

PETROLOGY AND PETROFABRICS OF THE
JACOBSTOWN SANDSTONE IN THE VICINITY OF THE
KEWEENAW FAULT

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ABSTRACT

PETROLOGY AND PETROFABRICS OF THE JACOBSTOWN SANDSTONE IN THE VICINITY OF THE KEWEENAW FAULT

By Ann E. Cascaddan

The Jacobstown sandstone has been brought into contact with the Portage Lake lava series by displacement along the Keweenaw fault. At many locations the originally horizontal sandstone has been thrust into a vertical position or even overturned by forces associated with the faulting.

Sandstone outcrops were sampled at varying distances from the actual fault contact and petrographic and petrofabric studies were made on thin sections prepared from the samples.

The results showed that there is: 1) a sedimentary fabric which is represented, in most cases, by a girdle in the bedding plane, 2) a weak BC girdle, 3) an AB girdle, often quite well defined, and 4) the suggestion, in a few diagrams, of an AC girdle.

It is postulated that the sedimentary fabric is an original depositional fabric and the remaining fabrics are the result of forces associated with the faulting.

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SANDSTONE IN THE VICINITY OF THE KEWEENAW FAULT

By
Ann E. Cascaddan

A THESIS

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INTRODUCTION

The Jacobsville sandstone has been studied extensively by several investigators in an effort to determine its age and stratigraphic position. Its relationship to the Keweenaw fault has also been noted and theories have been advanced as to how the faulting caused the disturbance of the sandstone.

Although several petrofabric analyses have been made on quartzites adjacent to major and/or minor faults in order to determine the nature of the stresses associated with the faulting, there have been no similar studies on non-recrystallized materials associated with faults. It is the purpose of this thesis to make a petrofabric study of samples of the Jacobsville sandstone taken at various distances from the Keweenaw fault in an effort to determine what effect, if any, the forces associated with this major fault had on the fabric of the sandstone. Even if the study did not reveal much about the nature of the faulting, or forces associated with the faulting, it was hoped by the author that it would be possible to determine whether or not a fabric, either sedimentary or tectonic, would develop in material which had not been recrystallized.

Geography

The studied areas are located in the Keweenaw Peninsula and, for the most part, in Houghton County along the Keweenaw fault. Samples were also taken near

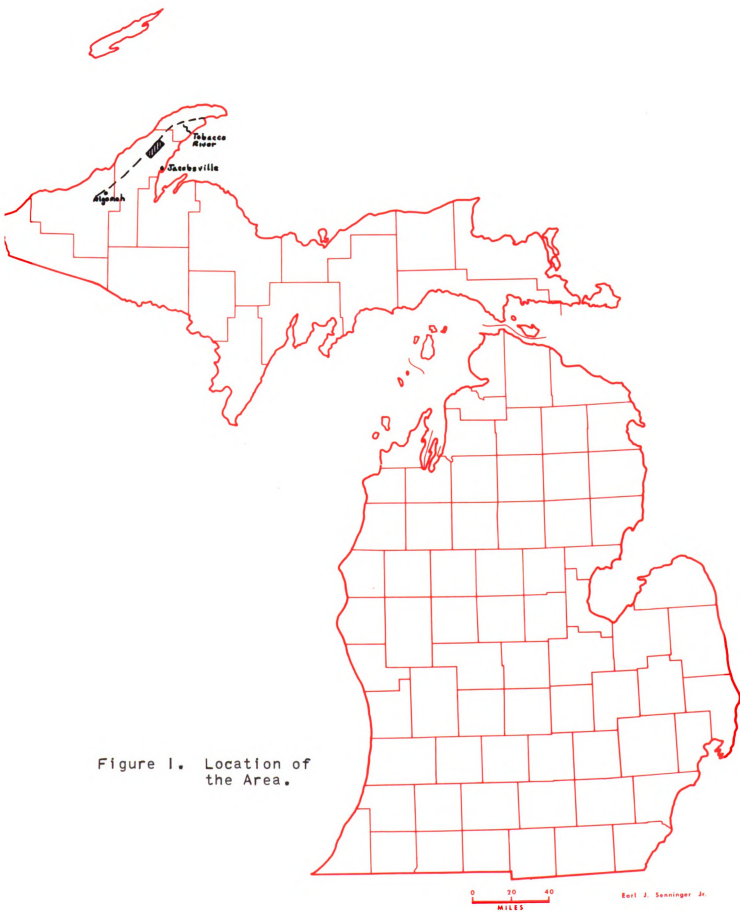
the Algoma mine, which is located $1\frac{1}{2}$ miles east of Mass, Michigan, and from the Tobacco River in Keweenaw County (Figure 1). The general area is extensively covered by glacial deposits, and the best sandstone outcrops are found in deep ravines which have been cut by streams flowing over the Keweenaw fault.

Previous Investigations

Although the Natural Wall (page 15) has attracted the attention of geologists for years, there have been very few detailed studies of the structural features of the Jacobsville sandstone and their relationship to the Keweenaw fault. Irving and Chamberlin (1885) wrote the first definitive descriptive work of areas along the fault contact, incorporating into their paper the observations of earlier investigators. From their observations of the actual junction of the Jacobsville (Eastern) sandstone and the Keweenaw fault, and of the nature of the disturbances in the sandstone adjacent to the fault, Irving and Chamberlin concluded that:

"The Keweenaw Series is much older than the Eastern (Potsdam) Sandstone; that it was upturned, faulted along the escarpment, and much eroded before the deposition of the Eastern Sandstone; that the sandstone was laid down unconformably against and upon the Keweenaw Series which stood as a sea cliff in the Potsdam Seas; and that subsequently minor faulting along the old line ensued, disturbing the contact edge of the sandstone." (1)

1) Irving, R. D., and Chamberlin, T. C., "Observations on the Junction Between the Eastern Sandstone and the Keweenaw Series on Keweenaw Point, Lake Superior", United States Geological Survey, Bulletin 23, 1885, page 480.



Hamblin (1958) made a detailed study of the Jacobsville formation, including the structure, petrology, and heavy minerals in an effort to determine the geologic history of the area.

He found, as previous investigators, that the sandstone is relatively undisturbed except near the Keweenaw fault. Hamblin, however, dates the fault as post-Jacobsville partially on the basis of the predominant structural trends of the formation at Limestone Mountain. Here the Jacobsville sandstone and the Limestone Mountain sediments are folded into an anticline and syncline, the trends of which parallel the Keweenaw fault and suggest, to Hamblin, that the folding in the area is related to the compressional forces which caused the faulting. If this is true, then the Keweenaw fault is probably post-Devonian, since Devonian rocks are involved in the folding.

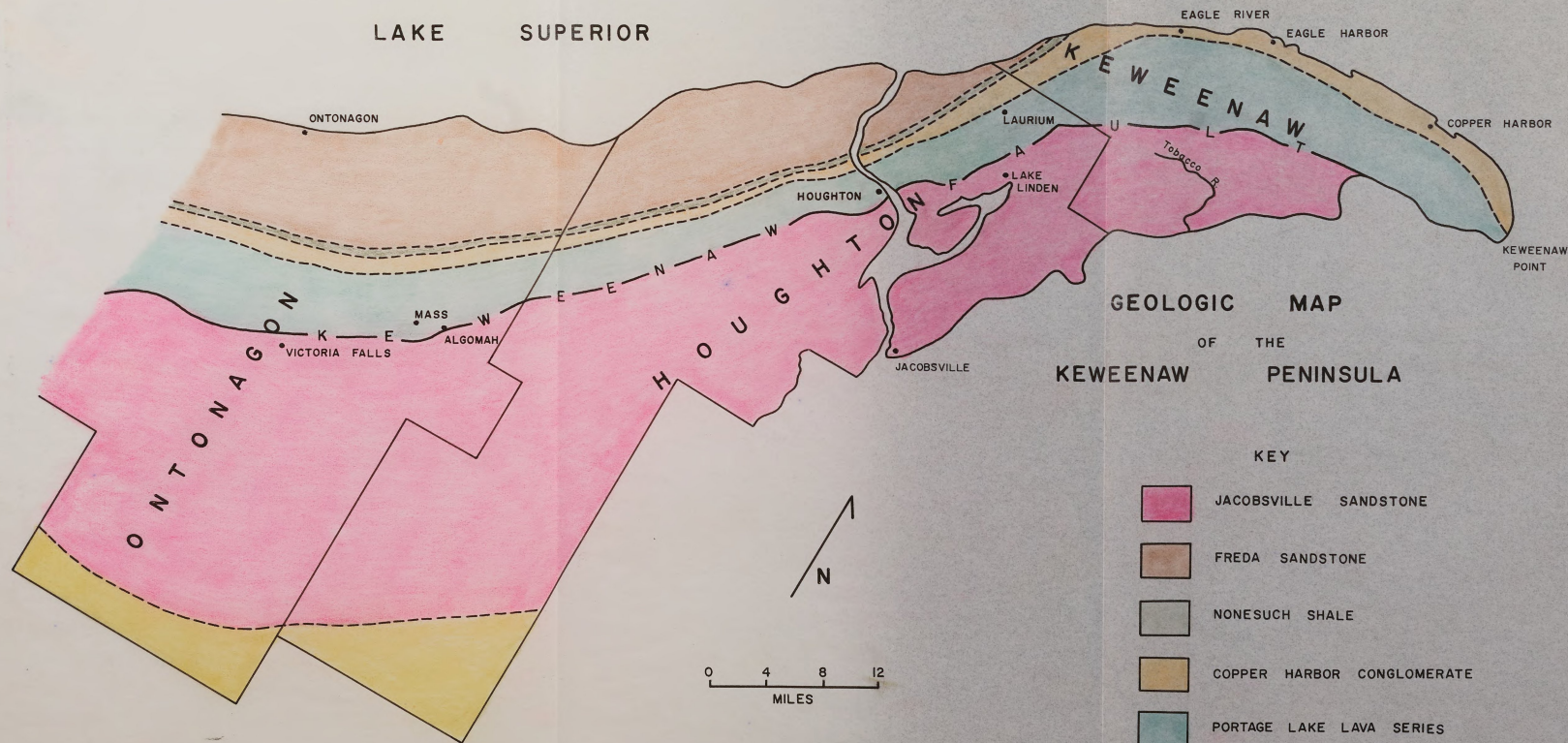
GENERAL GEOLOGY

Lithologic Setting

The stratigraphic sequence of the Keweenaw Peninsula is, from oldest to youngest; the Portage Lake lava series, which has been locally intruded by small rhyolite bodies, the Copper Harbor conglomerate, the Nonesuch shale, the Freda sandstone, and the Jacobsville sandstone. A generalized map of the Keweenawan geology is included as Figure 2.

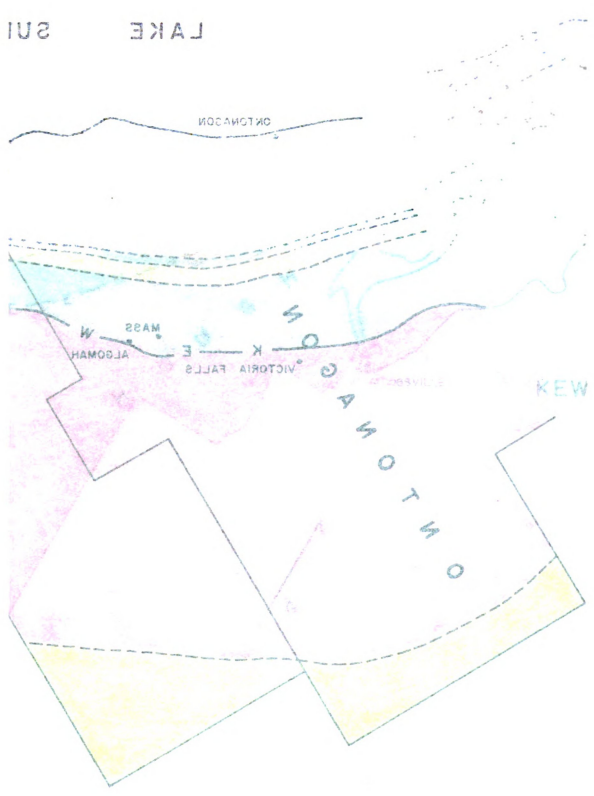
The Portage Lake lava series is a thick sequence of flows ranging in composition from olivine basalt to andesite. Individual flows vary in thickness from a few feet to over 1300 feet, and may extend from a few hundred feet to over forty miles in length along the strike. The flow tops are amygdaloidal, averaging five to ten feet in thickness. Many of the amygdules have been filled with calcite, epidote, and quartz. Interbedded with the flows are conglomerates with rhyolitic pebbles.

The Copper Harbor conglomerate overlies the Portage Lake lava series. This formation consists mainly of rounded to sub-angular rhyolitic pebbles and boulders, with minor quantities of basalt fragments. Matrix material is of similar composition. Sandstone lenses and fine-grained andesitic lava flows are interstratified with the conglomerate. The thin amygdaloidal tops of the lava flows have calcite, chlorite, and zeolite mineral fillings.



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LAKE



The Nonesuch shale is mainly siltstone. The upper part is a gray to reddish-gray siltstone with minor quantities of gray silty shale. The lower part is a dark gray siltstone with a few coarse-grained arkose beds near the base. Total thickness of this formation is about 600 feet.

The Freda is a light gray to red, fine to medium-grained sandstone with occasional interbedded red shale and conglomerate layers. The contact between the Nonesuch and the Freda is transitional. Total thickness of the Freda is approximately 500 feet.

The Jacobsville sandstone is primarily a buff or salmon colored, fine to medium-grained, well sorted sandstone with minor amounts of reddish-brown pebble conglomerate, red shale, and silty shale. Well rounded quartz grains averaging $\frac{1}{4}$ to $\frac{1}{2}$ millimeter in diameter are the main mineral constituent.

Four facies of this formation have been defined by Hamblin (1958).

1. Conglomerate facies. This facies is confined to the base of the formation. Well rounded and highly spherical felsite and granite porphyry clasts ranging from granules to boulder size are the main constituents. Minor quantities of diabase and amygdaloidal basalt pebbles are also included. Matrix material is a poorly cemented sandstone. Channel structures indicate that this is a fluvial deposit. This facies is well exposed in the Wall Ravine, where it was definitely shown, through heavy mineral studies, by

Hamblin, to be Jacobsville.

2. Lenticular sandstone facies. This facies is dominant in lateral and vertical extent. It is a red-brown, medium-grained, well sorted sandstone. Prominent sedimentary features include channel-and-fill structures and fluvial trough cross-stratification.

