock fragments versus stratigraphic position (in relative descending order) are shown in figure 25. The six western outcrop samples contain 0-23% metamorphic fragments, whereas the one eastern sample contains 36% metamorphic fragments. No trends of composition changing with stratigraphic position are evident.

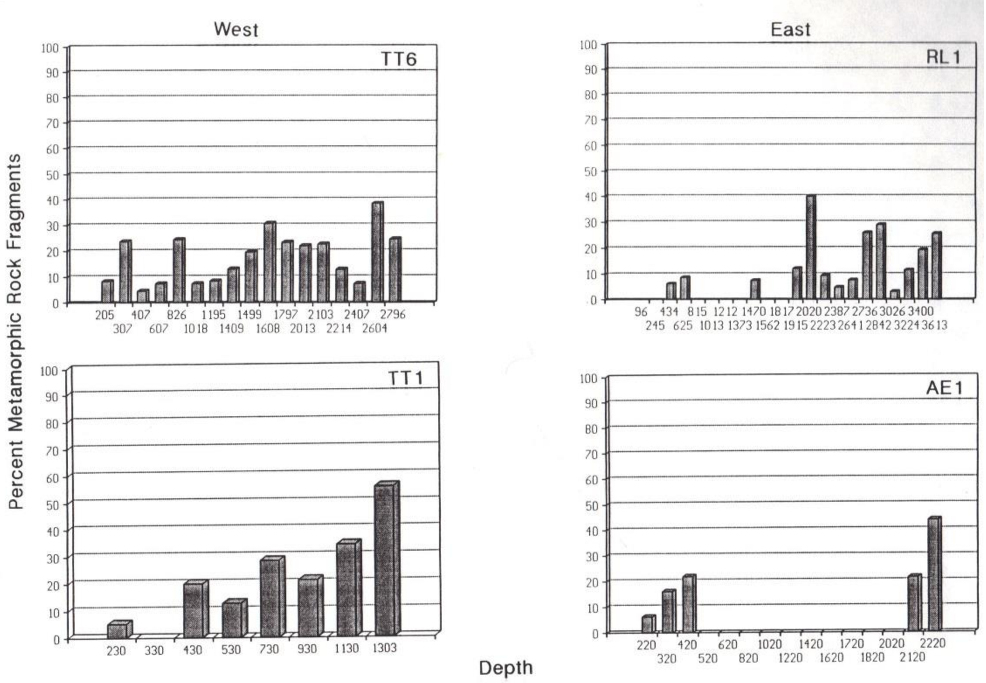


Fig. 24. Graphs illustrating percent metamorphic rock fragments versus depth for the four drill cores east and west of Lake Gogebic. The western cores show a slight tendency to more metamorphic rock fragments than the eastern cores.

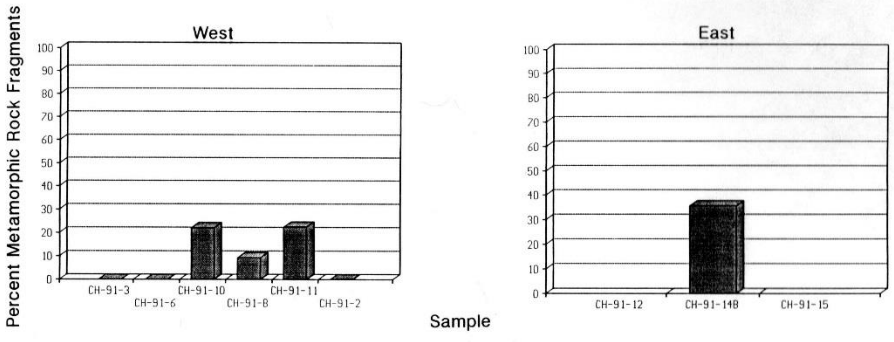


Fig. 25. Graphs illustrating percent metamorphic rock fragments versus stratigraphic position (in descending stratigraphic order) for outcrop samples east and west of Lake Gogebic. The one eastern sample contains slightly more metamorphic rock fragments than the western outcrop samples.

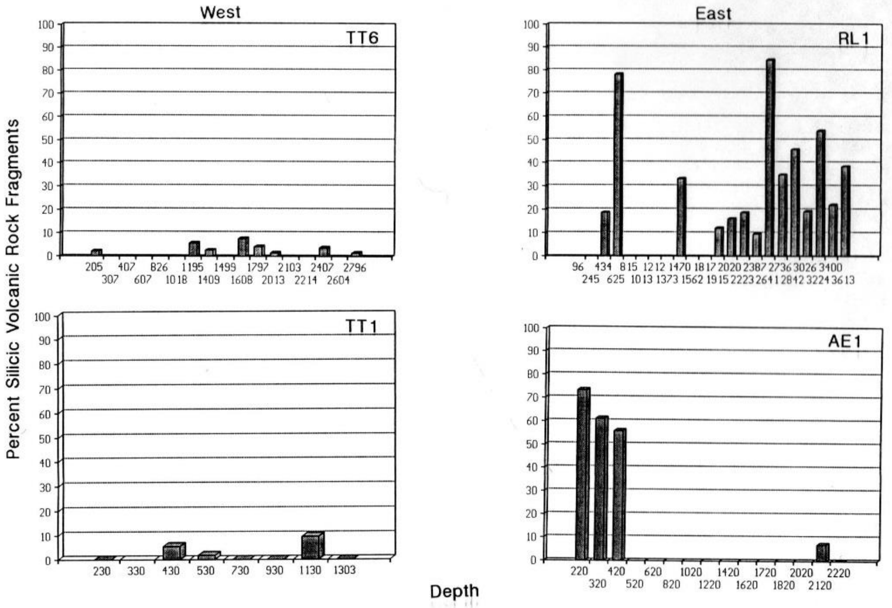


Fig. 26. Graphs illustrating percent silicic volcanic rock fragments versus depth for the four drill cores east and west of Lake Gogebic. The eastern samples commonly contain silicic volcanic rock fragments, whereas they are virtually absent from the western cores.

<u>Volcanic silicic Rock Fragments.</u> Granophyric, felsic and patchy silicic (snowflake?) rock fragments were included under the category volcanic silicic

rock fragments. Overall the two western drill cores contain significantly less silicic volcanic rock fragments (0-10%) than the two eastern drill cores (0-85%), as shown in figure 26. No trends of composition changing with depth are evident, with the exception of AE1. The graph of AEI clearly shows an increase in percentage of silicic volcanic fragments upsection.

The graphs of percent silicic volcanic rock fragments versus stratigraphic position (in relative descending stratigraphic order) for the eastern and western outcrop samples are shown in figure 27. The eastern outcrop sample contains 0% volcanic rock fragments and the western outcrop sample contains 0-3% volcanic silicic rock fragments. No trends of composition changing with depth are evident.

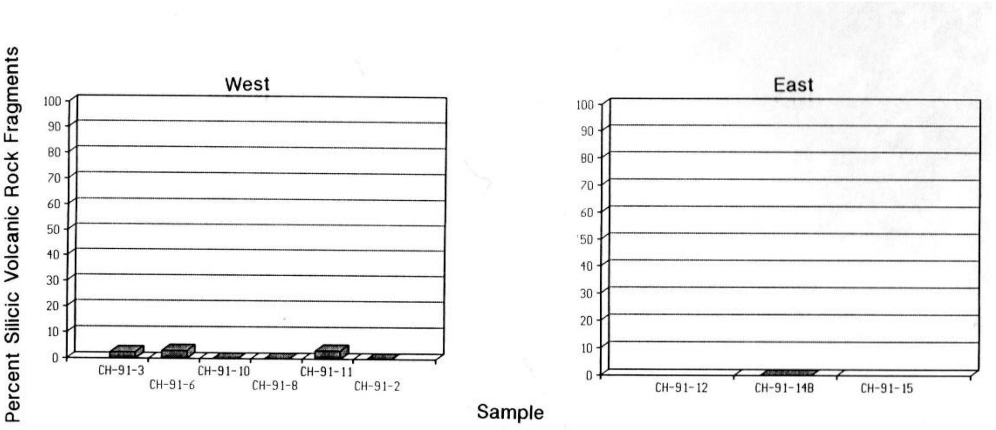


Fig. 27. Graphs illustrating percent silicic volcanic rock fragments versus stratigraphic position (in relative descending order) for the outcrop samples east and west of Lake Gogebic.

<u>Volcanic Mafic Rock Fragments.</u> Although commonly weathered, mafic volcanic rock fragments can be distinguished based on texture and sometimes on mineralogy. Only the western drill cores TT1 and TT6 contain mafic volcanic rock fragments (0-36%), as shown in figure 28. No trends of composition changing with depth are evident. Similarly the western outcrop samples contain 0-7% and the eastern outcrop samples contain 0% mafic volcanic rock fragments, as shown in figure 29. No trends of composition changing with depth are evident.

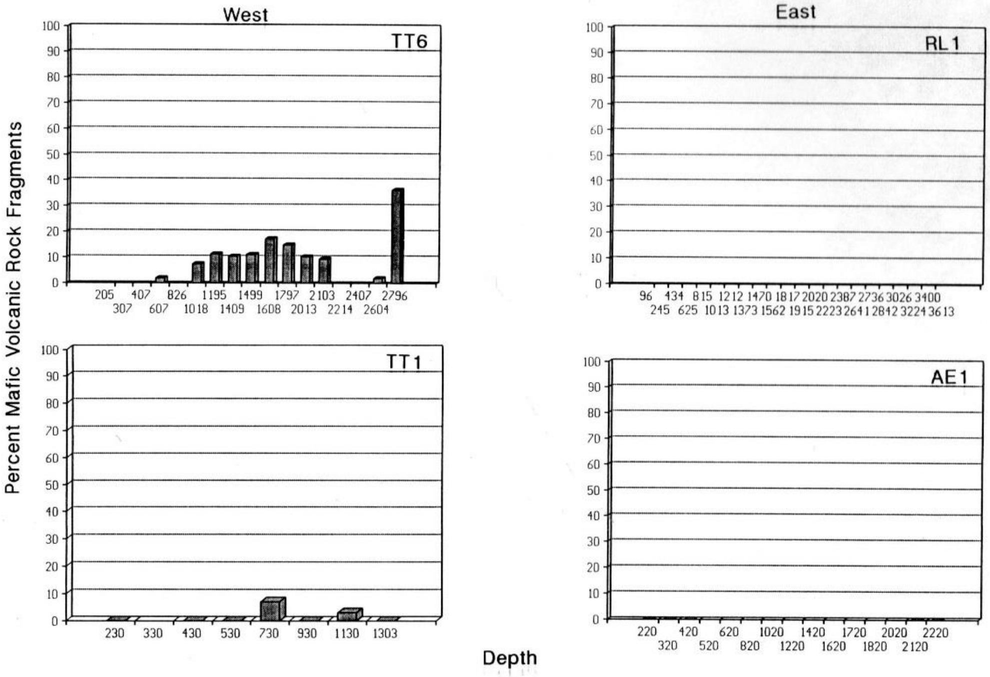


Fig. 28. Graphs illustrating percent mafic volcanic rock fragments versus depth for the four drill cores east and west of Lake Gogebic. Only the western drill cores contain any mafic volcanic rock fragments.

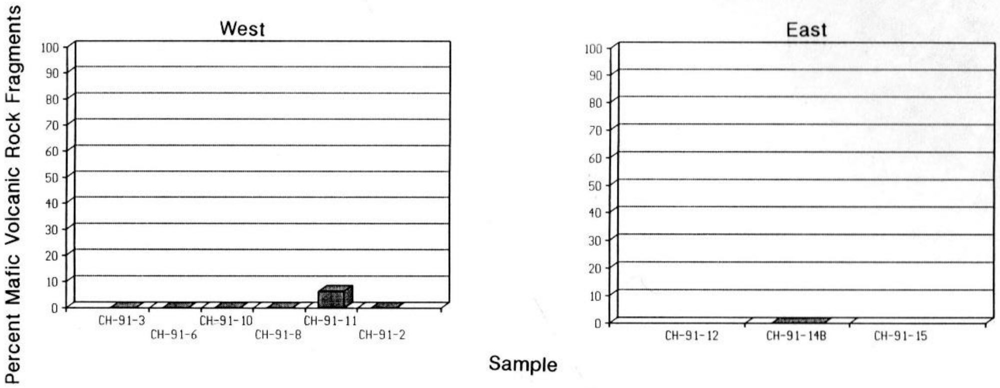


Fig. 29. Graphs illustrating percent mafic volcanic rock fragments versus stratigraphic position (in descending stratigraphic order) for the outcrop samples east and west of Lake Gogebic. Only one western samples contains any mafic volcanic rock fragments.

Sedimentary Rock Fragments

Shale clasts, quartzose sandstone clasts and iron- formation clasts were included under the category sedimentary rock fragments. The graphs of percent sedimentary rock fragments versus depth for the four drill cores are shown in figure 30. The western cores TT1 and TT6 contain 0-13% sedimentary rock fragments, similarly the eastern cores AEI and RLI contain 0-17% sedimentary rock fragments. No trends are evident. Likewise, the western outcrop samples contain 0-15% sedimentary rock fragments and the eastern outcrop sample has 0%, as shown in figure 31.

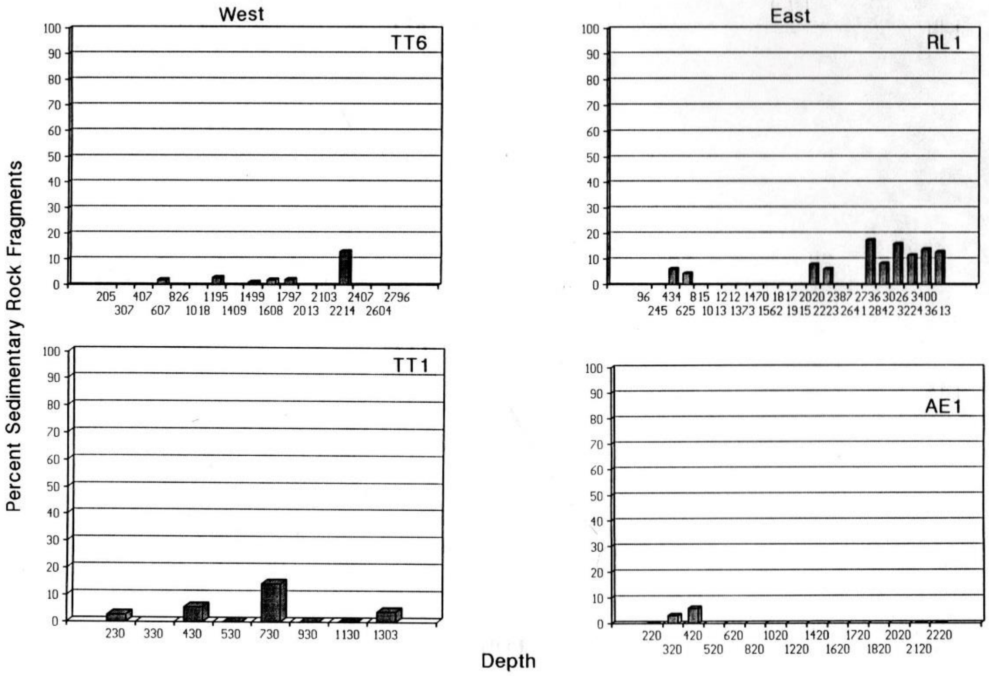


Fig. 30. Graphs illustrating percent sedimentary rock fragments versus depth for the four drill cores east and west of Lake Gogebic.

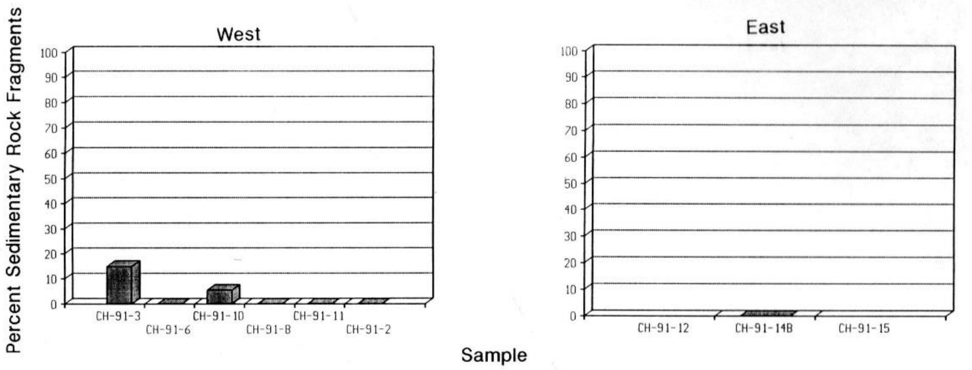


Fig. 31. Graphs illustrating percent sedimentary rock fragments versus stratigraphic position (in relative descending stratigraphic order).

Dickinson (1970) defined lithic grains as aphanitic grains, where the subgrains within the lithic grain are smaller than sand size (0.0625mm). For this study all of the grains counted as rock fragments, with exception of the plutonic rock fragments, met Dickinson's criteria for lithic grains. In order to use Dickinson's triangular diagram, the rock fragment data from this study was recalculated to conform with Dickinson's criteria for lithics. First by removing the plutonic rock fragment counts from the other rock fragment counts (now reclassified as lithics). Had these plutonic rock fragments been counted using Dickinson's method they would have been counted as either monocrystalline quartz or as potassium feldspar. It was observed during point counting that many of the plutonic rock fragments contained slightly more quartz than feldspar. Therefore, 60% of the plutonic counts were added to the previous monocrystalline quartz counts and 40% of the plutonic counts were added to the previous feldspar counts.

Two additional triangular diagrams were used to further differentiate the samples. One triangular diagram (Qp-Lvm- Lsm), used by Ingersoll and Suczek (1979), uses lithic populations to differentiate sand and sandstone from three primary tectonic settings (magmatic arcs, suture belts and rifted continental margins).

Plots of Jacobsville Sandstone data (east and west of Lake Gogebic) on Qp-Lvm-Lsm triangular diagrams are shown in figure 32. Ingersoll's Qp- Lvm-Lsm diagram (figure 33) illustrates where sand and sandstone data from different tectonic regimes plot. When the plot of Jacobsville Sandstone data from west of Lake Gogebic (figure 32) is compared to Ingersoll's plot of tectonic settings (figure 33) it can be seen that the data falls mostly within the rifted continental margin. The plot of Jacobsville Sandstone data from east of

Lake Gogebic is similar to the western data set, except the data spreads out and shifts closer to the Lvm mode.

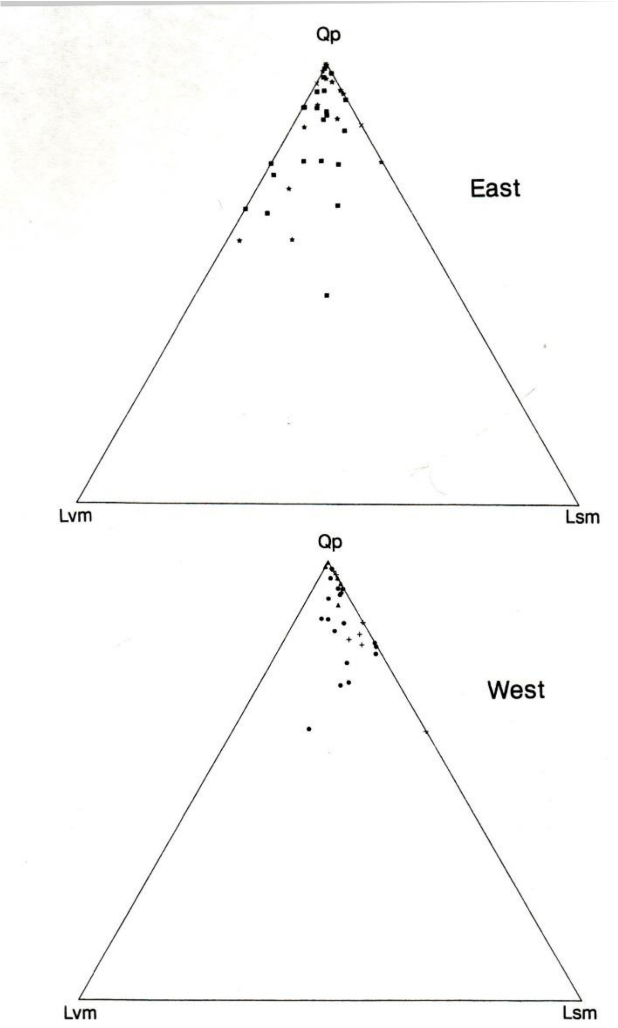


Fig. 32. Qp-Lvm-Lsm ternary plots for samples east and west of Lake Gogebic. The eastern samples spread out a little more than the western samples. However when both plots are compared to Ingersoll and Suczek's 1979 ternary plot differentiating primary tectonic settings (Fig. 33), they plot closest to their rifted continental margin setting.

The second triangular diagram (LmLpLs-Lvsi-Lvma) was used because it best differentiated Jacobsville Sandstone petrographic data west of Lake Gogebic from data east of the lake. The mode LmLsLp was calculated by adding metamorphic, sedimentary and plutonic grains together. The mode Lv-si consists of silicic volcanic lithics and the mode Lv-ma consists of mafic volcanic lithics. Figure 34 best illustrates one difference between the western and eastern Jacobsville Sandstone samples which is the presence or absence of silicic or mafic volcanic fragments.

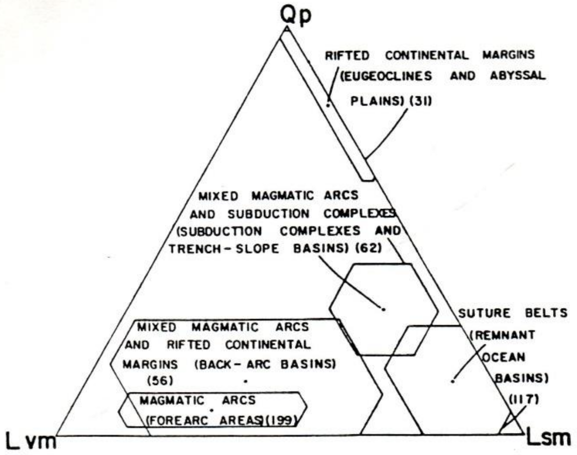


Fig. 33. Qp-Lvm-Lsm ternary plot used by Ingersoll and Suczek to differentiate between primary tectonic settings. From Ingersoll and Suczek, 1979.

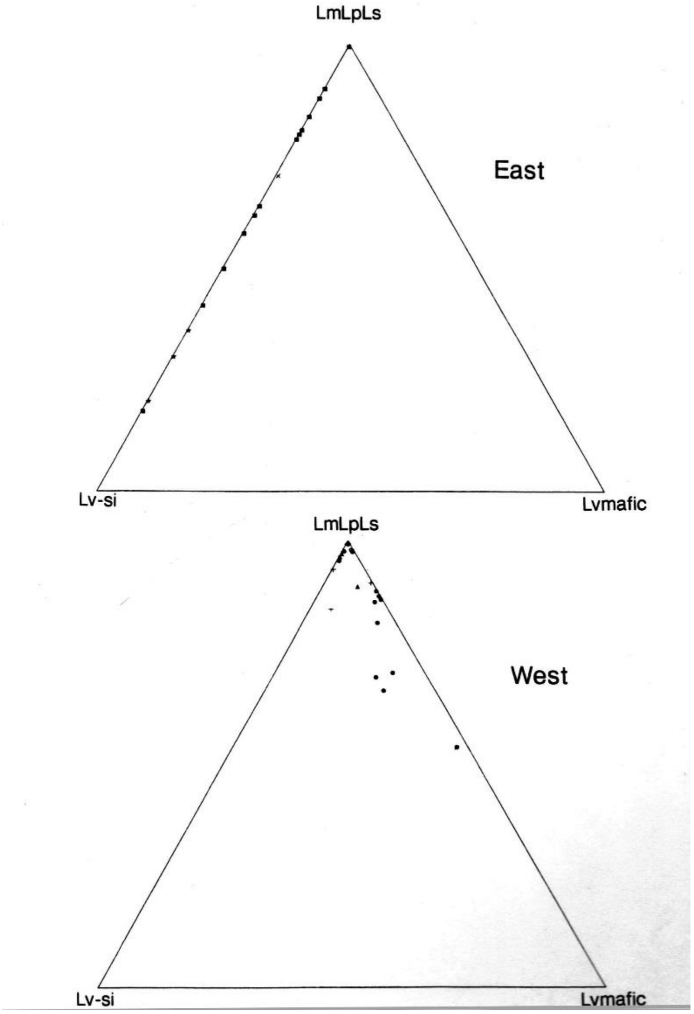


Fig. 34. LmLpLs-Lvsi-Lvma ternary plot. End point LmLpLs represent metamorphic, plutonic and sedimentary rock fragments. End points Lvsi and Lvma represent silicic volcanic and mafic volcanic rock fragments respectively. This plot best illustrates the lack of mafic volcanics in the eastern samples and the presence of only minor amounts of silicic volcanics in the western samples.