3. Massive sandstone facies. The massive sandstone facies is well exposed in many areas of the Keweenaw such as Victoria Falls, Hungarian Falls, and Keweenaw Bay Cliffs. Massive beds averaging five feet or more in thickness characterize this facies. The light red to white color of the sandstone may be related to its higher permeability and resultant greater leaching. Trough cross-stratification and oscillation ripple marks indicate that this facies formed in an environment changing from fluvial to lacustrine.

4. Red siltstone facies. The red siltstone facies is local in extent, with its best exposure north of Jacobsville. Sandstone interbedded with it indicates that this facies formed in an alternating fluvial and lacustrine environment.

Structural Setting

The Keweenaw Peninsula is on the southern side of the Lake Superior syncline of Keweenawan age. In a vertical cross-section, perpendicular to the strike, early Keweenawan rocks dip steeply (60°) and later ones progressively less steeply (down to 25°) northwestward to the center of the basin.

Transverse to the general strike of the Lake Superior syncline are broad (up to 100 miles across), open cross folds that plunge down the dip of the larger fold. Superimposed on these large folds are small (five to ten miles across) open folds of a similar nature and trend, although some are sub-parallel to the Keweenaw fault.

The Jacobsville sandstone is almost flat lying with a slight regional dip of one to six degrees to the northwest. This formation is relatively undeformed except in the vicinity of the Keweenaw fault and near Limestone Mountain where some folds have developed, possibly as a result of stresses associated with the faulting.

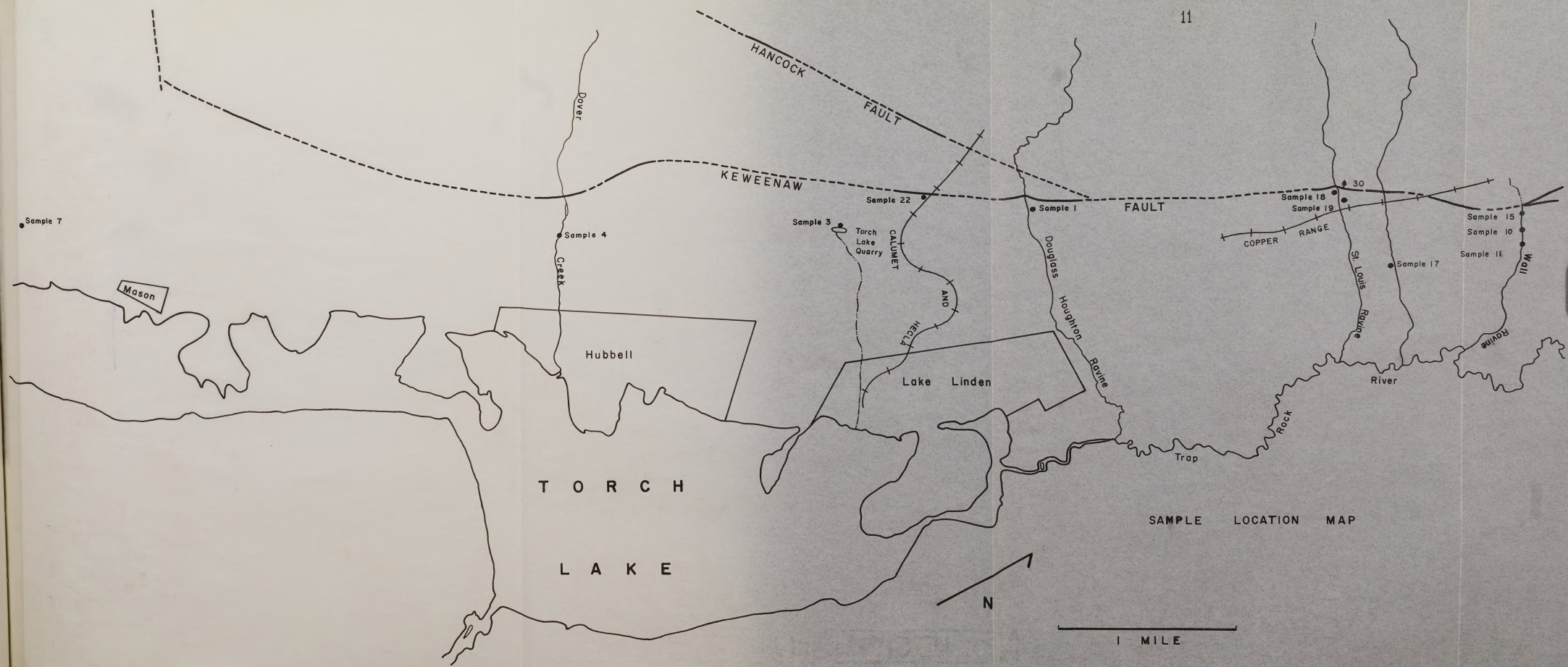
The greatest fault in the region is the Keweenaw fault. This is a reverse fault with a northeast strike and a variable dip of 20 to 70 degrees northwest, along which the lava flows have been thrust over the younger Jacobsville formation. In general, the northwestward dipping lava flows on the hanging-wall side of the fault are bent downward so that in places the dip is reversed. The flat lying sandstone on the footwall is turned up abruptly in a number of locations such as the Saint Louis Ravine and the Wall Ravine (Figure 3). In other locations the sandstone near the fault is relatively undisturbed with only minor warping evident.

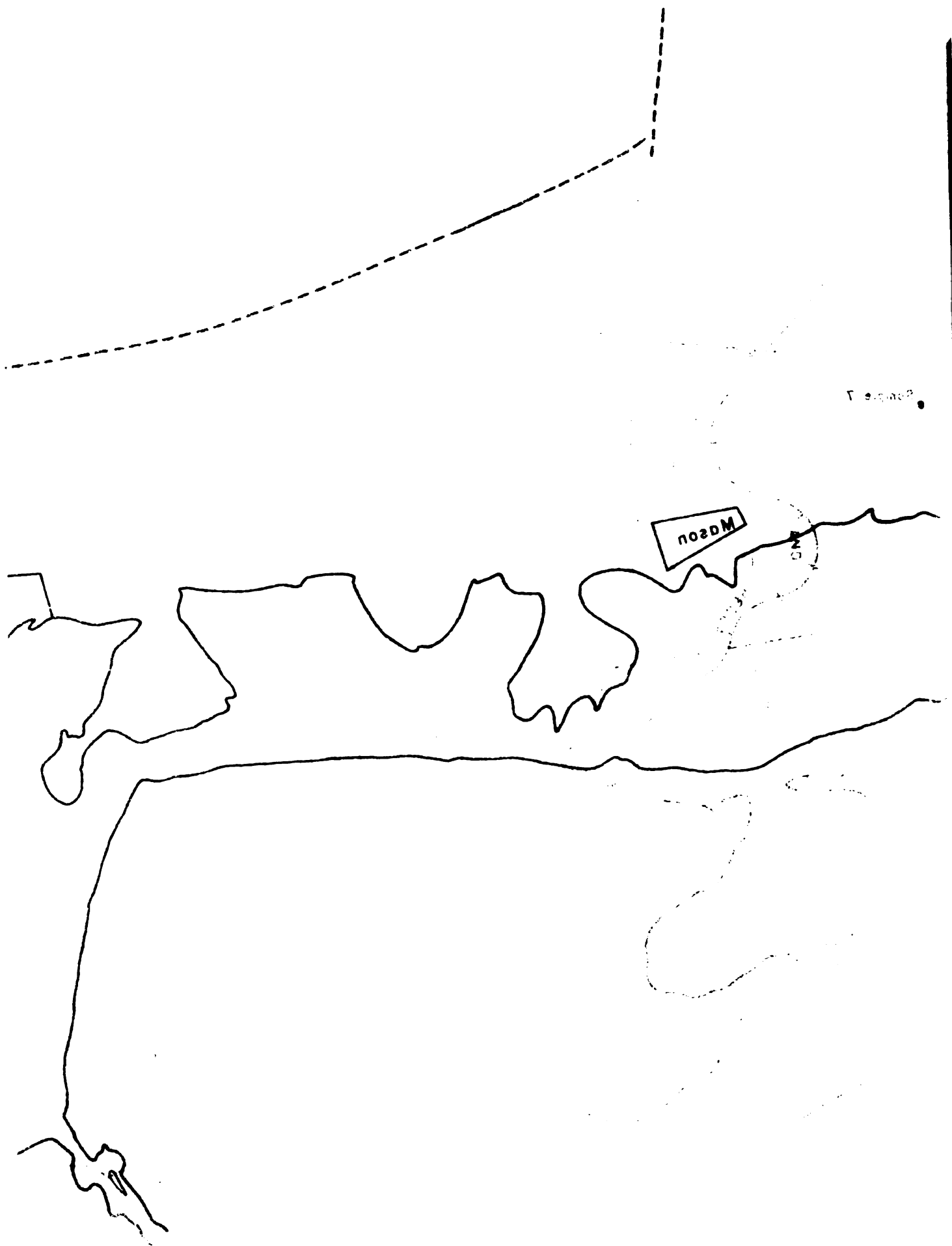
PROCEDURE

The field work for this study was accomplished in the summer of 1967. The Jacobsville sandstone was sampled at several locations along the Keweenaw fault, at varying distances from the actual fault contact (Figure 3).

The strike and dip of each sample was measured in the outcrop. The specimen was marked with a north arrow and horizontal lines and then detached from the outcrop.

Two perpendicular thin sections were cut from each sample. In each, the c-axis orientations of 200 small and 200 large quartz grains were measured using a Leitz microscope and a 4-axis universal stage. The orientations were plotted on a Schmidt equal area net and the concentrations of c-axes were determined using a counter of 1 cm radius and a counting grid measuring 1 cm between intersections. The large and small quartz grains were plotted separately.





PETROGRAPHY

Microscopic analyses of the samples from the studied areas indicate that the sandstone is definitely Jacobsville at all of the localities. The thin sections compare almost identically in composition and percent of constituents to the samples taken from the type section at Jacobsville. There are, however, slight variations from area to area in the amount of quartz present, and the amount and composition of the matrix material.

The Jacobsville sandstone is composed mainly of subangular to rounded detrital quartz grains which are present in amounts ranging from 53 to 80 percent of the total constituents. Many of the quartz grains contain strings of gas bubbles and brownish, glassy inclusions. Many also show undulatory extinction. A high percentage of the quartz grains were fractured in the sample from the Algomah mine area, which was taken only a few feet from the fault contact. In all sections a few grains of polycrystalline quartz were recognized. Some of the quartz grains have secondary overgrowths and in the area of the Tobacco River the sandstone has a siliceous matrix.

The feldspars occur as subangular to rounded grains. Microcline occurs as fresh grains in amounts ranging from one to five percent of the total constituents. The orthoclase and plagioclase present is usually altered to sericite which is stained with iron oxide. The feldspar is present in amounts less than 15 percent in all sections.

The matrix in most sections consists of fine particles of quartz and feldspar along with sericite, hematite, and leucoxene. It is the hematite cement that gives the red color to the sandstone. Notable exceptions in the composition of the matrix occur in the Tobacco River area where the matrix is siliceous, and the sandstone is almost a quartzite; at Algomah where most of the matrix material has been removed; and at Jacobsville where most of the cementing material is carbonate.

The accessory minerals present are ilmenite, hematite, leucoxene, zircon, apatite, garnet, and tourmaline. Augite, biotite, chlorite, epidote, and lithic fragments also occur in minor amounts. (Figure 4).

There is nothing in the petrography of the samples that gives any clue to the nature of the faulting. There is no orientation of the long axes of the quartz grains in the thin sections. The occurrence of crushed grains at Algomah is probably due to the faulting. However, this same abundance of crushed grains is not present in sections from other localities where the sandstone has been thrust into a vertical position. The percentage of grains with undulatory extinction does not seem to be dependent on the sample location with respect to the fault.

There is some variation in the size of the grains from sample to sample. The average range in size is .1 millimeter to .5 millimeter, with an occasional grain measuring as large as 2 millimeters.

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PETROFABRICS

The Wall Ravine

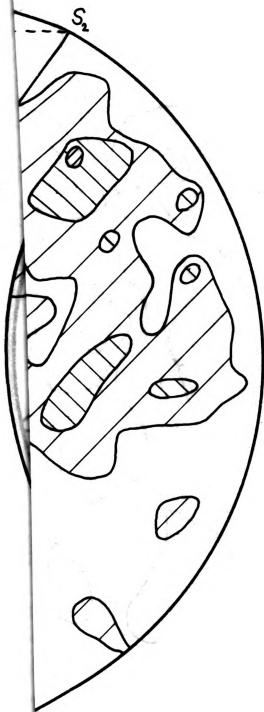
The Wall Ravine is located approximately 1.5 miles east of the town of Laurium in the north half of Sec. 20, T. 56, R. 33 W. (Figure 3). Here the Jacobsville sandstone has been thrust into an almost vertical position along the Keweenaw fault. Horizontal joints give the sandstone the appearance of artificial masonry, thus the name Natural Wall. The dip of the sandstone decreases eastward until, within a few hundred yards from the fault the formation is almost horizontal. Toward the fault from the Natural Wall a block of sandstone is observed that has been rotated into a position perpendicular to the Wall, presumably by the Mayflower cross fault which intersects the Keweenaw fault in this area.

Sample 11 was taken from the Natural Wall where it outcrops on the north side of the Wall Ravine, approximately 600 feet from the fault contact. The orientation of the sample is N20E, 86SE. The fabric diagrams of both large and small grains (Figures 5,6,7, and 8) show a weak concentration parallel to the bedding plane which probably represents a sedimentary imbrication. There is the suggestion of a concentration in the form of a broken AB girdle with low maxima, parallel to the fault plane. It is also possible to define a weak BC girdle, probably parallel to real and/or incipient joint planes which are related to

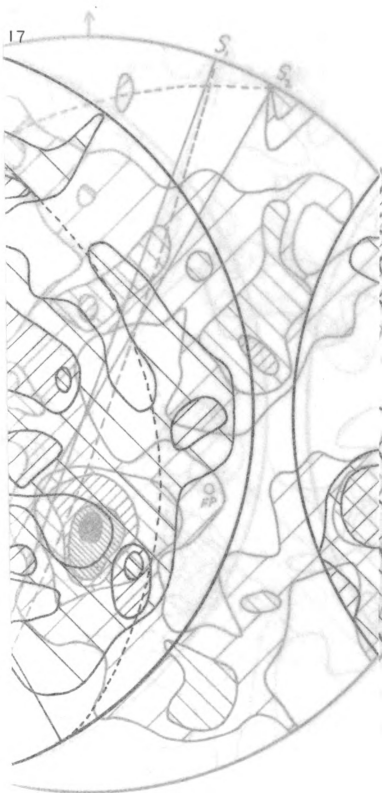
the thrusting. The combined diagrams (Figures 9 and 10) show these same general trends, but in a less well defined manner.