Accessory Minerals

Accessory minerals included single grains of garnet, staurolite, epidote/clinozoisite, opaques, mafic minerals (usually amphibole), and indeterminate grains. Listed in table 4 are the average values (in percent) of the accessory minerals for the four drill cores and the outcrop samples.

Table 4. Accessory minerals (in volume %)

WEST		EAST	
Outcrops	2.8	Outcrops	2.0
Core TT1	9.8	Core AEI	1.3
Core TT6	8.9	Core RLI	3.0
Average	7.2	Average	2.1

The percentage of each type of accessory mineral for each sample can be found in appendix II. Overall the western samples contain a greater percent of accessory minerals than the eastern samples.

Staurolite and garnet grains are the only two accessory minerals with identifiable source areas. Metamorphic isograds on figure 2 show the location of kyanite- staurolite, staurolite-andalusite, garnet, and biotite grade Penokean metamorphism. Graphs of percent staurolite and garnet versus depth for the four drill cores are shown in figure 35. The two western drill cores contain significantly more garnet and staurolite than the eastern drill cores. A trend of increasing staurolite and garnet with depth can toe seen in TT1. However, no trends are evident in the other three cores.

Graphs of percent staurolite and garnet versus stratigraphic position (in relative stratigraphic order) for the six western outcrop samples and the three eastern outcrop samples are shown in figure 36. A small amount of garnet and staurolite is present in two western samples and none is present in the eastern outcrop samples. The two western samples containing garnet and staurolite are from the sandstone layers interbedded with the conglomerate layers containing high percentages of vein quartz.

Heavy Mineral Data

Four western and three eastern outcrop sandstone samples were disaggregated and processed to obtain heavy mineral concentrates. Tables 5-7 list the composition of each sample fraction. The four western samples are both texturally and compositionally more immature than the three eastern samples.

Table 5. Heavy Mineral Distribution of Magnetic Fraction at .30 Amperes (using Franz Magnetic Separator)

	West				East		
	CH-91-2	CH-91-3	CH-91-6	CH-91-8	CH-91-12	CH-91-14	CH-91-15
Magnetite	tr	tr	tr	tr	2%		
Ilmenite	15-25%	5%	5%	10%	5%	5%	20%
Amphibole							tr
Staurolite	tr			30%			
Garnet	tr						
Tourmaline							
Monazite							
Zircon					tr		
Epidote							
AlSi							
Rutile							
Quartz							20%
Polymineralic	tr	tr	tr	tr			
FeO	tr	tr	tr	tr	tr	tr	30%
Hematite	tr	5%	5%	2%	tr	tr	20%
Mica		tr	2%	tr	tr	tr	
Pyrite					2%		

Table 6. Heavy Mineral Distribution of Magnetic Fraction at .80 Amperes (using Franz Magnetic Separator)

West							
	CH-91-2	CH-91-3	CH-91-6	CH-91-8	CH-91-12	CH-91-14	CH-91-15
Magnetite							
Ilmenite	tr	tr	tr	tr	10%		tr
Amphibole	-						
Staurolite	-			30%			
Garnet							
Tourmaline	10%			15%	20%	tr	30%
Monazite			tr				tr
Zircon					40-50%		tr
Epidote		tr	tr				
AlSi		tr					
Rutile							
Quartz							
polymineralic	tr	tr	tr	tr	10%	tr	30%
FeO							
Hematite		tr	tr	tr			
Mica	tr	tr	tr	tr			
Pyrite							

Table 7. Heavy Mineral Distribution of Non-Magnetic Fraction at .80 Amperes (using Franz Magnetic Separator)

W	West				East		
	CH-91-2	CH-91-3	CH-91-6	CH-91-8	CH-91-12	CH-91-14	CH-91-15
Magnetite							
Ilmenite							
Amphibole							
Staurolite							
Garnet							
Tourmaline							
Monazite							
Zircon	tr	3-4%	5%	4%	30%		10-20%
Epidote							
AlSi	tr	tr	tr				
Rutile	5%	5%	-	15%	tr		tr
Quartz	10%	10%	15%	10%	10%		
Polymineralic	20%	20%	20%	5%			tr
FeO							
Hematite							
Mica	tr	tr	tr	tr			
Pyrite	tr						

Three western samples (CH-91-2, CH-91-3 and CH-91-6) contain a similar suite of heavy minerals including ilmenite, magnetite, rutile, zircon, hematite, tourmaline (CH-91-2 only), apatite (CH-91-2 only), and possibly kyanite or andalusite. The fourth western sandstone sample (CH-91- 8) contains a large amount of staurolite along with ilmenite, magnetite, tourmaline, rutile, and zircon. The minerals in all four of these western samples are dominantly euhedral, although a small percentage are well rounded; indicating at least two generations of heavy minerals are present. All staurolite grains are fractured and appear to be broken fragments of coarser grains.

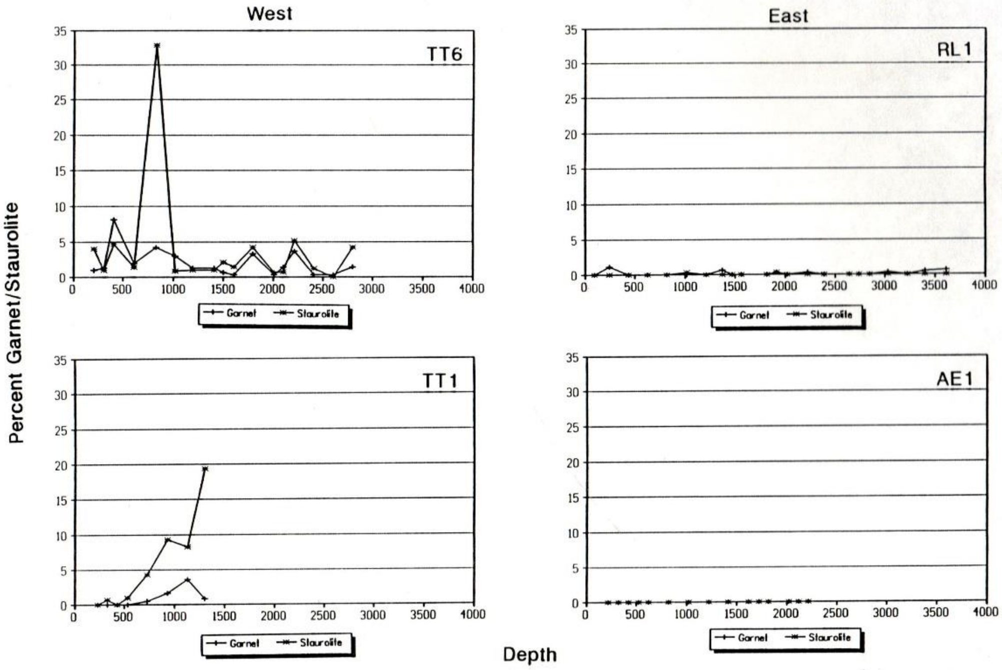


Fig. 35. Graphs illustrating percent staurolite and garnet versus depth for the four drill cores. The western samples contain far greater amounts of staurolite and garnet than the eastern samples.

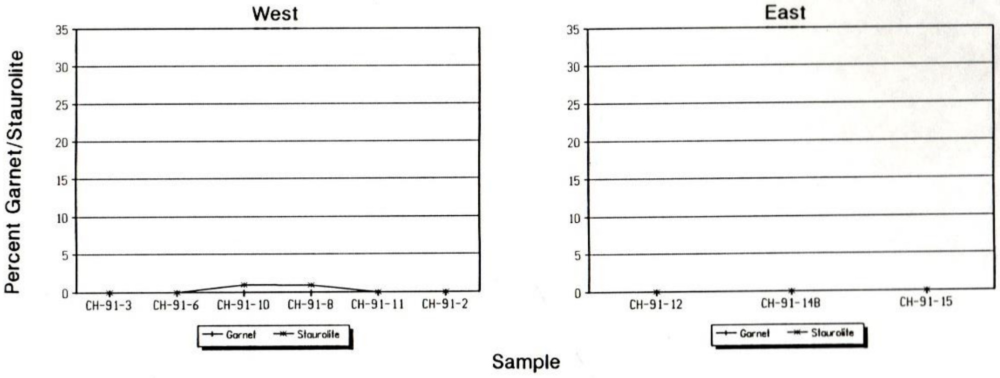


Fig. 36. Graphs of percent staurolite and garnet versus stratigraphic position (in relative stratigraphic order) for the six western outcrop samples and the three eastern outcrop samples.

The three eastern samples (CH-91-12. CH-91-14, and CH-91-15) are composed of a much more mature suite of heavy minerals, including ilmenite, magnetite, zircon, tourmaline and rutile. One exception is sample CH-91-14 which contained very few heavy minerals composed of ilmenite and only a trace of tourmaline. Sample CH-91-15 also contained trace amounts of monazite and weathered amphiboles. The heavy minerals from the eastern samples were all well rounded.

Table 8. Summary of lateral differences found in the Jacobsville Sandstone west and east of Lake Gogebic

avg. grain size 0.9 mm	avg. grain size 0.4 mm
dominated by conglomerate and coarse sandstone	dominated by medium- fine sandstone
poorly to moderately sorted	moderately to well sorted
avg. $Q_{55.3}F_{21.1}R_{13.0}A_{10.6}$	avg. $Q_{74.2}F_{17.6}R_{4.5}A_{3.7}$
minor (<10%) silicic volcanics	up to 80% silicic volcanics
presence of mafic volcanics	absence of mafic volcanics
immature heavy mineral suite	mature heavy mineral suite
dips 9-34 degrees	dips 0-10 degrees
No consistent vertical trends were seen in the four drill cores or in the outcrop samples, east or west of Lake Gogebic	

DISCUSSION

Comparison with Previous Work

Conglomerates. The first comprehensive study of the Jacobsville Sandstone was done by Hamblin (1958), who noted the presence of local basal conglomerates and scattered lenses of conglomerate. He reported that the basal conglomerates were composed primarily of vein quartz (50-60%) and feldspar (15- 25%), with lesser quantities of quartzite, chert, slate, iron formation and peridotite (each less than 10%). The western edge of Hamblin's field area was Victoria Dam, which is approximately 35 km northeast of Lake Gogebic.

More recently Abel (1985) also described local basal conglomerates and stated "scattered pebbles and one-pebble- thick lags in sandstone beds are more common and widespread than true clast supported conglomerates." Like Hamblin, the western edge of Abel's field area ended at Victoria Dam.

In contrast, this study has found that the conglomerates studied west of Lake Gogebic are not restricted to the basal units but are found throughout the section. These conglomerates are clast supported, fluvial deposits and are dominated by either iron-formation clasts or vein quartz.

Brojanigo (1984) examined conglomerates along the Keweenaw Fault near Bete Grise Bay, which he determined were local alluvial fans composed of basalt clasts derived from the Portage Lake Volcanics north of the Keweenaw fault. He concluded that there had been reverse movement and uplift on the Keweenaw fault during Jacobsville Sandstone deposition to form the alluvial fans.

Sandstone. Abel (1985) subdivided his study area of the Jacobsville Sandstone into three areas based on higher and lower percentages of lithics (figure 37). His area B contained an average of 28% lithics whereas his areas A and C contained 8.2% and 9.7% respectively. Abel’s averages, from his area C, for quartz, feldspar, lithics and accessory grains match reasonably well with this study's averages for all samples east of Lake Gogebic (table 9).

Table 9. Comparison of Abel's Area *C* and Eastern Samples (this study)

Constituent	Abel's area C	Eastern Samples
Q	73.8%	74.2%
F	15.6	17.6
L	9.7	4.5
A	0.7	3.7

Abel's explanation for the high lithic count in area B was a closer proximity to source. His higher lithic count in area C when compared to this study's eastern samples might be because more of his samples were taken along the coast closer to his area B, whereas this study has samples closer to Lake Gogebic, farther away from Hamblin's Northern Michigan highlands.

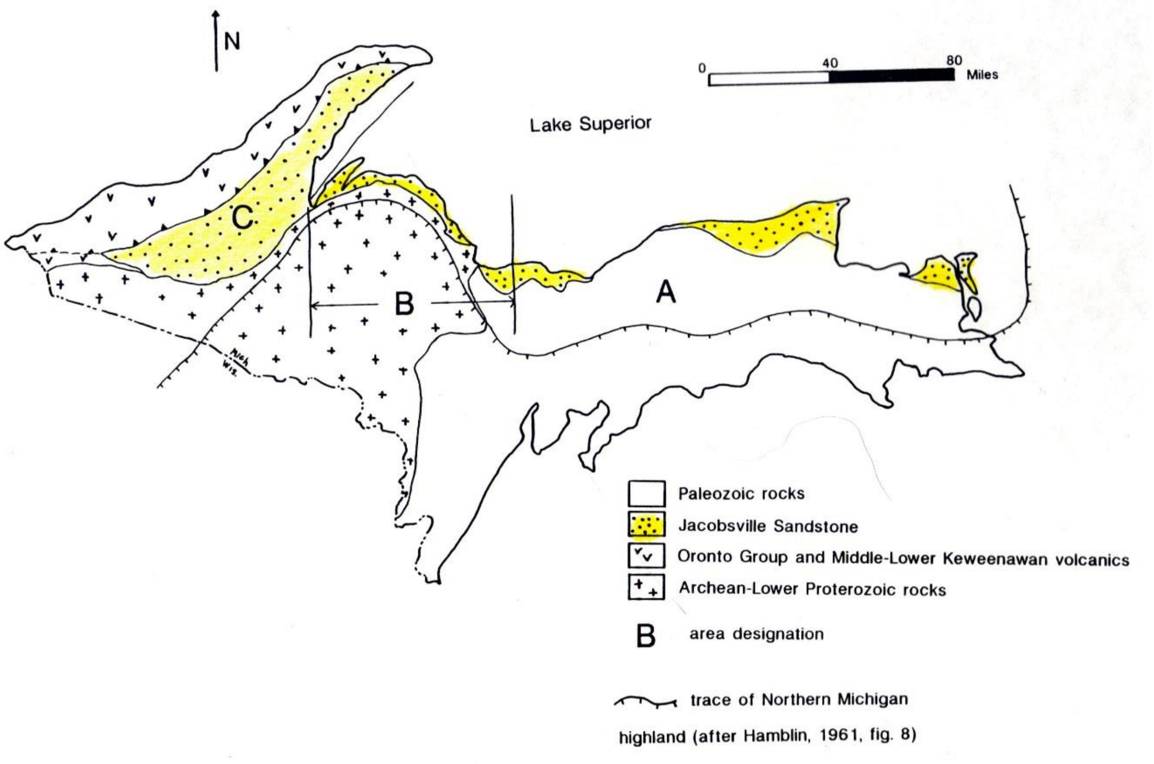


Fig. 37. Map illustrating Abel's A, B, and C area designations based on higher (area B) and lower percentages of lithics (areas A and C). Abel's percentages of quartz, feldspar, lithic and accessory grains from his area C match reasonably well with this study's averages for all samples east of Lake Gogebic. Modified from Abel (1985).

Bowers (1989) did a detailed petrologic study of the RL1 drill core and divided the core into four units based on bedding styles. Bowers' QFL averages match very closely with this study's averages, except for feldspar (table 10). The difference in feldspar percentages probably stems from the fact that he point-counted unstained slides and this study used slides stained for potassium feldspar. In the course of this study numerous untwinned feldspars were found that would have been unidentifiable except for the presence of a stain.

Table 10. Comparison of Bower's QFL and this study's QFR averages for RL1 drill core

Bower's RL1	This study's RL1
Q 71.3%	Q 68.1%
F 15.7%	F 20.5%
L 6.8%	R 5.6%
A 5.9%	A 5.8%

Bower defined his unit 1 as the upper 45 to 400 feet, unit 2 from 400 to 1700 feet, unit 3 from 1700 to 2500 feet, and unit 4 from 2500 to 3630 feet. This study proposes only three units based on high and low monocrystalline quartz values. Unit 1 from 45 to 1400 feet contains mostly greater than 50% Qm, unit 2 from 1400 to 2700 feet contains mostly less than 50% Qm and unit 3 from 2700 to 3630 feet contains mostly greater than 50% Qm (figure 14). These units are not discernable from the graphs of polycrystalline quartz or rock fragments (figures 16 and 20). However, percent feldspar (figure 18) changes at approximately the same depths, with less than 25% in unit 1, greater than 253 in unit 2 and less than 20% in unit 3. Regardless of the number of units or the exact placement of unit boundaries in the RL1 drill core, units of high and low monocrystalline quartz are not seen in any other drill core.

Provenance

<u>Lithologies from a Southerly Source.</u> Rocks from the Marquette Range Supergroup in the Gogebic iron Range are the only source of iron-

formation, quartzite, metasiltstone and chert. Although coarse vein quartz is found in Marquette Range Supergroup rocks, Archean rocks probably contain more vein quartz volumetrically and are the most likely source. Plutonic rock pebbles (weathered granite, granophyre, and clasts of coarse feldspar) and sand-sized plutonic rock fragments are derived from the Archean. Metamorphic clasts from the sandstone are dominantly schist from Early Proterozoic and Archean rocks. The only occurrences of staurolite and garnet are in rather localized areas to the south (see metamorphic zones in figure 2). It is uncertain if the mafic volcanic lithologies are derived from the Powder Mill Group, located to south, or from the Portage Lake Volcanics, located to the north. The fact that more volcanic grains are found lower in the section supports the possibility that they are derived from the Powder Mill Group. However, more rhyolite conglomerate clasts were also found lower in the section and there is no known southerly source for rhyolites.

<u>Lithologies from a Northerly Source.</u> Both conglomerate and sand-size clasts of undeformed sandstone and siltstone are derived from Keweenawan rocks located to the north. As noted above, rhyolite clasts are derived from the north. Siliceous volcanic sand-sized grains are most likely derived from the north. Although there is potentially a local source area to the south and west of Lake Gogebic, no sand-sized silicic volcanic grains were found west of Lake Gogebic.

Considering Brojanigo's (1984) data indicating that alluvial fans, located in the Jacobsville Sandstone along the Keweenaw fault, on the Keweenaw Peninsula, are composed of lithologies derived from the north, it is possible siliceous volcanic grains found in the Jacobsville Sandstone east of Lake Gogebic are also derived from the north. Table 11 clearly illustrates that the dominant source area for lithologies found in the Jacobsville Sandstone is to the south. A northerly source is certain only for unmetamorphosed sandstone and siltstone and most likely for siliceous volcanic clasts.

Table 11. Summary table of lithology source areas
(X definite source, O probable source)

Lithology	Northern	Southern	Indeterminate
Conglomerate		X	
Iron-formation		X	
Vein Quartz		X	
Quartzite		X	
Metasiltstone		X	
Chert		X	
Granite			
Rhyolite	O		
Sandstone	X		
Siltstone	X		O
Basalt			
Sandstone			
Plutonic		X	
Metamorphic		X	
Volcanic-Si	O		
Volcanic-Ma			O
Sedimentary			O
Heavy Minerals			
Staurolite		X	
Garnet		X	
Other			O

Tectonic Setting

Previous workers have proposed various rift models for the Midcontinent Riff System. Daniels and Elmore (1988) proposed that passive foundering of the rift allowed "burial of pre-Keweenawan rock by terrigeneous clastics - Oronto Group and equivalents, and subsequent burial of the Oronto Group by various fluvial/deltaic/lacustrine facies of the Jacobsville and Bayfield Group sediments" (figure 38). However, to date there are no known deltaic or lacustrine facies of the Jacobsville sandstone; all of the conglomerates and sandstones examined for this study are fluvial and there is no evidence of standing water of any kind as drawn on their diagram. This discrepancy between predicted and observed sedimentological patterns suggests that the tectonic setting for the Jacobsville Sandstone needs to be re-examined. Furthermore, new seismic information is available that provides a framework for interpreting the Jacobsville Sandstone.

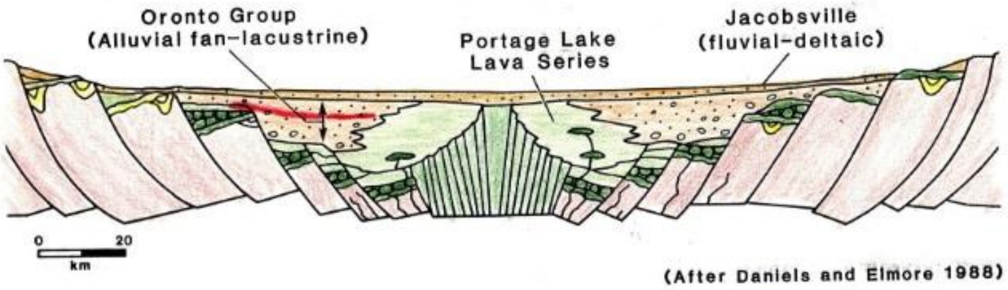


Fig. 38. Late Keweenawan rift model from Daniels and Elmore (1988). They believed that passive foundering of the rift allowed "burial of pre-Keweenawan rock by terrigeneous elastics - Oronto Group and equivalents, and subsequent burial of the Oronto Group by various fluvial/deltaic/lacustrine facies of the Jacobsville and Bayfield Group sediments".

A north-south seismic reflection profile (Hinze and others, 1990) of the southern margin of Lake Superior passed approximately 10 miles east of the AE-1 drill hole. The approximate location of drill hole AE-1 is projected on their interpreted cross section (figure 39) and their interpreted thickness of the Jacobsville Sandstone matches closely with the measured thickness. Hinze and others (1990) presented diagrammatic profile sketches illustrating the evolution of the southern margin of the western Lake Superior portion of the Midcontinent rift system (figure 40). In their profile F they also infer that the Jacobsville Sandstone was a rift-fill sediment that completely covered a subsiding basin. However, the lack of basinwide laterally continuous units in the Jacobsville Sandstone, as documented in this study, is evidence that Jacobsville sedimentation was not a simple basinwide infilling of a rift that was slowly subsiding in its late thermal stage.