About 72 feet upstream from the Natural Wall itself, the sandstone forms a waterfall approximately four feet high. The orientation of the sample (10) taken from this outcrop is N4W, 60NE. The fabric diagrams for this sample (Figures 11 and 12) show a well developed girdle with maxima of two to three percent in the plane of the bedding, which is also nearly the BC plane. The clearly defined girdle may be a result of the combination of a weak BC girdle and a weak bedding plane girdle, which act to reinforce each other. There is also the suggestion of an AB girdle, that is, a concentration parallel to the plane of the fault.

A third sample (15) was taken 215 feet upstream from the Natural Wall from an outcrop in the stream bed which is nearly perpendicular to the Wall. The bedding bows slightly northwest-northeast, the sample orientation being N70W, 66SW. Joints perpendicular to the bedding are displayed, as in the Natural Wall. The orientation of this outcrop can be explained by its proximity to the Mayflower cross fault. Forces responsible for the cross fault probably rotated the bed from an original position nearly parallel to the Natural Wall. The fact that the present orientation of the bed was not caused by the major faulting is illustrated by the fabric diagrams. Figures 13, 14, 15, 16, 17, and 18 show the present orientation of the bedding. It is clear that there is no good relationship of the fabric elements



GLOMERATIC FACIES.
FA CONTOURS 3-2-1%.
NE.FP IS THE FACE POLE



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FIGURE 6. SAMPLE 11 VER
500 QUARTZ
2 IS THE BED
OF THE FAULT

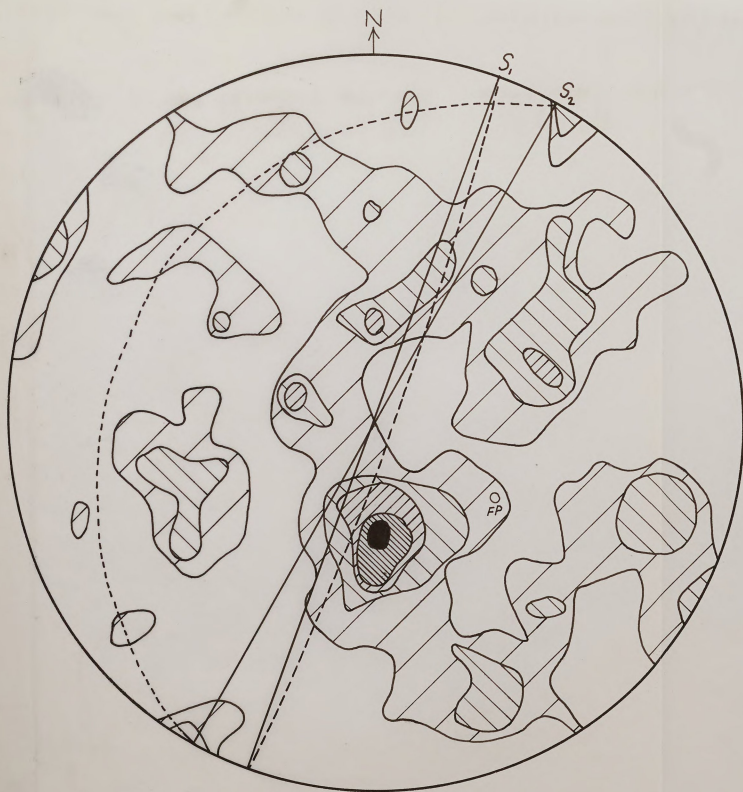


FIGURE 5. SAMPLE 11, VERTICAL CUT, WALL RAVINE, CONGLOMERATIC FACIES.
200 QUARTZ C-AXES; GRAIN SIZE 2-3mm. CONTOURS 5-4-3-2-1%
S₁ IS THE BEDDING PLANE. S₂ IS THE FAULT PLANE. FP IS THE FACE POLE
OF THE FAULT.

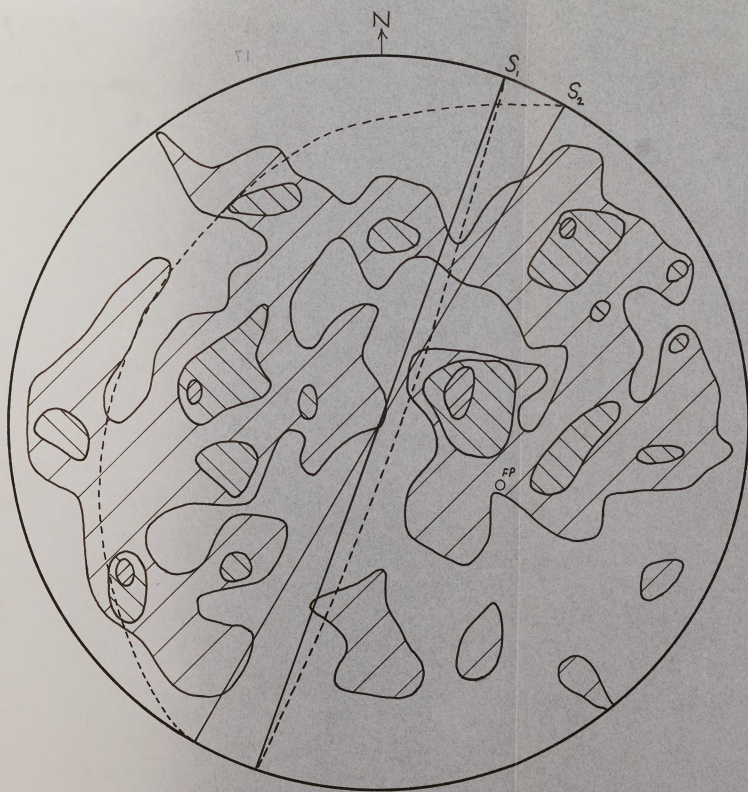


FIGURE 6. SAMPLE 11, VERTICAL CUT, WALL RAVINE, CONGLOMERATIC FACIES.
200 QUARTZ C-AXES; GRAIN SIZE 1-3mm. CONTOURS 3-2-1%
S₁ IS THE BEDDING PLANE. S₂ IS THE FAULT PLANE. FP IS THE FACE POLE
OF THE FAULT.

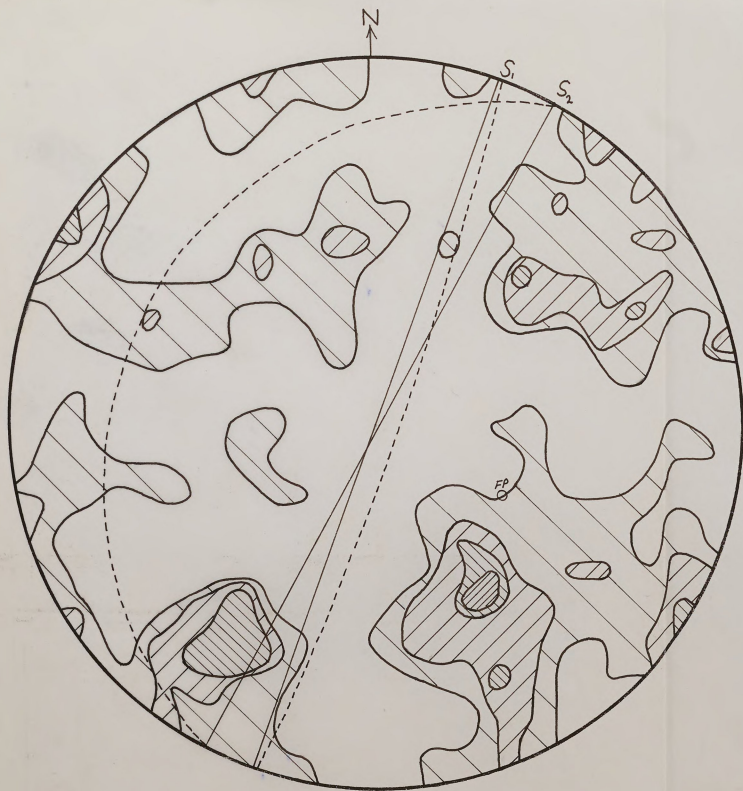


FIGURE 7. SAMPLE 11, HORIZONTAL CUT, WALL RAVINE, CONGLOMERATIC FACIES.
200 QUARTZ C-AXES; GRAIN SIZE $> 3\text{mm}$. CONTOURS 4-3-2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE
OF THE FAULT.

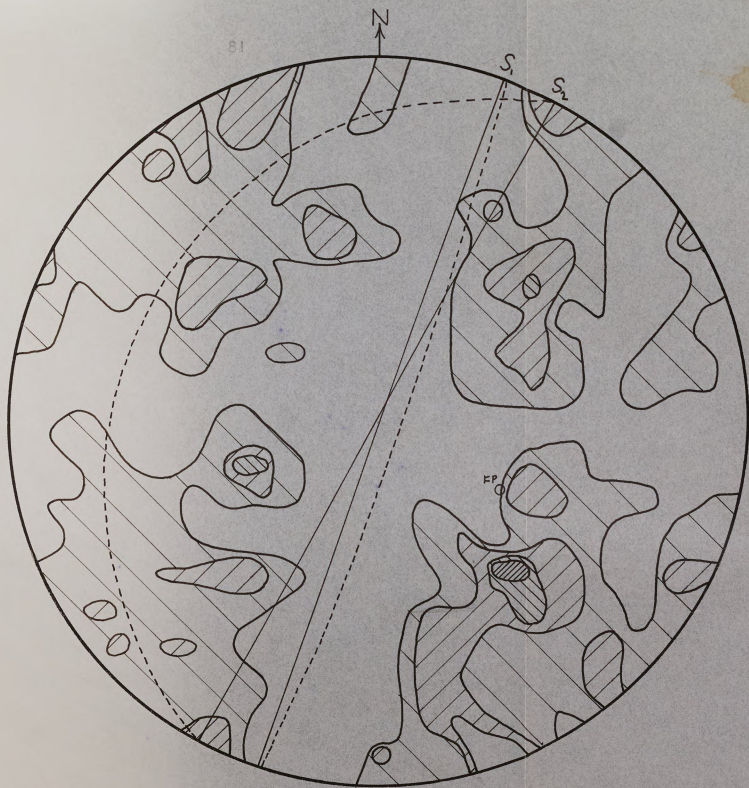


FIGURE 8. SAMPLE 11, HORIZONTAL CUT, WALL RAVINE, CONGLOMERATIC FACIES.
200 QUARTZ C-AXES; GRAIN SIZE 1-3mm. CONTOURS 4-3-2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE
OF THE FAULT.

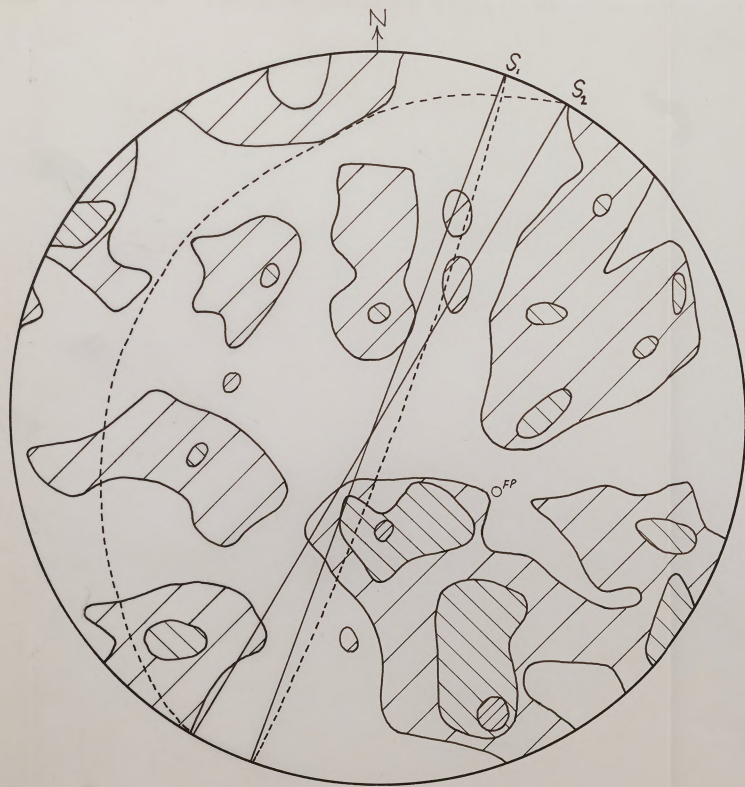


FIGURE 9. SAMPLE 11, COMBINED DIAGRAM, WALL RAVINE, CONGLOMERATIC FACIES.
400 QUARTZ C-AXES; GRAIN SIZE ≥ 3 mm, CONTOURS 3-2-1 %.
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE
OF THE FAULT.

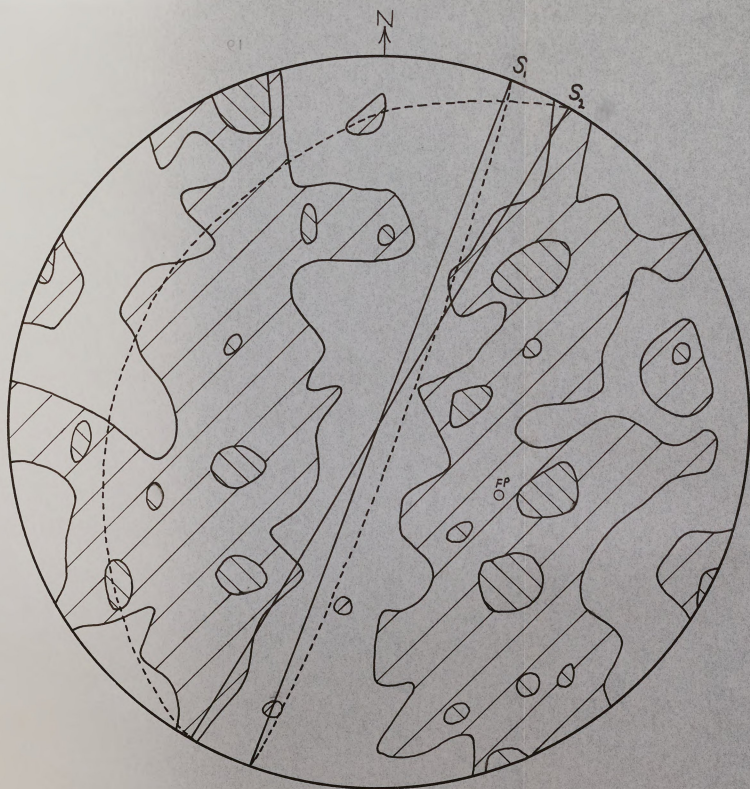


FIGURE 10. SAMPLE 11, COMBINED DIAGRAM, WALL RAVINE, CONGLOMERATIC FACIES.
400 QUARTZ C-AXES; GRAIN SIZE ≥ 3 mm, CONTOURS 2-1 %.
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE
OF THE FAULT.