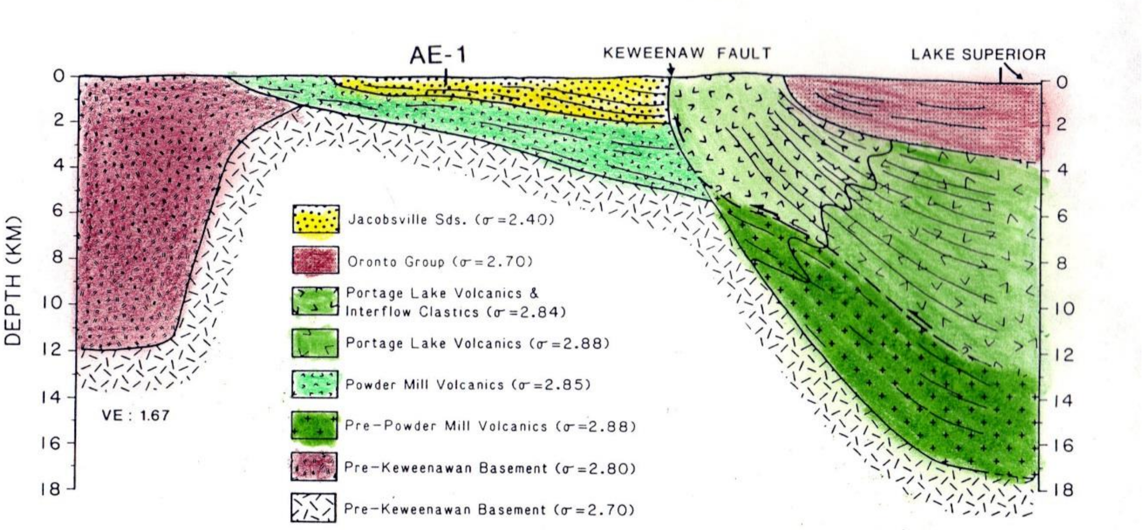


Fig. 39. Interpreted north-south seismic reflection profile of the southern margin of Lake Superior, located approximately 10 miles east of drill hole AE1 (from Hinze and others, 1990). The projected location of drill hole AE1 is shown on this profile. The interpreted thickness of the Jacobsville Sandstone closely matches the section measured in the AE-1 drill core.

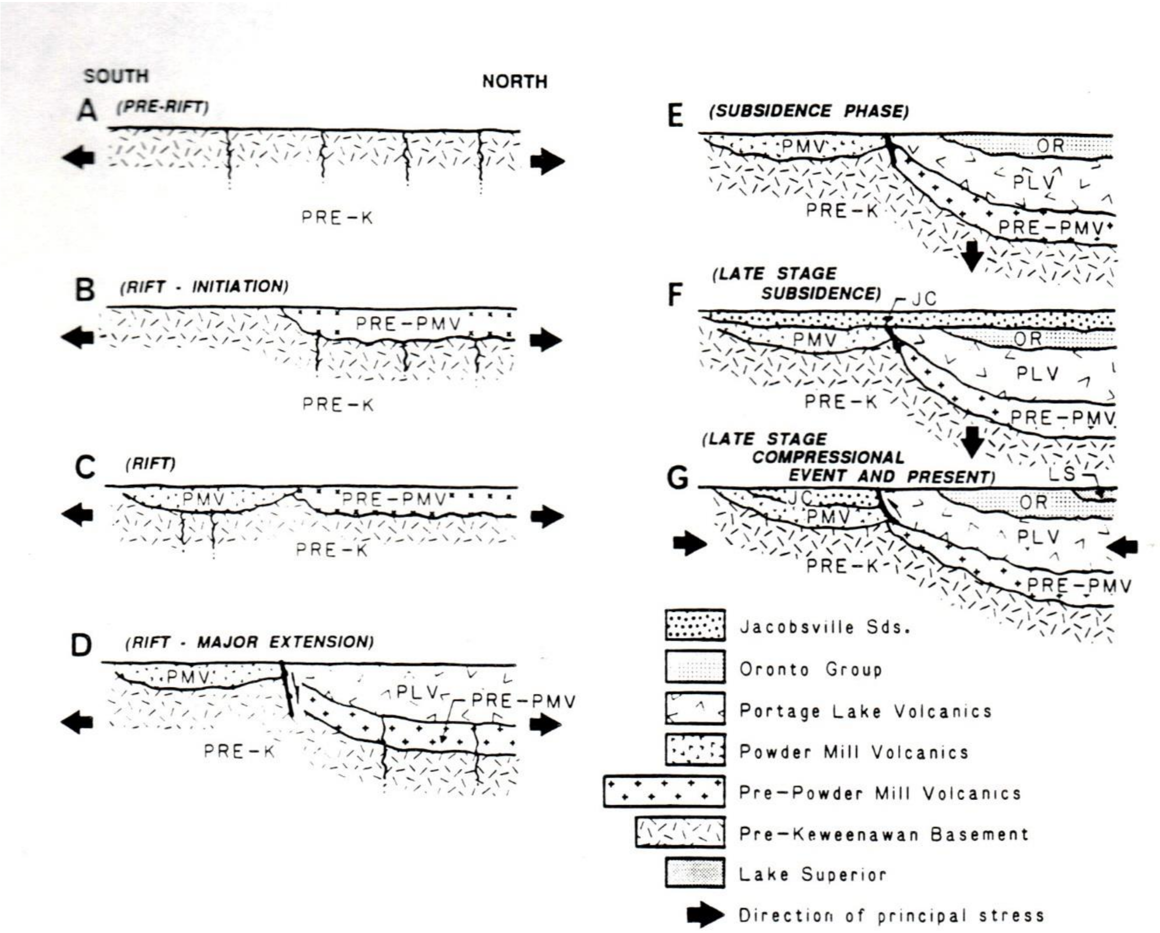


Fig. 40. Diagrammatic sketches (from Hinze and others, 1990) of interpreted seismic reflection profiles shown in figure 39, from a) inception of the Midcontinent Rift System rifting event to g) the present day illustrate the evolution of the southern margin of the western bake superior Basin, sketches are not to scale and represent different time intervals. Arrows indicate direction of principle stress. In the profile F, Hinze and others infer that the Jacobsville Sandstone was a rift-fill sediment that completely covered a subsiding basin. However the lack of basinwide laterally continuous units in the Jacobsville Sandstone, as documented in this study, is evidence that Jacobsville Sandstone sedimentation was not a simple basin wide infilling of a rift that was slowly subsiding in its late thermal stage.

In contrast to the models of these previous studies, data from this study indicate a more complex depositional system composed of multiple basins, each undergoing different degrees of tectonic activity. A southerly source for lithologies, steeper dip angles, and a predominance of conglomerate in the Jacobsville Sandstone west of Lake Gogebic» in contrast to the Jacobsville Sandstone east of the lake, are all evidence of a western basin receiving sediments from a tectonically active area located to the south.

Recent work by Cannon and others (1990) as well as Cannon and others (in press) documents the presence of listric thrust faults (the Marenisco and Pelton Creek faults, figure 2) south of the Jacobsville basin during the time of Jacobsville deposition at about 1060 Ma. They propose as much as 30 km of uplift along the Marenisco and Pelton Creek faults near the present day Michigan-Wisconsin state line and less than 15 km of uplift south the TT1 and TT6 drill holes. West of Lake Gogebic, the distance between the Marenisco fault and the southern edge of the preserved Jacobsville Sandstone ranges from 8 km near Lake Gogebic to 30 km at the western terminus of the Jacobsville Sandstone.

I propose that rotation of the upper bounding plate of these faults and the subsequent erosion of Early Proterozoic and Archean units produced the steeper dips in the Jacobsville Sandstone west of Lake Gogebic and created the uplifted source of the conglomerates.

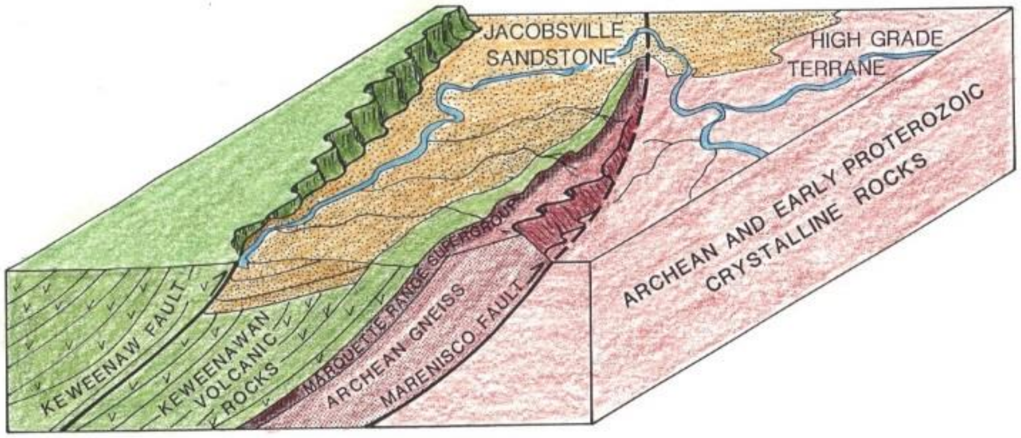
Rb-Sr dating of biotites was used by Cannon and others (1990) as well as Cannon and others (in press) to determine the timing of movement on the Marenisco and Pelton Creek faults. Because Rb-Sr dates record when biotites cool below 270 degrees C, these dates provide a record of uplift and cooling of basement rock south of the Jacobsville basin at about 1060 Ma. This uplift was caused by thrusting and erosional unroofing of the upper plate of the Marenisco and Pelton Creek fault.

The presence of regional thrust faults within a rift system is an uncommon occurrence. The thrust faults within the Midcontinent rift system document a period of regional compression occurring at about 1060 Ma, approximately 30 m.y. after the end of rift magmatism and during thermal subsidence. The Grenville orogeny occurring to the east is believed to have prevented the rift from successfully opening to a new ocean and probably provided the compression necessary to invert the center of the rift along these thrust faults (Cannon and Hinze, 1992). This shift from extensional to compressional tectonics changed late rift sedimentation from a central thermally subsiding basin collecting sediments from the rift shoulders, to a more complex system of multiple rift-flanking basins. These rift-flanking basins are sandwiched between thrust faults which inverted the central rift and the rift shoulders.

The areal extent and northerly dips of the conglomerate facies west of Lake Gogebic coincides spatially with the position of the upper plate of the Marensico and Pelton Creek faults as determined independently by Cannon and others (in press). This correspondence suggests that the conglomerate facies of the Jacobsville Sandstone were derived from upthrust southerly sources. Increasing dip angles with depth in the Jacobsville Sandstone west of Lake Gogebic records progressive northern rotation of the upper plate of the Marenisco and Pelton Creek faults throughout Jacobsville Sandstone deposition.

East of Lake Gogebic the Marenisco fault continues beneath the Jacobsville Sandstone and can be traced as a magnetic anomaly because of uplifted underlying basalts. Apparently, east of the lake only the base of the Jacobsville Sandstone was disturbed and sedimentation of the Jacobsville Sandstone kept pace or occurred faster than displacement along the fault (W, Cannon, USGS$_{TJ}$ 1992, personal communication).

The provenance data of this work, combined with the tectonic interpretations of Cannon and others (in press) allows construction of the sedimentologic system illustrated in Fig, 41, This block diagram shows the inferred topography created during uplift along the Marenisco and Keweenaw faults as well as the depositional basin and drainage system during Jacobsville Sandstone deposition (figure 41), Displacement along the Keweenaw fault diminished west of Lake Gogebic until there is almost no discernable offset along the fault at the Wisconsin and Michigan state line. In compensation, displacement along the Marenisco and Pelton Creek faults increased to the west (W. Cannon, USGS., 1992, personal communication). Although active thrusting has shifted southward from the Keweenaw fault to the Marenisco and Pelton Creek faults, the same amount of total crustal shortening (about 30 km) has occurred along the rift in this vicinity.



Fig, 41, Block diagram illustrating the sedimentologic system during Jacobsville Sandstone deposition. Diagram shows inferred topography created during uplift along the Marenisco and Keweenaw faults as well as the depositional basin and drainage system during Jacobsville Sandstone deposition. (Diagram from W. Cannon, USGS, written communication, 1992)

Southerly highlands, created by movement along the Marenisco fault, shed debris northward to alluvial fans and into local drainages. Most likely, conglomerates in these local fluvial systems were dominantly composed of iron-formation, because of the close proximity of the Gogebic Iron Range and the resistance of iron-formation to abrasion and weathering. Larger rivers draining the more southerly Archean and Early Proterozoic rocks would have been carrying a different assemblage with more resistant rock types such as vein quartz and quartzite. These rivers would also have been carrying garnet and staurolite, minerals found only in southerly metamorphic zones (figure 2). These rivers are inferred to have been deflected around the tectonically active southern highlands and turned to the northwest or west once north of the termination of the Marenisco fault near the present Lake Gogebic. Hamblin's (1958) paleocurrent data from Victoria Dam, Agate Falls and Wolverine Falls support the west-northwest drainage on the western end of the Jacobsville Sandstone (figure 42) as suggested by my provenance data. Once these rivers were west of any uplift along the Keweenaw fault they most likely drained northward into the central rift basin.