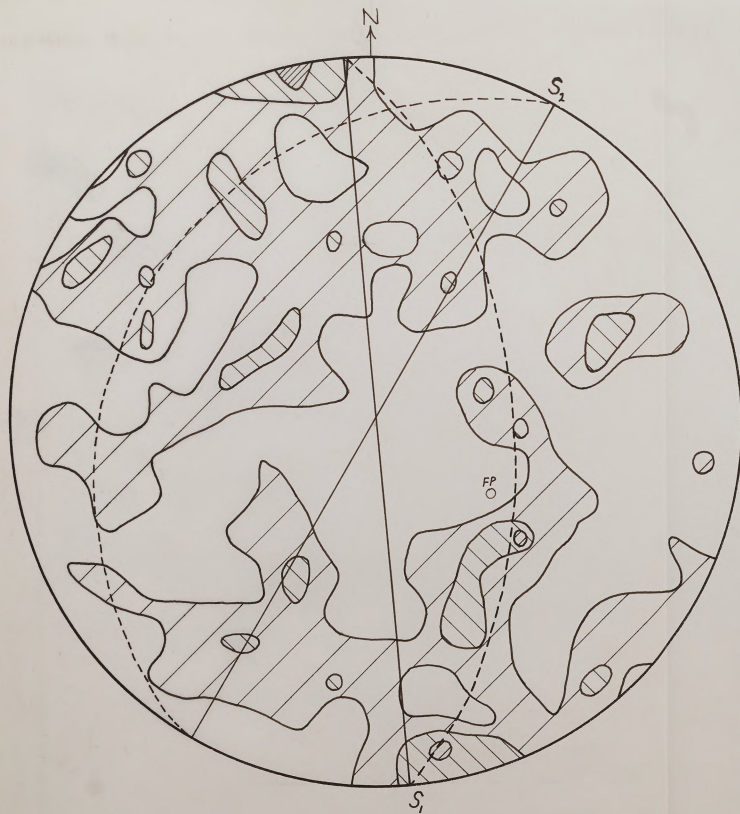


FIGURE 11. SAMPLE 10, HORIZONTAL CUT, WALL RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE $> .3$ mm, CONTOURS 3-2-1% S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

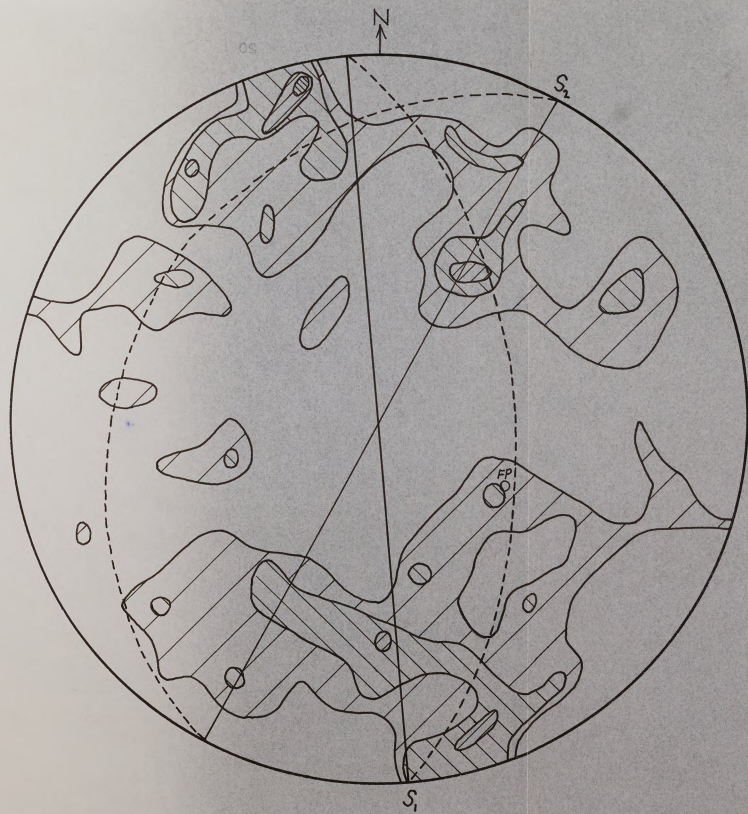


FIGURE 12. SAMPLE 10, HORIZONTAL CUT, WALL RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE $.1 - .3$ mm, CONTOURS 4-3-2-1% S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

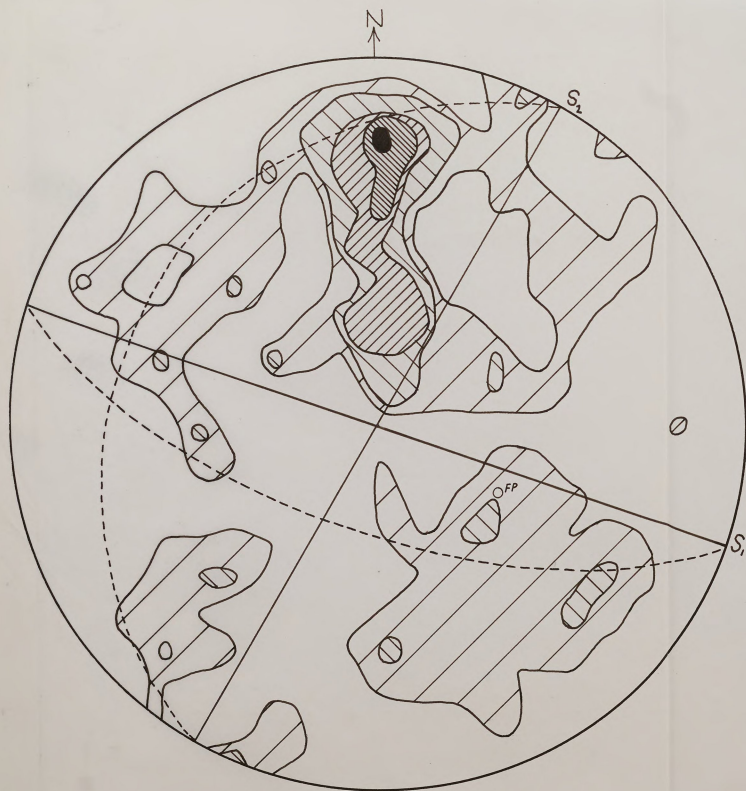


FIGURE 13. SAMPLE 15, VERTICAL CUT, WALL RAVINE, CONGLOMERATIC FACIES.
200 QUARTZ C-AXES; GRAIN SIZE > 3 mm. CONTOURS 5-4-3-2-1 %
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE
OF THE FAULT.

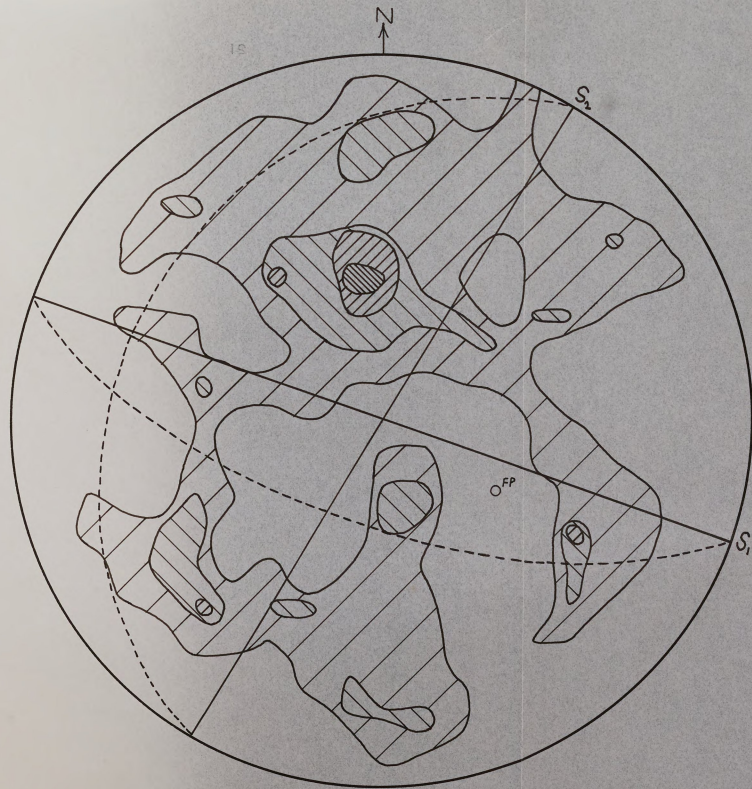


FIGURE 14. SAMPLE 15, VERTICAL CUT, WALL RAVINE, CONGLOMERATIC FACIES.
200 QUARTZ C-AXES; GRAIN SIZE .1-3 mm. CONTOURS 4-3-2-1 %
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE
POLE OF THE FAULT.



FIGURE 15. SAMPLE 15, HORIZONTAL CUT, WALL RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE 7-3mm. CONTOURS 3-2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

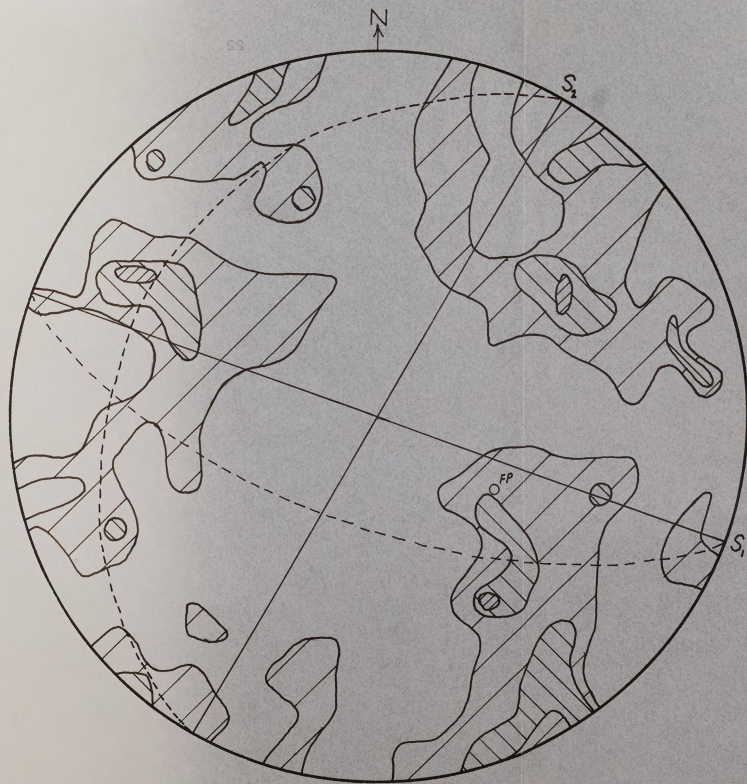


FIGURE 16. SAMPLE 15, HORIZONTAL CUT, WALL RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE 1-3mm. CONTOURS 3-2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.



FIGURE 17. SAMPLE 15, COMBINED DIAGRAM, WALL RAVINE, CONGLOMERATIC FACIES.
400 QUARTZ C-AXES; GRAIN SIZE $> .3\text{mm}$. CONTOURS 3-2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE
POLE OF THE FAULT.

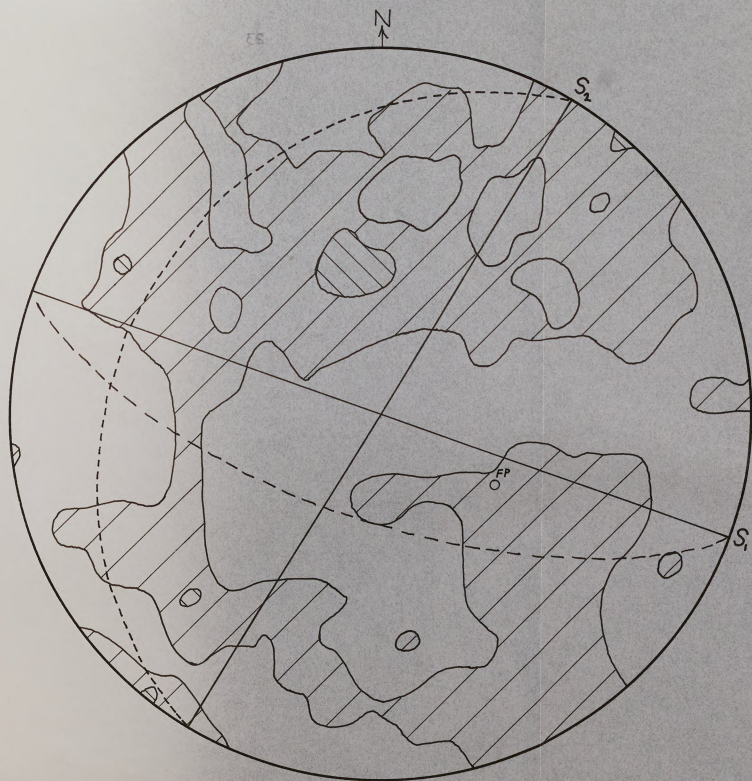


FIGURE 18. SAMPLE 15, COMBINED DIAGRAM, WALL RAVINE, CONGLOMERATIC FACIES.
400 QUARTZ C-AXES; GRAIN SIZE $.1-.3\text{mm}$. CONTOURS 2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE
POLE OF THE FAULT.

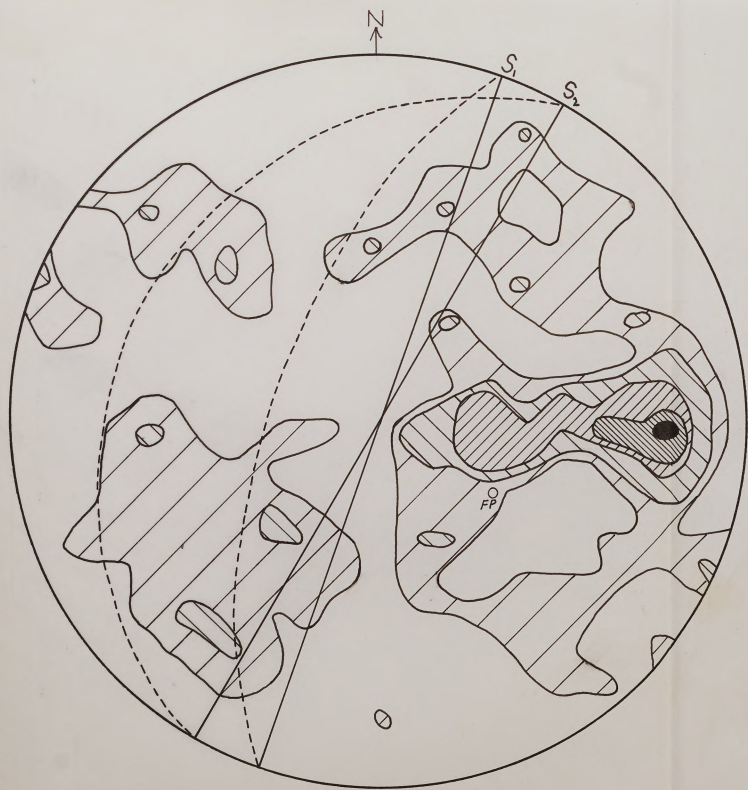


FIGURE 19. SAMPLE 15, VERTICAL CUT, WALL RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE > 3 mm. CONTOURS 5-4-3-2-1%. S_1 IS THE BEDDING PLANE WHICH HAS BEEN ROTATED PARALLEL TO THE NATURAL WALL. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

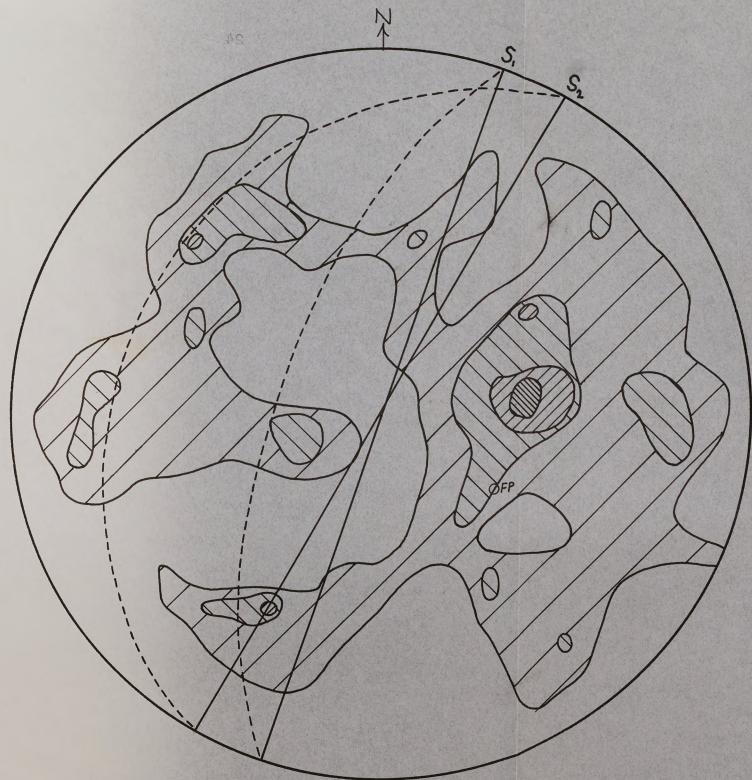


FIGURE 20. SAMPLE 15, VERTICAL CUT, WALL RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE 1-3 mm. CONTOURS 4-3-2-1%. S_1 IS THE BEDDING PLANE WHICH HAS BEEN ROTATED PARALLEL TO THE NATURAL WALL. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

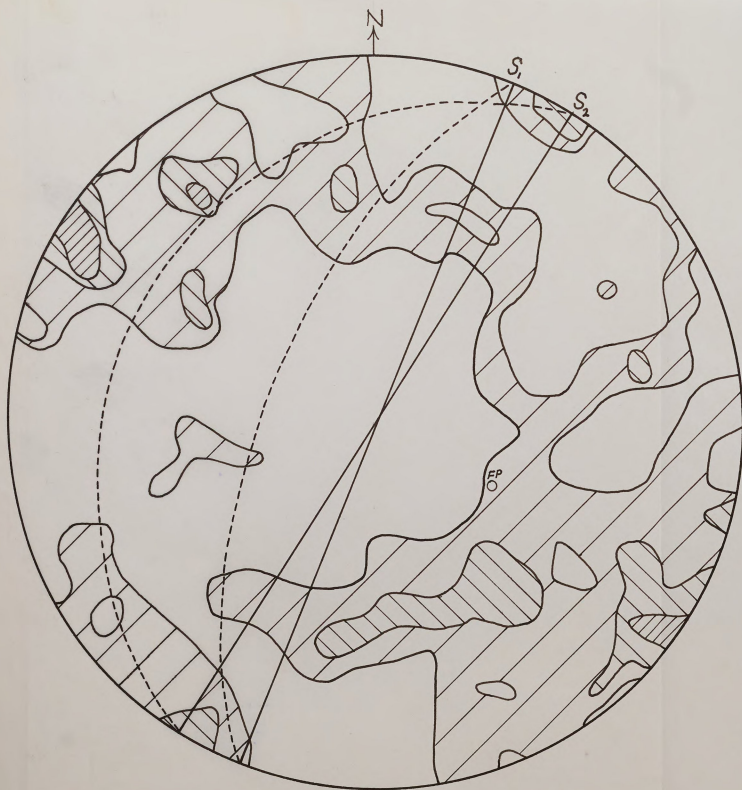


FIGURE 21. SAMPLE 15, HORIZONTAL CUT, WALL RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE > 3 mm. CONTOURS 3-2-1 %.
 S_1 IS THE BEDDING PLANE WHICH HAS BEEN ROTATED PARALLEL TO THE NATURAL WALL. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

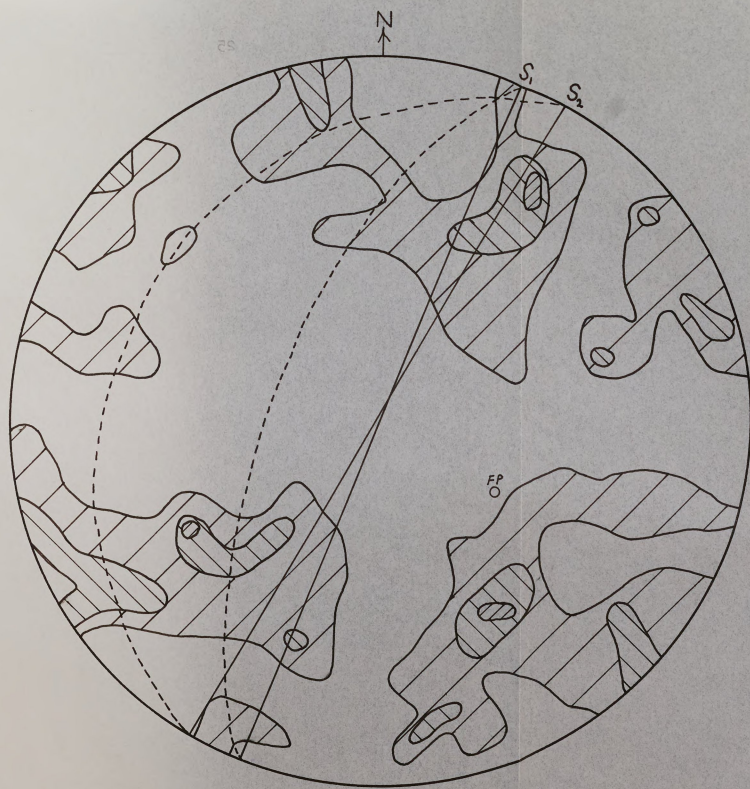


FIGURE 22. SAMPLE 15, HORIZONTAL CUT, WALL RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE 1-3 mm. CONTOURS 3-2-1 %.
 S_1 IS THE BEDDING PLANE WHICH HAS BEEN ROTATED PARALLEL TO THE NATURAL WALL. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

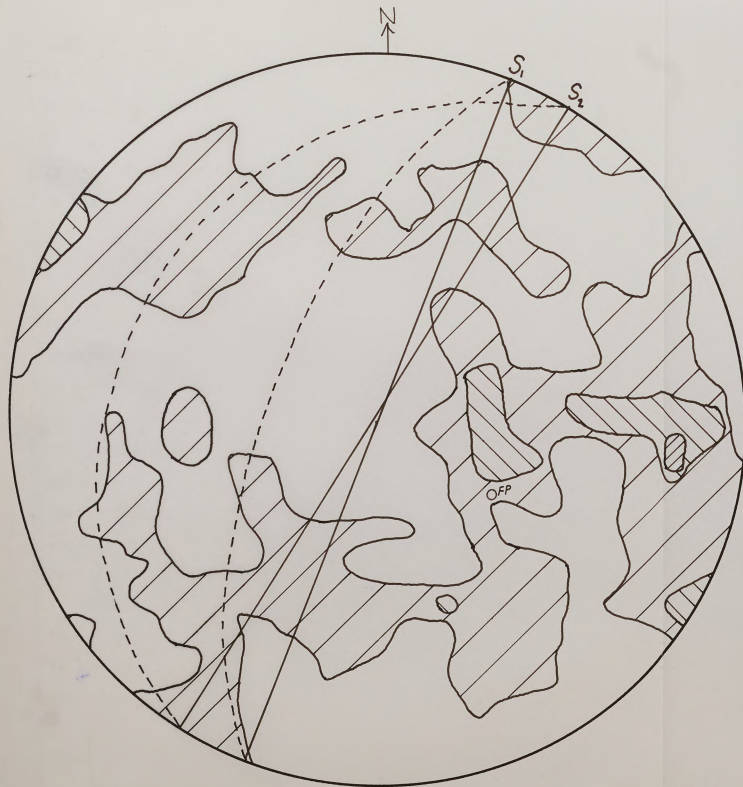


FIGURE 23. SAMPLE 15, COMBINED DIAGRAM, WALL RAVINE, CONGLOMERATIC FACIES. 400 QUARTZ C-AXES; GRAIN SIZE $> 3\text{mm}$. CONTOURS 3-2-1%. S_1 IS THE BEDDING PLANE WHICH HAS BEEN ROTATED PARALLEL TO THE NATURAL WALL. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

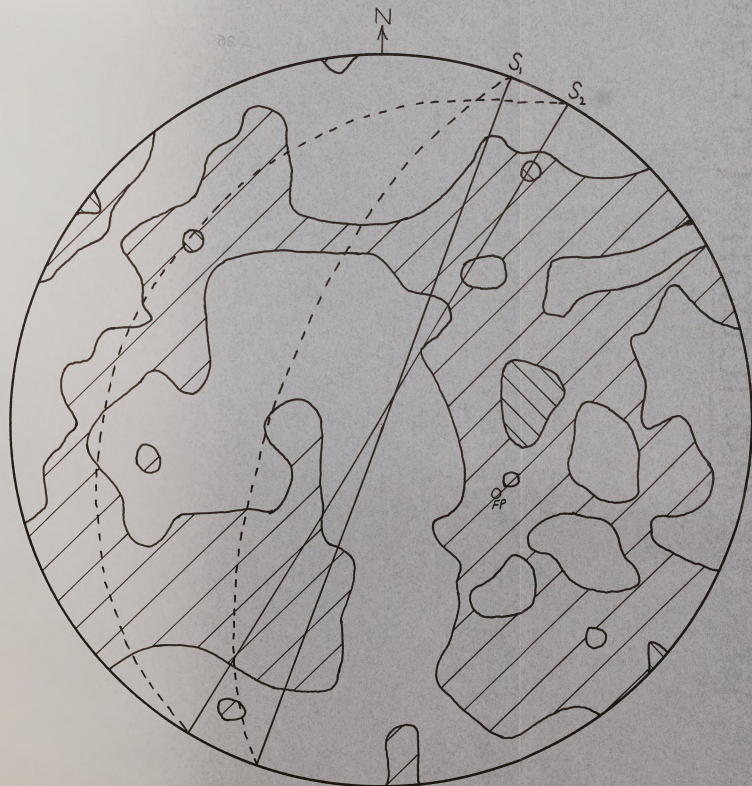


FIGURE 24. SAMPLE 15, COMBINED DIAGRAM, WALL RAVINE, CONGLOMERATIC FACIES. 400 QUARTZ C-AXES; GRAIN SIZE $1-3\text{mm}$. CONTOURS 2-1%. S_1 IS THE BEDDING PLANE WHICH HAS BEEN ROTATED PARALLEL TO THE NATURAL WALL. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

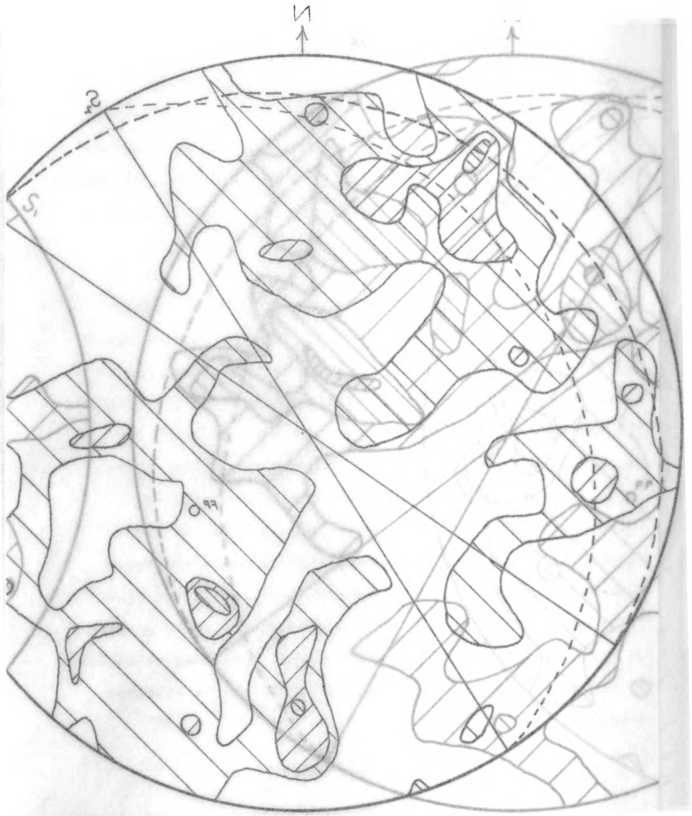


FIGURE 2: Sample 17, Vertical cut vicinity of the Wall Ravine Conglomerate. Facies 500 Quartz Gases; Grain size > 3mm. Contours 3-5. P is the bedding plane. F is the fault plane. 2 is the fault plane. 5 is the fault plane.