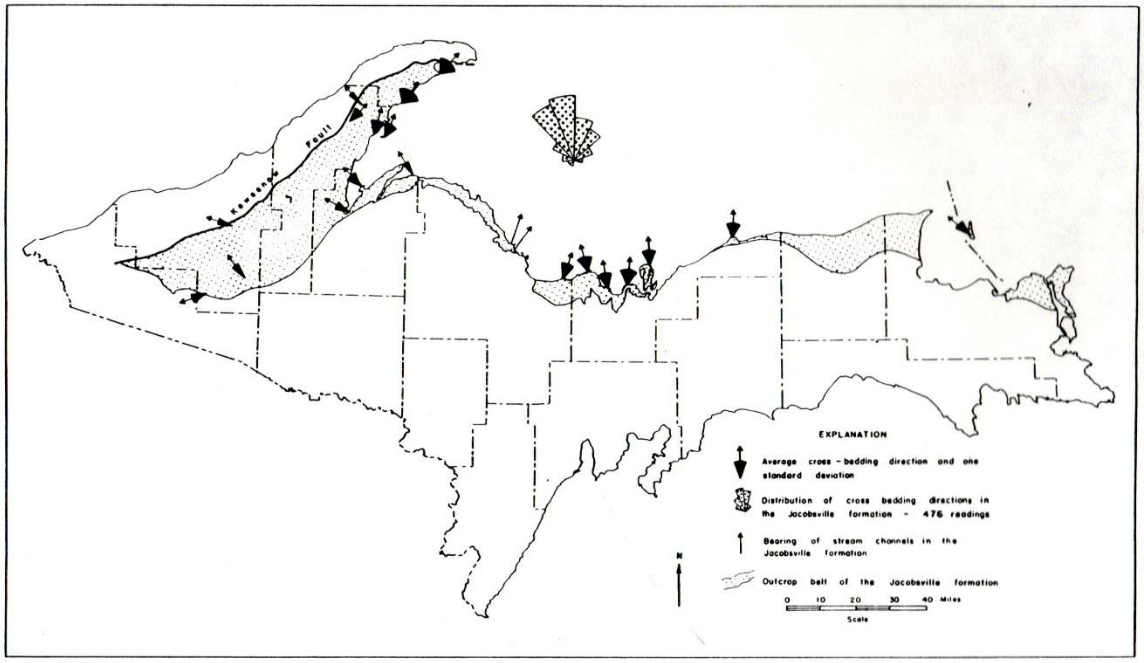


Fig. 42. Map illustrating paleocurrent directions from cross-bedding measurements (from Hamblin, 19 5B, fig. 29), The three western-most paleocurrent directions support the interpreted drainage basin shown in figure 41.

SUMMARY

The Jacobsville Sandstone was deposited in multiple basins, each undergoing varying degrees of compressional tectonic activity. One basin of Jacobsville Sandstone is west of Lake Gogebic and contains conglomerates throughout the stratigraphic section, dipping from 35 to 9 degrees to the north, and composed dominantly of iron-formation clasts. Another basin east of the lake contains only local basal conglomerate, dipping less than 10 degrees and composed of dominantly vein quartz or basalt clasts.

The composition of the Jacobsville Sandstone east of Lake Gogebic as determined by this study, in agreement with compositions determined by previous workers, indicates a southerly source except for a possible northerly source for the silicic lithics. The Jacobsville Sandstone west of Lake Gogebic is dominated by lithologies from a southerly source. The only lithologies from a northern source are sandstone, siltstone, and rhyolite.

Previous rift models for the Midcontinent rift system proposed that extensional tectonics continued throughout the deposition of the Oronto Group sediments. Daniels and Elmore (1988) even suggested that extensional tectonics continued throughout the deposition of the Jacobsville Sandstone. Data from this study supports an alternative interpretation that the Jacobsville Sandstone was deposited, at least in part, during a compressional tectonic regime. A lack of laterally continuous units, as well as steeper dips and coarser clast sizes west of Lake Gogebic all indicate a separate western basin controlled by uplift along a thrust fault south of the basin.

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APPENDIX I

TT1 grain size

Depth of sample (feet)	Average grain size (mm)	Wentworth size class
230	1.3	VC
330	.6	C
*430	.9	C
*530	1.2	VC
*730	.6	C
*930	.6	C
*1130	1.4	VC
*1300	1.4	VC
Average	1	C-VC

*Slide contained grains coarser than sand sized and were not included in grain size measurement.

TT6 grain size

Depth of sample (feet)	Average grain size (mm)	Sand size class
*205.5	1.3	VC
*307	.9	C
*407	.9	C
*607	1.4	VC
*826	1.0	C-VC
*1018	1.1	VC
1195	.5	M-C
1409	.6	C
1499	1.4	VC
1608	.5	M-C
*1797	1.3	VC
2013	.9	C
2103	.9	C
*2214	.9	C
*2407	.7	C
*2604	.6	C
2796	.7	C
Average	.9	C

*Slide contained grains coarser than sand sized and were not included in grain size measurement.

RL1 grain size

Depth of sample (feet)	Average grain size (mm)	Sand size class
96	.1	VF
245	.3	M
434	.7	C
625	.3	M
815	.2	F
1013	.6	C
1212	.4	M
*1373	.3	M
*1470	1.2	VC
1562	.8	C
1817	.4	M
1915	.6	C
2020	.6	C
*2223	.8	C
2387	.8	C
2641	.2	F
2736	.4	M
2842	.4	M
*3026	.7	C
3224	.5	M-C
3500	.8	C
3613	.4	M
Average	.5	M-C

*Slide contained grains coarser than sand sized and were not included in grain size measurement.

AE1 grain size

Depth of sample (feet)	Average grain size (mm)	Sand size class
220	.5	C
320	.6	C
420	.5	C
520	.5	M
620	.4	M
820	.8	C
1020	.4	M
1220	.4	M
1420	.4	M
1620	.2	F
1720	.3	M
1820	.4	M
2020	.1	VF
2120	.6	C
*2220	.7	C
Average	.4	M

*Slide contained grains coarser than sand sized and were not included in grain size measurement.

Outcrop West

Sample number	Average grain size (mm)	Wentworth size class
*3	1.2	VC
*6	1.0	C-VC
10	.9	C
*8	.9	C
*11	.6	C
2	1.0	C-VC
Average	.9	C

Outcrop East

Sample number	Average grain size (mm)	Wentworth size class
12	.4	M
14B	.2	F
15	.1	F
Average	.2	M-F

*Slide contained grains coarser than sand sized and were not included in grain size measurement.

APPENDIX II

Data in Percent

	TT1-1a-1	TT1-2	TT1-3	TT1-4	TT1-6	TT1-8	TT1-10	TT1-12
Depth	230	330	430	530	730	930	1130	1303
QFR (Data in percent total QFR)								
Qm	29.4	40.3	27.1	21.3	49.1	45.4	37.1	23.5
Qp	33.0	34.0	26.4	35.9	20.5	21.6	33.2	28.8
F	26.1	22.8	26.4	25.6	22.2	16.0	14.1	17.1
R	11.4	3.0	20.1	17.2	8.2	17.0	15.6	30.6
Qp (Data in percent of total QFR)								
Qp (total)	33.0	34.0	26.4	35.9	20.5	21.6	33.2	28.8
Q2-3	10.8	14.6	8.8	5.9	11.7	7.7	6.8	5.9
Q>3	22.2	19.0	17.6	30.0	8.8	13.4	26.3	22.9
Qchert	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Qchal	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0
Feldspar (Data in percent of total QFR)								
F (total)	26.1	22.8	26.4	25.6	22.2	16.0	14.1	17.1
K	26.1	22.8	26.4	25.6	19.9	16.0	12.7	17.1
P	0.0	0.0	0.0	0.0	1.2	0.0	0.5	0.0
?	0.0	0.0	0.0	0.0	1.2	0.0	1.0	0.0
ROCK FRAG. (Data in percent of total rock frag.)								
R (%QFR)	11.4	3.0	20.1	17.2	8.2	17	15.6	30.6
PLUTONIC	89.5		65.5	83.6	28.6	63.6	34.4	40.4
VOL-SI	0.0		5.5	1.8	0.0	0.0	9.4	0.0
VOL-MAFIC	0.0		0.0	0.0	7.1	0.0	3.1	0.0
META	5.3		20.0	12.7	28.6	21.2	34.4	55.8
SED	2.6		5.5	0.0	14.3	0.0	0.0	3.8
INDETERMINATE	2.6		3.6	1.8	21.4	15.2	18.8	0.0
TOTAL	100		100	100	100	100	100	100
MICA (Data in percent of total framework grains)								
M	0.3	6.0	8.5	0.0	8.1	2.4	5.1	6.7
OTHER (Data in percent of total framework grains)								
Other	2.3	4.0	2.6	2.4	10.9	19.4	14.8	21.8
Garnet	0.0	0.0	0.0	0.0	0.5	1.6	3.5	0.8
Staurolite	0.0	0.7	0.0	0.9	4.3	9.3	8.2	19.3
Mafic	0.0	0.0	0.3	0.0	0.0	0.4	0.8	0.0
Opaques	0.6	0.3	0.0	0.6	2.4	2.4	0.4	1.7
Indeterminate	1.8	3.0	2.3	0.9	3.8	4.8	1.2	0.0
Epidote/clino.	0.0	0.0	0.0	0.0	0.0	0.8	0.8	0.0
INTERSTITIAL (Data in percent of total counts)								
I	14.5	25.5	23.3	18.0	33.2	23.9	26.4	16.5
QFR (total counts)	333	268	273	320	171	194	205	170
FRAMEWORK (total counts)	342	298	307	328	211	248	256	238
TOTAL COUNTS (per slide)	400	400	400	400	316	326	348	285
%qfr (of total counts)	83.3	67.0	68.3	80.0	54.1	59.5	58.9	59.6
%framework (of total counts)	85.5	74.5	76.8	82.0	66.8	76.1	73.6	83.5

TT6 (Data in percent)

Depth	205	307	407	607	826	1018	1195	1409	1499
QFR (Data in percent of total QFR)									
Qm	23.7	29.2	30.5	28.5	32.7	37.2	50.4	44.8	20.8
Qp	28.0	20.5	28.1	23.8	22.1	27.8	24.6	24.2	29.2
F	32.3	30.5	32.8	30.9	25.1	17.6	12.1	17.3	15.2
R	16.0	19.8	8.6	16.7	20.5	17.3	12.9	13.7	34.7
Qp (Data in percent of total QFR)									
Qp (total)	28.0	20.5	28.1	23.8	22.1	27.9	24.6	24.2	29.2
Q2-3	10.3	4.7	16.4	7.4	4.0	7.4	8.8	10.8	8.8
Q>3	17.3	15.1	11.7	16.4	18.1	19.9	13.2	13.4	20.1
Qchert	1.1	1.1	0.0	0.0	0.0	1.1	3.4	0.0	0.0
Qchal	0.0	0.3	0.0	0.0	0.0	0.3	1.5	0.0	0.3
FELDSPAR (Data in percent of total QFR)									
F (total)	32.3	30.5	32.8	31.0	25.1	17.6	12.1	17.3	15.3
K	25.7	18.5	24.2	21.7	22.1	17.6	12.1	15.9	14.6
P	4.3	7.4	6.3	8.4	0.0	0.0	0.0	1.4	0.0
?	8.0	16.1	6.9	3.4	6.9	0.0	0.0	0.0	2.3
ROCK FRAG. (Data in percent of total rock frag.)									
R (%QFR)	16.0	19.8	8.6	16.7	20.5	17.3	12.9	13.7	34.7
PLUTONIC	87.5	71.2	86.4	88.9	73.2	50.0	28.6	47.4	63.6
VOL-SI	2.1	0.0	0.0	0.0	0.0	0.0	5.7	2.6	0.0
VOL-MAFIC	0.0	0.0	0.0	1.9	0.0	7.4	11.4	10.5	11.2
META	8.3	23.7	4.5	7.4	24.4	7.4	8.6	13.2	19.6
SED	0.0	0.0	0.0	1.9	0.0	0.0	2.9	0.0	0.9
INDETERMINATE	2.1	5.1	9.1	0.0	2.4	35.2	42.9	26.3	4.7
Total	100	100	100	100	100	100	100	100	100
MICA (Data in percent of total framework grains)									
M	1.5	1.6	4.3	6.0	2.7	1.2	3.2	4.4	3.9
OTHER (Data in percent of total framework grains)									
Other	6.2	3.5	16.1	5.2	37.3	6.8	8.4	8.8	4.2
Garnet	0.9	1.3	8.1	1.9	4.2	2.9	1.3	1.3	0.6
Staurolite	4.0	1.0	4.7	1.4	32.8	0.9	1.0	0.9	2.1
Mafic	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Opaques	0.3	0.3	0.3	0.0	0.3	0.6	1.6	0.6	0.6
Indeterminate	0.9	0.3	1.2	1.4	0.3	2.1	4.2	3.4	0.9
Epidote/clino.	0.0	0.6	1.6	0.5	0.0	0.3	0.3	2.5	0.0
INTERSTITAL (Data in percent of total counts)									
I	18.8	21.5	19.5	9.0	17.0	15.3	23.2	20.3	16.3
QFR(total counts)	300	298	256	323	199	312	272	277	308
FRAMEWORK (total counts)	325	314	322	364	332	339	308	319	335
TOTAL COUNTS (per slide)	400	400	400	400	401	400	401	400	400
%qfr	75.0	74.5	64.0	80.8	49.6	78.0	67.8	69.3	77.0
%framework (of total counts)	81.3	78.5	80.5	91.0	82.8	84.8	76.8	79.8	83.8