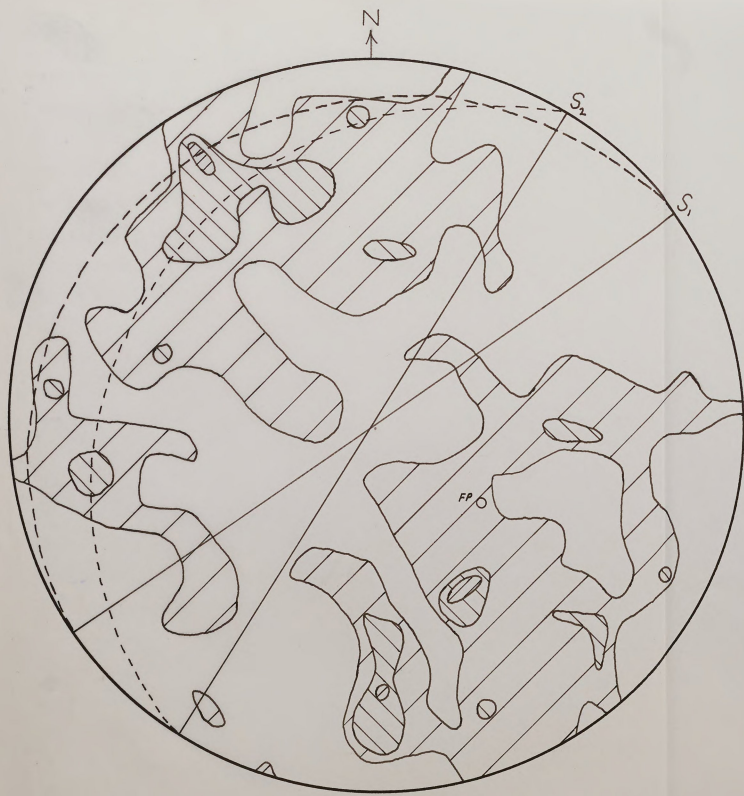


FIGURE 25. SAMPLE 17, VERTICAL CUT, VICINITY OF THE WALL RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE $> 3\text{mm}$, CONTOURS 3-2.1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

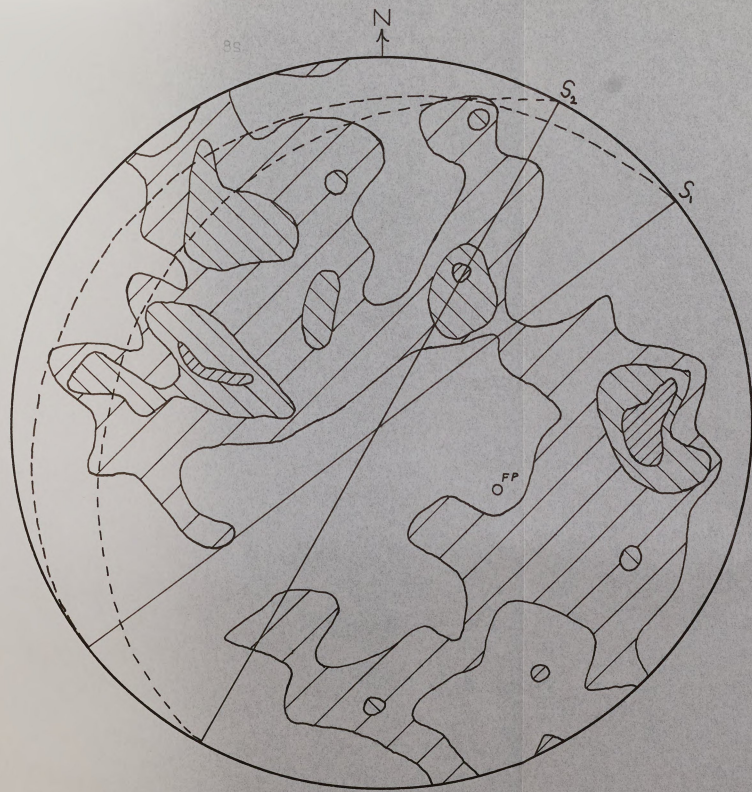


FIGURE 26. SAMPLE 17, VERTICAL CUT, VICINITY OF THE WALL RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE 1-3mm, CONTOURS 3-2.1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

examined lie in the vicinity of the old Saint Louis mine, approximately one mile east of Laurium.

The sandstone is overturned near the fault contact, the northwesterly dip being an overturned dip, as indicated by cut-and-fill cross bedding, rather than one indicative of the sandstone passing beneath or being overridden by the basalt. Eastward, the dips pass through the vertical position, seen also in the Wall Ravine, to a southeasterly direction and then decrease until the formation is nearly horizontal a few hundred feet from the fault. The sandstone at this location is very thin bedded, almost shaly, and interbedded with conglomerate.

Sample 18 was taken approximately 150 feet from the fault contact and no sandstone was seen outcropping above this point. Cut-and-fill cross bedding indicates that this outcrop has been overturned, the orientation being N50E, 64NW. The fault at this location has an orientation N25E, 30NW.

The fabric diagrams (Figures 27, 28, 29, 30, 31, and 32) show the presence of a BC girdle, especially well defined in Figures 27 and 28. There is also the suggestion of an AB girdle and a fairly well defined bedding plane girdle. A broken AC girdle is suggested, however, in most cases there is a very well defined central minimum which disrupts the girdle. The combined diagrams (Figures 31 and 32) show the tendencies mentioned above, but in a somewhat less well defined manner.

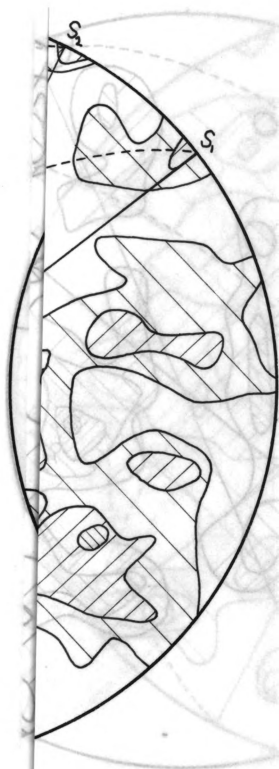


FIG. GLOMERATIC FACIES.
 TOURS 4-3-2-1 % S₁ IS
 THE FACE POLE OF

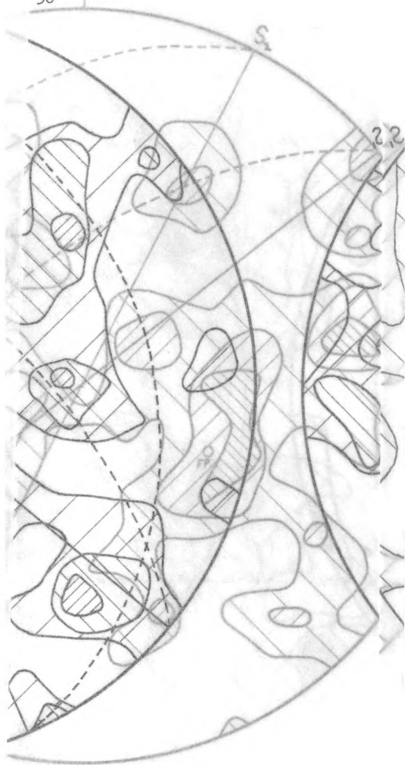


FIG. GLOMERATIC FACIES.
 TOURS 4-3-2-1 % S₁ IS
 THE FACE POLE OF

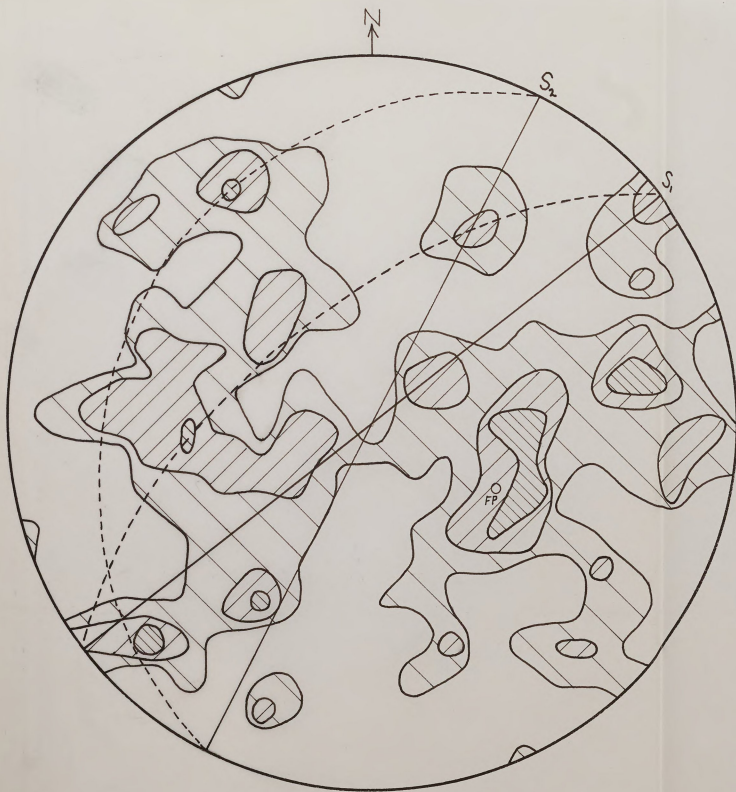


FIGURE 27. SAMPLE 1B, VERTICAL CUT, SAINT LOUIS RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE > 3 mm. CONTOURS 3-2-1%. S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

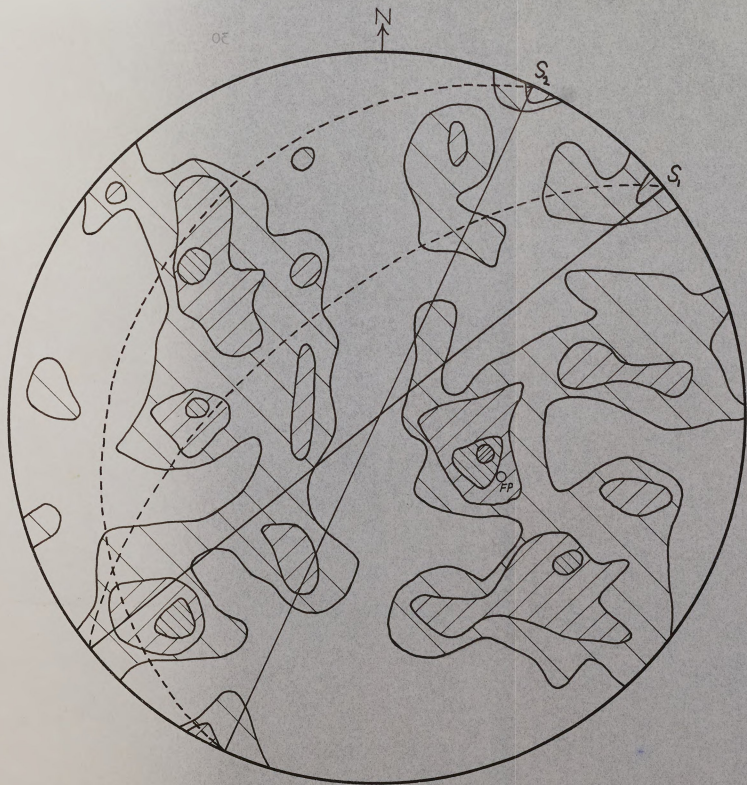


FIGURE 28. SAMPLE 1B, VERTICAL CUT, SAINT LOUIS RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE 1-3 mm. CONTOURS 4-3-2-1%. S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

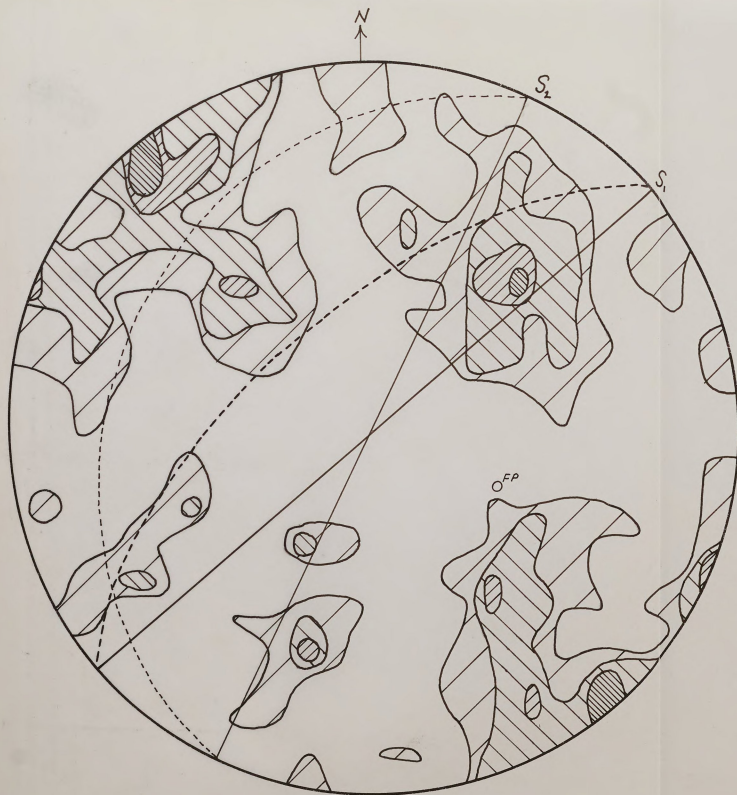


FIGURE 29. SAMPLE 1B, HORIZONTAL CUT, ST. LOUIS RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE $> .3$ mm, CONTOURS 4-3-2-1%. S_1 IS THE BEDDING PLANE, S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