TT6 (data in percent)

Depth	1608	1797	2013	2103	2214	2407	2604	2796
QFR (Data in perce								
Qm	41.8	33.1	35.3	23.7	35.8	43.5	36.0	29.2
Qp	26.4	39.0	24.4	40.1	33.6	26.5	26.0	29.2
F	14.4	11.5	18.6	15.6	22.3	20.7	20.7	12.9
R	17.4	16.4	21.8	20.6	8.4	9.2	17.3	28.8
Qp (Data in percen								
Qp (total)	26.4	39.0	24.4	40.1	33.6	26.5	26.0	29.2
Q2-3	8.7	6.6	6.1	8.9	6.9	10.2	8.3	10.0
Q>3	15.7	31.7	17.3	28.4	26.3	16.3	17.3	18.3
Qchert	5.7	2.3	2.3	5.7	0.0	0.0	1.1	0.0
Qchal	0.3	0.0	0.3	0.8	0.4	0.0	0.0	0.8
FELDSPAR (Data in								
F (total)	14.4	11.5	18.6	15.6	22.3	20.7	20.7	12.9
K	14.0	11.5	18.6	10.1	22.3	20.7	20.7	9.2
P	0.3	0.0	0.0	2.3	0.0	0.0	0.0	2.1
?	0.0	0.0	0.0	9.2	0.0	0.0	0.0	4.6
ROCK FRAG. (Data								
R (%QFR)	17.4	16.4	21.8	20.6	8.4	9.2	17.3	28.8
PLUTONIC	17.3	21.3	54.4	45.3	56.5	81.5	50.0	20.3
VOL-SI	7.7	4.3	1.5	0.0	0.0	3.7	0.0	1.4
VOL-MAFIC	17.3	14.9	10.3	9.4	0.0	0.0	1.9	36.2
META	30.8	23.4	22.1	22.6	13.0	7.4	38.5	24.6
SED	1.9	2.1	0.0	0.0	13.0	0.0	0.0	0.0
INDETERMINATE	25.0	34.0	11.8	22.6	17.4	7.4	9.6	17.4
Total	100	100	100	100	100	100	100	100
MICA (Data in perc								
M	3.8	1.5	6.2	7.0	4.0	5.6	8.6	4.6
OTHER (Data in per								
Other	8.0	12.3	1.5	3.5	12.5	3.7	2.7	10.9
Garnet	0.3	3.3	0.3	1.4	3.7	0.3	0.3	1.4
Staurolite	1.5	4.2	0.6	0.7	5.2	1.2	0.0	4.2
Mafic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
Opaques	0.6	0.9	0.3	0.3	0.6	0.0	0.0	1.8
Indeterminate	4.4	2.4	0.3	1.0	3.0	1.2	1.5	2.8
Epidote/clino.	1.2	1.5	0.0	0.0	0.0	0.9	0.9	0.0
INTERSTITAL (Data								
I	15.3	16.8	15.5	28.3	18.0	19.0	15.5	29.0
QFR(total counts)	299	287	312	257	274	294	300	240
FRAMEWORK (total counts)	339	333	338	287	328	324	338	284
TOTAL COUNTS (per slide)	400	400	400	400	400	400	400	400
%qfr	74.8	71.8	78.0	64.3	68.5	73.5	75.0	60.0
%framework	84.8	83.3	84.5	71.8	82.0	81.0	84.5	71.0

			RL1 percent data					RL1 (percent)	
	RL1-5	RL1-17	RL1-33	RL1-54	RL1-79	RL1-105	RL1-131	RL1-152	RL1-165
depth	96	245	434	625	815	1013	1212	1373	1470
QFR (Data in percent total QFR)									
Qm	67.4	68.1	44.9	56.8	76.3	61.1	77.9	62.4	28.3
Qp	5.3	8.0	27.1	11.7	4.2	14.4	13	13.2	46.6
F	23.9	20.6	22.8	24.8	19.1	21.8	8.8	20.1	17.4
R	3.3	3.4	5.3	6.6	0.4	2.7	0.3	4.2	7.7
Qp (Data in percent of total QFR)									
Qp (total)	5.3	8.0	27.1	11.7	4.2	14.4	13.0	13.2	46.6
Q2-3	2.7	5.5	12.2	7.1	2.7	6.9	5.7	4.4	11.7
Q>3	2.3	2.5	14.9	4.3	1.5	6.9	6.3	7.5	34.3
Qchert	0.3	0.0	0.0	0.3	0.0	0.6	0.6	0.6	0.6
Qchal	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.6	0.0
FELDSPAR (Data in percent of total QFR)									
F (total)	23.9	20.6	22.8	24.9	19.1	21.9	8.8	20.1	17.4
K	15.9	19.3	18.8	21.1	14.9	14.4	8.5	14.7	17.4
P	5.3	0.3	4.0	3.7	4.2	5.7	0.3	5.3	0.0
?	2.7	0.9	0.0	0.0	0.0	1.8	0.0	0.0	0.0
ROCK FRAG. (Data in percent of total rock frag.)									
R (%QFR)	3.3	3.4	5.3	6.6	0.4	2.7	0.3	4.2	7.7
PLUTONIC			68.8	4.3					51.9
VOL-SI			18.8	78.3					33.3
VOL-MAFIC			0.0	0.0					0.0
META			6.3	8.7					7.4
SED			6.3	4.3					0.0
INDETERMINATE			0.0	4.3					7.4
TOTAL			100.0	100.0					100.0
MICA (Data in percent of total framework grains)									
M	3.8	0.0	0.3	0.3	15.1	2.9	0.0	2.7	0.3
OTHER (Data in percent of total framework grains)									
Other	1.6	5.2	0.3	2.0	2.5	0.6	0.6	3.2	0.6
Garnet	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.6	0.0
Staurolite	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0
Mafic	0.0	0.0	0.0	0.3	0.0	0.0	0.3	0.0	0.0
Opaques	0.3	2.9	0.0	0.6	1.9	0.3	0.0	1.2	0.6
Indeterminate	1.3	1.2	0.3	1.1	0.0	0.0	0.3	1.2	0.0
Epidote/clino.	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.3	0.0
INTERSTITIAL (Data in percent of total counts)									
I	20.5	14.0	23.8	10.5	20.5	13.5	16.8	15.3	11.8
QFR (total counts)	301	326	303	350	262	334	331	319	350
FRAMEWORK (total counts)	318	344	305	358	318	346	333	339	353
TOTAL COUNTS (per slide)	400	400	400	400	400	400	400	400	400
%qfr (of total counts)	75.3	81.5	75.8	87.5	65.5	83.5	82.8	79.8	87.5
%framework (of total counts)	79.5	86.0	76.3	89.5	79.5	86.5	83.3	84.8	88.3

RL1 (percent)

	RL1-175	RL1-202	RL1-212	RL1-223	RL1-244	RL1-261	RL1-285	RL1-293	RL1-302
depth	1562	1817	1915	2020	2223	2387	2641	2736	2842
QFR (Data in perce									
Qm	43.3	50.7	43.5	41.1	38.4	38.3	42.8	71.3	53.9
Qp	26.7	13.3	18.9	26.7	22.0	26.8	12.9	11.7	22.5
F	27.9	32.6	27.6	24.9	30.5	28.8	39.5	9.9	15.7
R	2.1	3.3	9.9	7.3	9.0	6	4.8	7.1	7.8
Qp (Data in percen									
Qp (total)	26.7	13.3	18.9	26.7	22.0	26.8	12.9	11.7	22.5
Q2-3	10.7	10.4	5.1	9.1	12.4	12.1	7.4	3.4	13.4
Q>3	16.0	2.6	13.2	15.5	9.3	14.7	4.1	6.5	8.2
Qchert	0.0	0.4	0.3	2.1	0.0	0.0	1.5	1.2	1.0
Qchal	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.6	0.0
FELDSPAR (Data in									
F (total)	27.9	32.6	27.6	24.9	30.5	28.8	39.5	9.9	15.7
K	23.7	17.0	13.2	16.7	14.1	20.2	21.0	8.0	12.7
P	4.2	15.6	12.3	8.2	16.4	8.6	18.5	0.6	2.9
?	0.0	0.0	2.1	0.0	0.0	0.0	0.0	1.2	0.0
ROCK FRAG. (Data i									
R (%QFR)	2.1	3.3	9.9	7.3	9.0	6	4.8	7.1	7.8
PLUTONIC			75.8	36.0	59.4	81.0	0.0	13.0	8.3
VOL-SI			12.1	16.0	18.8	9.5	84.6	34.8	45.8
VOL-MAFIC			0.0	0.0	0.0	0.0	0.0	0.0	0.0
META			12.1	40.0	9.4	4.8	7.7	26.1	29.2
SED			0.0	8.0	6.3	0.0	0.0	17.4	8.3
INDETERMINATE			0.0	0.0	6.3	4.8	7.7	8.7	8.3
TOTAL			100.0	100.0	100.0	100.0	100.0	100.0	100.0
MICA (Data in perc									
M	1.7	3.7	0.3	1.9	3.4	0.6	11.6	0.3	8.2
OTHER (Data in per									
Other	0.6	6.6	4.0	3.3	2.9	0.6	7.5	1.5	4.8
Garnet	0.0	0.0	0.3	0.0	0.3	0.0	0.0	0.0	0.0
Staurolite	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0
Mafic	0.0	0.7	0.0	0.0	0.0	0.0	0.3	0.0	0.0
Opaques	0.3	3.0	1.4	0.6	0.8	0.0	4.5	0.3	1.4
Indeterminate	0.0	1.3	0.9	1.1	0.8	0.6	2.1	0.9	2.6
Epidote/clino.	0.3	1.7	1.1	1.7	1.1	0.0	0.6	0.3	0.9
INTERSTITIAL (Data									
I	13.8	24.8	13.0	10.0	5.5	12.3	16.3	17.5	10.0
QFR (total counts)	337	270	333	341	354	347	271	324	306
FRAMEWORK (total counts)	345	301	348	360	378	351	335	330	352
TOTAL COUNTS (per slide)	400	400	400	400	400	400	400	400	391
%qfr (of total counts)	84.3	67.5	83.3	85.3	88.5	86.8	67.8	81.0	78.3
%framework (of total counts)	86.3	75.3	87.0	90.0	94.5	87.8	83.8	82.5	90.0

	RL1-318	RL1-335	RL1-354	RL1-369
depth	3026	3224	3524	3613
QFR (Data in perce				
Qm	45.6	55.4	53.5	65
Qp	29.6	21.8	18.8	9.2
F	15.4	14.8	17.9	12.6
R	9.4	8	9.8	13.3
Qp (Data in percen				
Qp (total)	29.6	21.8	18.8	9.2
Q2-3	14.8	8.6	8.4	2.0
Q>3	13.3	12.3	9.2	6.5
Qchert	0.9	0.3	0.8	0.7
Qchal	0.6	0.6	0.3	0.0
FELDSPAR (Data in				
F (total)	15.4	14.8	17.9	12.6
K	13.9	14.8	16.0	9.5
P	1.5	0.0	1.4	2.4
?	0.0	0.0	0.5	0.7
ROCK FRAG. (Data i				
R (%QFR)	9.4	8	9.8	13.3
PLUTONIC	54.8	15.4	33.3	15.4
VOL-SI	19.4	53.8	22.2	38.5
VOL-MAFIC	0.0	0.0	0.0	0.0
META	3.2	11.5	19.4	25.6
SED	16.1	11.5	13.9	12.8
INDETERMINATE	6.5	7.7	11.1	7.7
TOTAL	100.0	100.0	100.0	100.0
MICA (Data in perc				
M	0.9	0.0	0.3	1.8
OTHER (Data in per				
Other	2.3	1.5	5.6	8.3
Garnet	0.3	0.0	0.5	0.6
Staurolite	0.0	0.0	0.0	0.0
Mafic	0.0	0.0	0.3	0.0
Opaques	1.2	0.6	3.3	7.0
Indeterminate	0.9	0.9	0.8	0.0
Epidote/clino.	0.0	0.0	0.8	0.6
INTERSTITIAL (Data				
I	14.5	17.5	2.3	19.0
QFR (total counts)	331	325	368	294
FRAMEWORK (total counts)	342	330	391	327
TOTAL COUNTS (per slide)	400	400	400	400
%qfr (of total counts)	82.8	81.3	92.0	73.5
%framework (of total counts)	85.5	82.5	97.8	81.8

				AE1 (percent)				
	AE1-1	AE1-2	AE1-3	AE1-4	AE1-5	AE1-7	AE1-9	AE1-11
Depth	220	320	420	520	620	820	1020	1220
Qm	53.9	55.2	52.8	81.9	70.7	60.7	70.3	77.1
Qp	16	19.1	18.2	14.9	17.4	22.3	13.2	10.4
F	16	16	14.4	1.8	10.0	13.8	14.2	12.5
R	14	9.7	14.7	1.5	1.9	3.1	2.3	0.0
Qp (Data in percent of total QFR)								
Qp (total)	16.0	19.1	18.2	14.9	17.4	22.3	13.2	10.4
Q2-3	3.7	6.3	6.7	5.6	9.6	9.1	7.9	4.1
Q>3	11.2	12.5	10.3	9.1	7.7	13.2	5.3	6.4
Qchert	1.1	0.3	0.6	0.0	0.0	0.0	0.0	0.0
Qchal	0.0	0.0	0.6	0.3	0.0	0.0	0.0	0.0
Feldspar (Data in percent of total QFR)								
F (total)	16.0	16.0	14.4	1.8	10.0	13.8	14.2	12.5
K	13.8	14.7	13.8	1.8	10.0	13.8	11.6	12.5
P	0.0	0.3	0.0	0.0	0.0	0.0	0.3	0.0
?	2.3	0.9	0.6	0.0	0.0	0.0	2.3	0.0
ROCK FRAG. (Data in percent of total rock frag.)								
R (%QFR)	14	9.7	14.7	1.5	1.9	3.1	2.3	0.0
PLUTONIC	12.2	6.5	4.0					
VOL-SI	73.5	61.3	56.0					
VOL-MAFIC	0.0	0.0	0.0					
META	6.1	16.1	22.0					
SED	0.0	3.2	6.0					
INDETERMINATE	8.2	12.9	12.0					
TOTAL	100	100	100					
MICA (Data in percent of total framework grains)								
M	0.0	0.0	0.0	0.0	0.3	2.4	1.3	0.0
OTHER (Data in percent of total framework grains)								
Other	0.3	1.2	0.3	0.0	1.0	0.6	0.6	0.3
Garnet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Staurolite	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mafic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Opaques	0.0	0.3	0.3	0.0	0.0	0.0	0.6	0.0
Indeterminate	0.3	0.9	0.0	0.0	1.0	0.6	0.0	0.3
Epidote/clino.	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INTERSTITIAL (Data in percent of total counts)								
I	12.5	19.3	14.5	14.5	21.3	18.0	22.8	13.5
QFR(total) counts)	349	319	341	342	311	318	303	345
FRAMEWORK (total counts)	350	323	342	342	315	328	309	346
TOTAL COUNTS (per slide)	400	400	400	400	400	400	400	400
%qfr (total counts)	87.3	79.8	85.3	85.5	77.8	79.5	75.8	86.3
%Framework (total counts)	87.5	80.8	85.5	85.5	78.8	82.0	77.3	86.5

	AE1 percent						
	AE1-13	AE1-15	AE1-16	AE1-17	AE1-19	AE1-20	AE1-21
Depth	1420	1620	1720	1820	2020	2120	2220
Qm	74.1	85.3	73.5	73.1	73.8	50.7	35.2
Qp	8.9	1.3	8.5	15.3	6.2	26.8	30.2
F	15.3	12.9	17	10.3	19	17.9	14.5
R	1.6	0.6	1	1.2	0.9	4.6	20.1
Qp (Data in percen							
Qp (total)	8.9	1.3	8.5	15.3	6.2	26.8	30.2
Q2-3	6.7	1.3	5.4	8.1	2.2	10.3	9.4
Q>3	2.2	0.0	3.2	7.2	3.1	16.2	20.8
Qchert	0.0	0.0	0.0	0.0	0.9	0.3	0.0
Qchal	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Feldspar (Data in							
F (total)	15.3	12.9	17.0	10.3	19.0	17.9	14.5
K	15.3	12.9	14.8	6.9	16.5	15.9	13.8
P	0.0	0.0	1.3	1.6	0.0	0.0	0.0
?	0.0	0.0	0.9	1.9	2.5	2.0	0.6
ROCK FRAG. (Data							
R (%QFR)	1.6	0.6	1	1.2	0.9	4.6	20.1
PLUTONIC						71.4	53.1
VOL-SI						7.1	0.0
VOL-MAFIC						0.0	0.0
META						21.4	43.8
SED						0.0	0.0
INDETERMINATE						0.0	3.1
TOTAL						100	100
MICA (Data in perc							
M	0.6	0.0	1.2	0.0	2.1	1.6	0.6
OTHER (Data in per							
Other	2.5	0.9	1.2	3.0	1.5	4.7	0.6
Garnet	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Staurolite	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mafic	0.0	0.0	0.0	0.0	0.0	0.9	0.0
Opaques	1.2	0.9	0.0	1.8	1.5	1.2	0.0
Indeterminate	1.2	0.0	1.2	1.2	0.0	2.5	0.6
Epidote/clino.	0.0	0.0	0.0	0.0	0.0	0.0	0.0
INTERSTITIAL (Data							
I	19.3	19.5	18.8	17.5	16.8	19.5	24.4
QFR(total) counts)	313	319	317	320	321	302	159
FRAMEWORK (total counts)	323	322	325	330	333	322	161
TOTAL COUNTS (per slide)	400	400	400	400	400	400	213
%qfr (total counts)	78.3	79.8	79.3	80.0	80.3	75.5	74.6
%Framework (total counts)	80.8	80.5	81.3	82.5	83.3	80.5	75.6

OUTCROP SAMPLES (percent)

	CH-91-3	West CH-91-6	CH-91-10	CH-91-8	CH-91-11	CH-91-2
QFR (Data in percent of total QFR)						
Qm	21.5	21.8	42.8	39.7	31.4	28.6
Qp	30.2	35.3	33.1	30.8	30.4	18.2
F	35.4	32.2	17.9	15.7	27.8	39.0
R	12.9	10.7	6.2	13.8	10.4	14.3
Qp (Data in percent of total QFR)						
Qp (total)	30.2	35.3	33.1	30.8	30.4	18.2
Q2-3	13.2	12.6	17.2	9.0	7.7	8.9
Q>3	16.7	22.4	15.9	21.8	22.4	9.2
Qchert	0.3	0.3	0.0	0.0	0.3	0.0
Qchal	0.0	0.0	0.0	0.0	0.0	0.0
Feldspar (Data in percent of total QFR)						
F (total)	35.4	32.2	17.9	15.7	27.8	39.0
K	35.4	32.2	17.9	15.4	27.1	39.0
P	0.0	0.0	0.0	0.0	0.3	0.0
?	0.0	0.0	0.0	0.3	0.3	0.0
ROCK FRAG, (Data in percent of total rock frag.)						
R (%QFR)	12.9	10.7	6.2	13.8	10.4	14.3
PLUTONIC	82.5	94.1	72.2	88.4	64.5	97.9
VOL-SI	2.5	2.9	0.0	0.0	3.2	0.0
VOL-MAFIC	0.0	0.0	0.0	0.0	6.5	0.0
META	0.0	0.0	22.2	9.3	22.6	0.0
SED	15.0	0.0	5.6	0.0	0.0	0.0
INDETERMINANT	0.0	2.9	0.0	2.3	3.2	2.1
TOTAL	100	100	100	100	100	100
MICA (Data in percent of total framework grains)						
M	0.9	2.1	2.9	2.4	0.0	0.6
OTHER (Data in percent of total framework grains)						
Other	3.7	2.1	3.9	3.3	1.3	2.6
Garnet	0.0	0.0	0.0	0.0	0.0	0.0
Staurolite	0.0	0.0	1.0	0.9	0.0	0.0
Mafic	0.0	0.0	0.0	0.0	0.0	0.0
Opaques	2.1	1.2	1.0	1.5	0.0	0.0
Indeterminate	1.5	0.9	1.9	0.9	1.3	2.6
Epidote/clino.	0.0	0.0	0.0	0.0	0.0	0.0
INTERSTITIAL (Data in percent of total counts)						
I	18.5	17.3	22.3	17.3	24.3	13.3
QFR (total) counts)	311	317	290	312	299	336
FRAMEWORK (total counts)	326	331	311	331	303	347
TOTAL COUNTS (per slide)	400	400	400	400	400	400
%qfr (of total counts)	77.8	79.3	72.5	78.0	74.8	84.0
%framework (of total counts)	81.5	82.8	77.8	82.8	75.8	86.8

OUTCROP SAMPLES (percent)
East

	CH-91-12	CH-91-14B	CH-91-15
QFR (Data in perce			
Qm	67.5	64.9	73.7
Qp	10.8	9.8	6.4
F	18.6	20.6	19.3
R	3.1	4.7	0.6
Qp (Data in percen			
Qp (total)	10.8	9.8	6.4
Q2-3	4.7	4.4	3.7
Q>3	5.8	5.4	2.8
Qchert	0.3	0.0	0.0
Qchal	0.0	0.0	0.0
Feldspar (Data in			
F (total)	18.6	20.6	19.3
K	18.1	18.9	18.7
P	0.0	0.3	0.0
?	0.5	1.4	0.6
ROCK FRAG, (Data			
R (%QFR)	3.1	4.7	0.6
PLUTONIC		21.4	
VOL-SI		0.0	
VOL-MAFIC		0.0	
META		35.7	
SED		0.0	
INDETERMINANT		42.9	
TOTAL		100	
MICA (Data in perc			
M	0.0	4.1	0.3
OTHER (Data in per			
Other	0.0	3.4	2.7
Garnet	0.0	0.0	0.0
Staurolite	0.0	0.0	0.0
Mafic	0.0	0.3	0.0
Opaques	0.0	0.3	1.2
Indeterminate	0.0	2.8	1.5
Epidote/clino.	0.0	0.0	0.0
INTERSTITIAL (Data			
I	4.8	20.0	15.8
QFR (total) counts)	381	296	327
FRAMEWORK (total counts)	381	320	337
TOTAL COUNTS (per slide)	400	400	400
%qfr (of total counts)	95.3	74.0	81.8
%framework	95.3	80.0	84.3