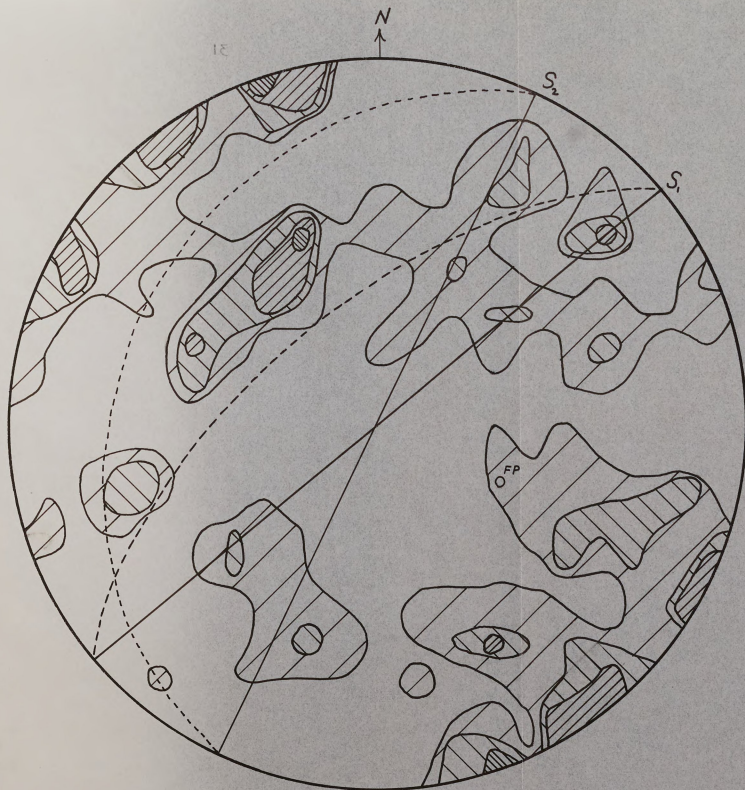


FIGURE 30. SAMPLE 1B, HORIZONTAL CUT, ST. LOUIS RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE $.1-.3$ mm, CONTOURS 4-3-2-1%. S_1 IS THE BEDDING PLANE, S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

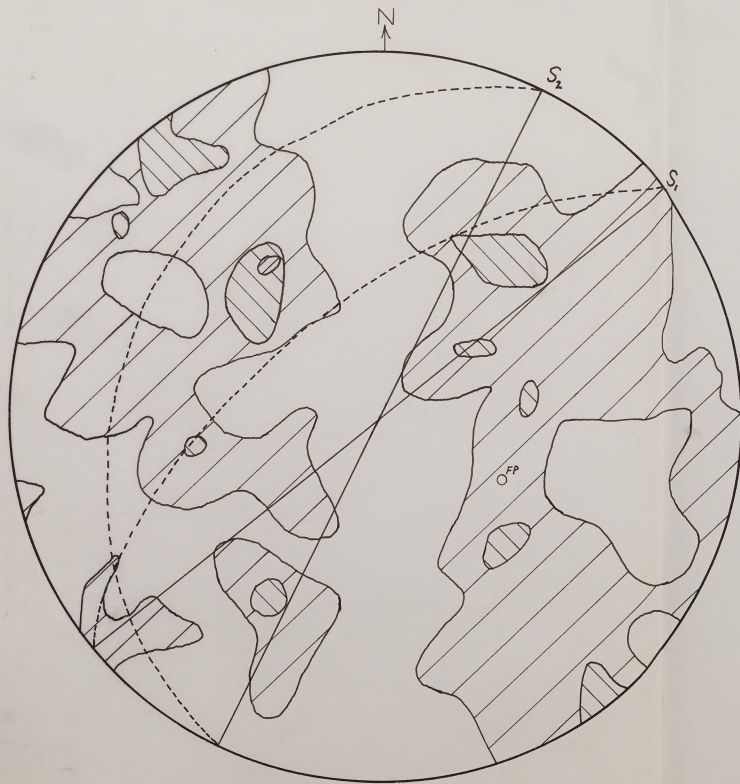


FIGURE 31. SAMPLE 18, COMBINED DIAGRAM, ST. LOUIS RAVINE, CONGLOMERATIC FACIES.
400 QUARTZ C-AXES; GRAIN SIZE $> .3\text{mm}$, CONTOURS 3-2-1%
 S_1 IS THE BEDDING PLANE, S_2 IS THE FAULT PLANE, FP IS THE FACE POLE
OF THE FAULT.

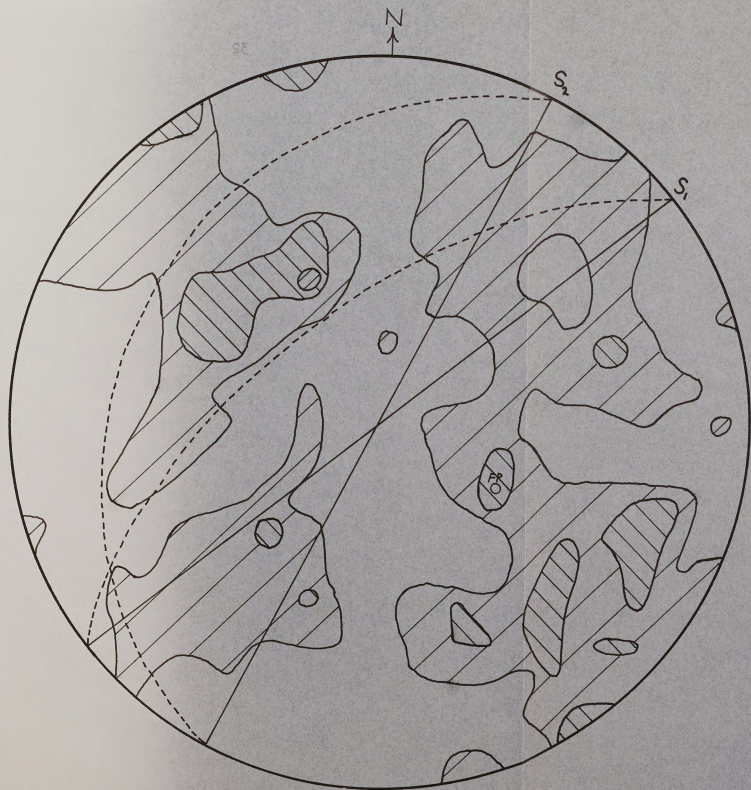


FIGURE 32. SAMPLE 18, COMBINED DIAGRAM, ST. LOUIS RAVINE, CONGLOMERATIC FACIES.
400 QUARTZ C-AXES; GRAIN SIZE $.1-.3\text{mm}$, CONTOURS 3-2-1%
 S_1 IS THE BEDDING PLANE, S_2 IS THE FAULT PLANE, FP IS THE FACE POLE
OF THE FAULT.

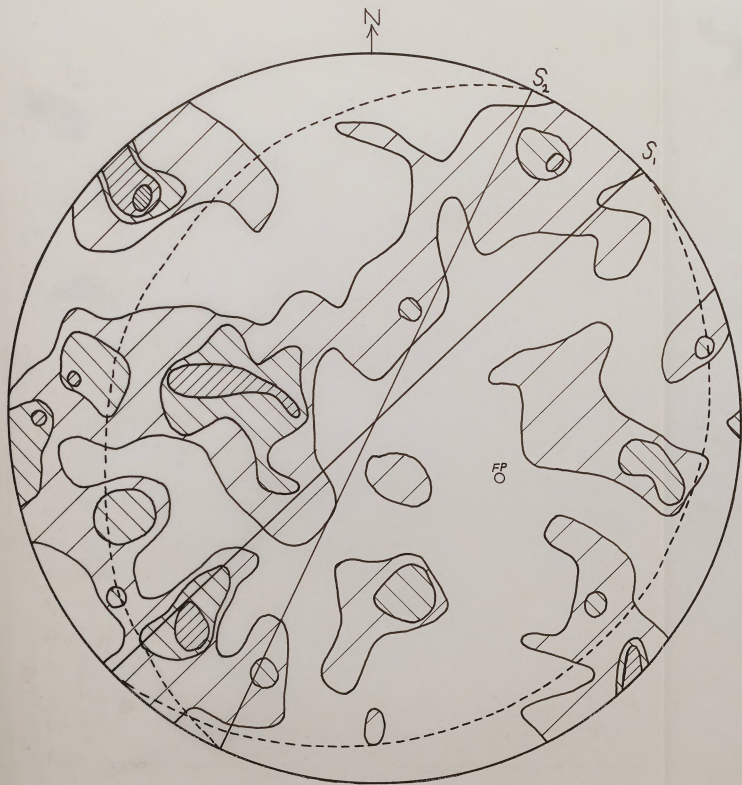


FIGURE 33. SAMPLE 19, VERTICAL CUT, SAINT LOUIS RAVINE, CONGLOMERATIC FACIES.
200 QUARTZ C-AXES; GRAIN SIZE > 3 mm, CONTOURS 4-3-2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE
OF THE FAULT.

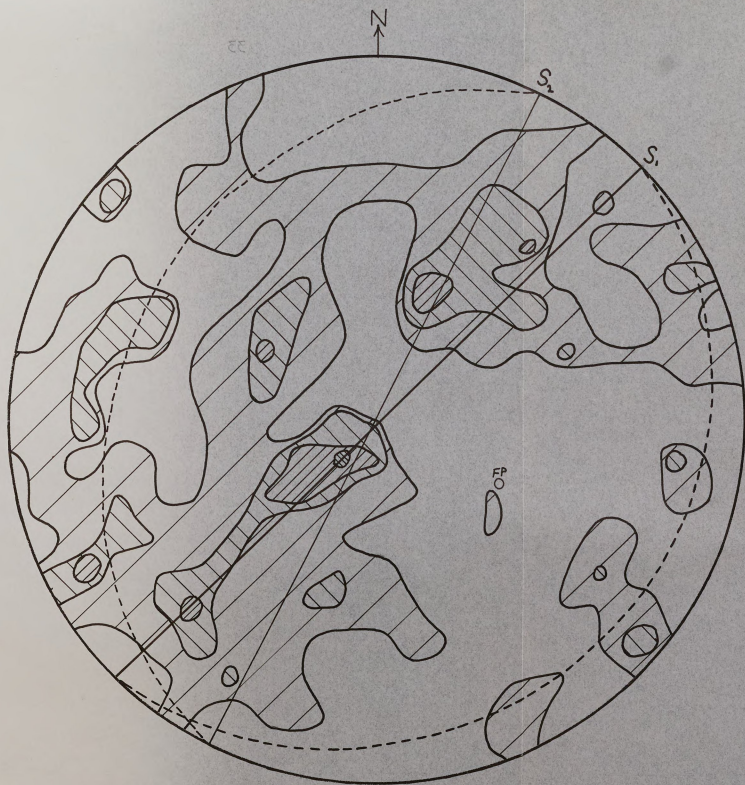


FIGURE 34. SAMPLE 19, VERTICAL CUT, SAINT LOUIS RAVINE, CONGLOMERATIC FACIES.
200 QUARTZ C-AXES; GRAIN SIZE .1-3 mm, CONTOURS 4-3-2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE
OF THE FAULT.



Figure 33. Sample 19, vertical cut, Saint Louis Ravine Conglomerate. The map shows the distribution of 500 Quartz C-axes (grain size > 3mm) contours 4-3-5-1. The dashed line 'S' is the bedding plane, 'FP' is the fault plane. The shaded areas are the fault zone.

Downstream, approximately 166 feet from sample 18, or 310 feet from the fault, the sandstone is not overturned and has an orientation N45E, 16SE. Sample 19 was taken from this outcrop. The fabric diagrams (Figures 33 and 34) show a fairly well defined sedimentary, bedding plane girdle and the suggestion of an AB girdle. A BC girdle, if present is broken and very faintly developed. Figure 33 shows a slight development of an AC girdle.

Douglass Houghton Ravine

The Douglass Houghton Ravine runs east and southeast through Sec. 31, T. 56, R. 32 W. (Figure 3). The sandstone at this location is not highly deformed as in the Saint Louis and Wall Ravines. The northwesterly dip indicates that the sandstone has been forced beneath or overridden by the basalt. It is possible, however, that this is an overturned dip similar to that observed in the Saint Louis Ravine, but no criteria for judging this were seen. The sandstone at this location is well indurated, quartzose, and interbedded with conglomerate.

Sample 1 was taken near the Douglass Houghton Falls. The first sandstone outcrop was seen approximately 100 feet from the fault contact. The sandstone is not highly deformed at this location (N20E, 23NW), the strike and dip of the bedding being nearly parallel to the fault.

The fabric diagrams (Figures 35, 36, 37, and 38) for the large and small grains show a well defined girdle in the plane of the bedding, which nearly corresponds to the

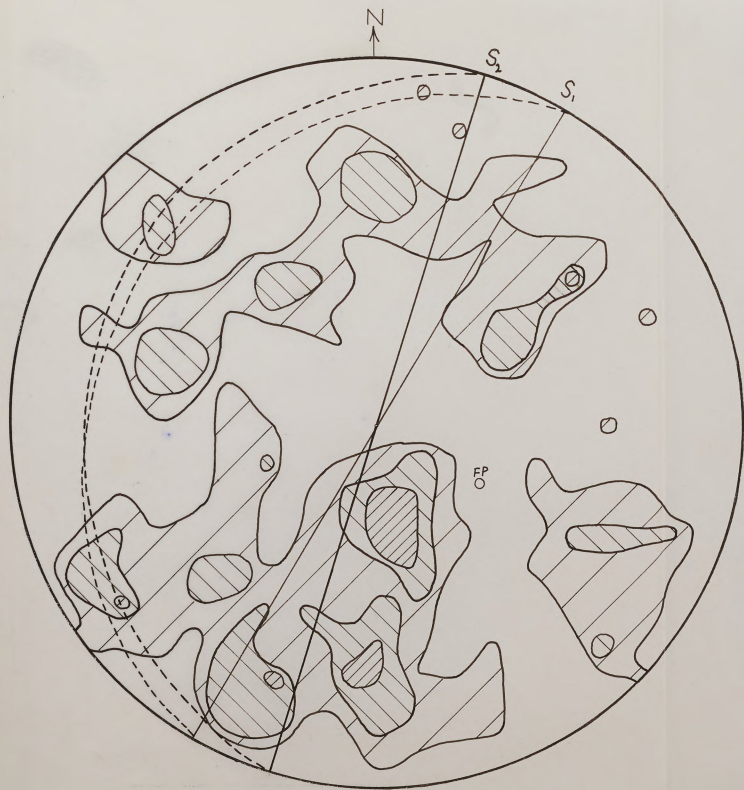


FIGURE 35. SAMPLE 1, VERTICAL CUT, DOUGLASS HOUGHTON RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE $> 3\text{mm}$. CONTOURS 3-2-1%. S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

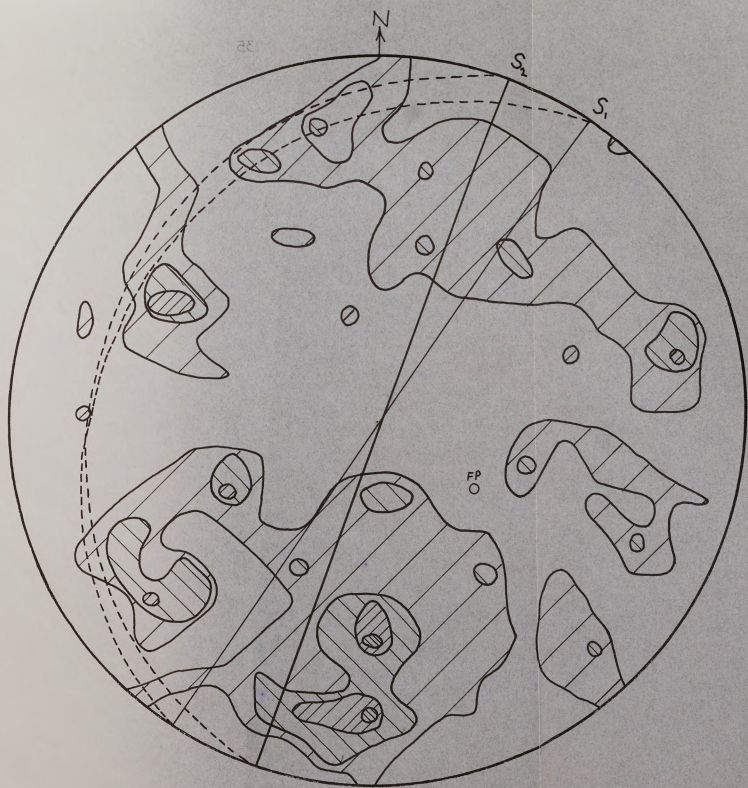


FIGURE 36. SAMPLE 1, VERTICAL CUT, DOUGLASS HOUGHTON RAVINE, CONGLOMERATIC FACIES. 200 QUARTZ C-AXES; GRAIN SIZE $1-3\text{mm}$. CONTOURS 4-3-2-1%. S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.



FIGURE 31. SAMPLE 1, VERTICAL CUT, DOUGLASS HOUGHTON RAVINE, CONGLOMERATIC FACIES, 200 QUARTZ C-AXES; GRAIN SIZE > 3 mm. CONTOURS 5-4-3-2-1% S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

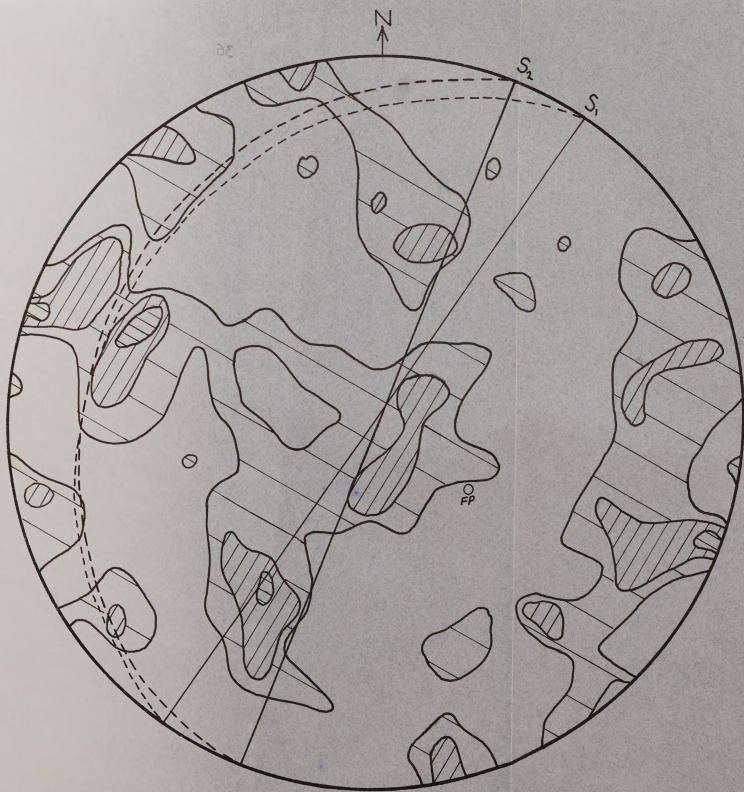


FIGURE 38. SAMPLE 1, VERTICAL CUT, DOUGLASS HOUGHTON RAVINE, CONGLOMERATIC FACIES, 200 QUARTZ C-AXES; GRAIN SIZE 1-3 mm. CONTOURS 3-2-1% S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

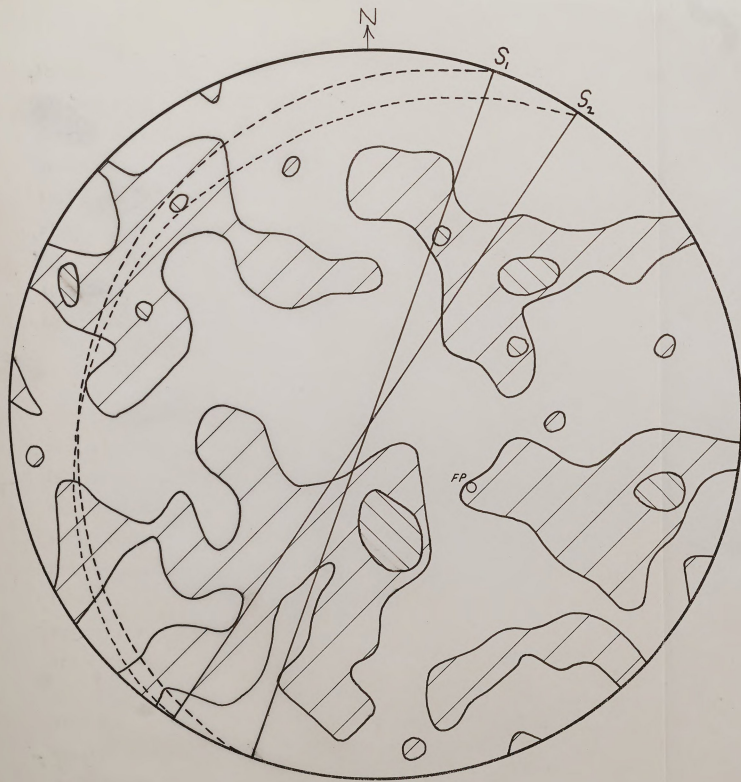


FIGURE 39. SAMPLE 1, COMBINED DIAGRAM, DOUGLAS HOUGHTON RAVINE, CONGLOMERATIC FACIES, 400 QUARTZ C-AXES; GRAIN SIZE $> .3$ mm. CONTOURS 2-1%. S_1 IS THE BEDDING PLANE, S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

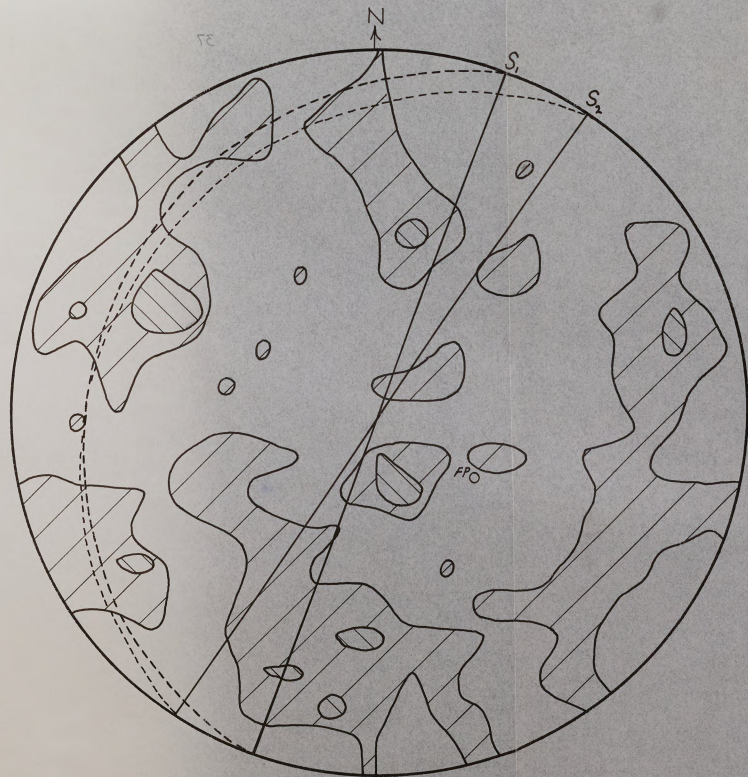


FIGURE 40. SAMPLE 1, COMBINED DIAGRAM, DOUGLAS HOUGHTON RAVINE, CONGLOMERATIC FACIES, 400 QUARTZ C-AXES; GRAIN SIZE $.1-.3$ mm. CONTOURS 2-1%. S_1 IS THE BEDDING PLANE, S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

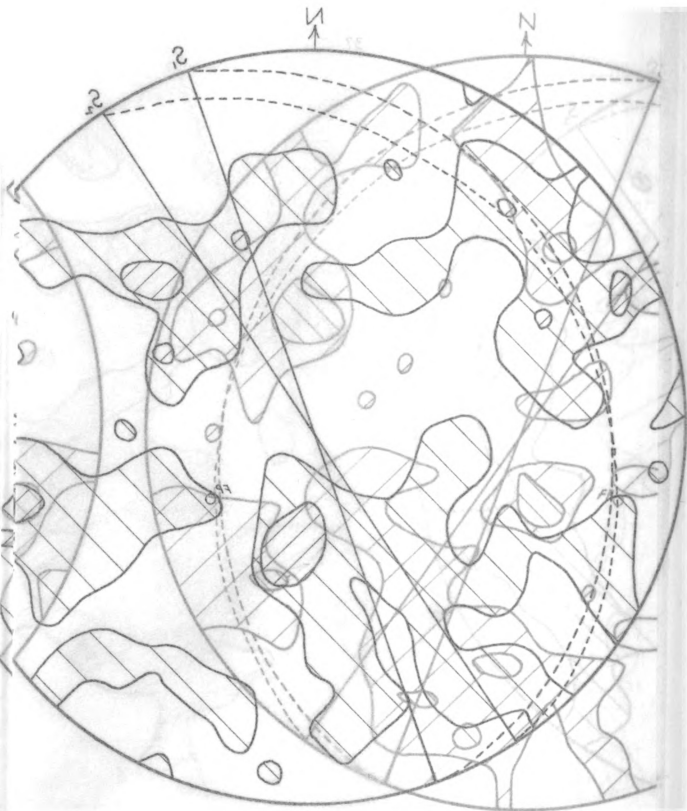


FIGURE 39. SAMPLE 1, COMBINED DIAGRAM, DOUGLAS HOUGHTON RAVINE,
CONGLOMERATIC FAULTS, 400' QUARTZ CAVES; GRAIN SIZE
7-3mm; CONTOURS 5-1' IS 2' IS THE BEDDING PLANE, 2' IS
THE FAULT PLANE, F.P. IS THE FACE OF THE FAULT.

AB plane. The tectonic and sedimentary fabrics probably act to reinforce each other, accounting for the well developed girdle. A fairly well defined BC girdle can be seen in Figures 35, 36, and 37. The author also believes that there is a faint suggestion of a girdle in the AC plane. This is especially noticable in Figures 37 and 38.

The combined diagrams (Figures 39 and 40) show the AB-bedding plane girdle well and also the suggestion of a BC girdle.

Hungarian Falls

The Hungarian Falls are located on the Dover Creek, approximately 1/2 mile northwest of the town of Hubble. (Figure 3). The river makes three falls, the first two over Keweenawan rocks, and the third, and main one, over the sandstone. The sandstone at this location is massive. The dips are low, ranging from 10° to horizontal, and vary in direction. The most common direction is northwest, however, dips to the northeast, southeast, and southwest are also observed.

An interesting feature noted in one thin section from this area is an example of cross bedding, which is visible megascopically on the slide, and defined by a concentration of opaque minerals. (Photo 1). This cross bedding is upside down relative to the top of the slide, or the direction the author called the top of the outcrop. Although the sandstone in this area has never been considered

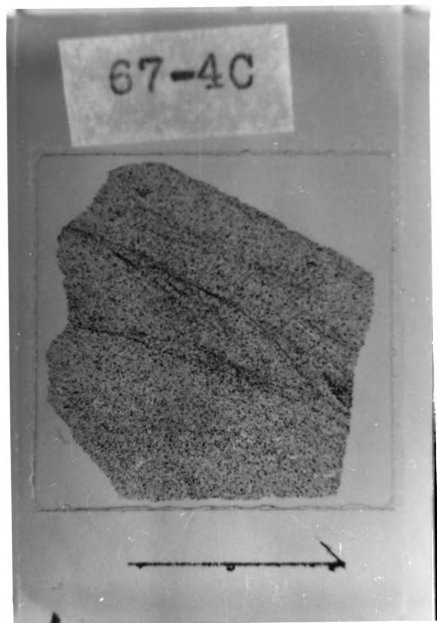


Photo 1. Thin Section Showing Cross Bedding Upside Down Relative to the Top of the Outcrop Which is Indicated by the Barb on the Arrow.

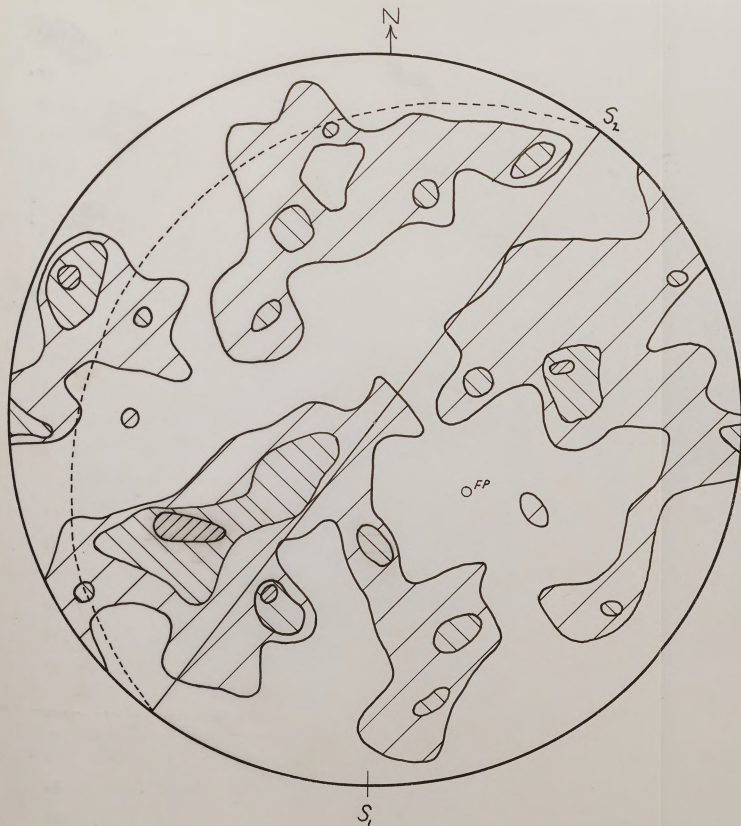


FIGURE 43. SAMPLE 22, VERTICAL CUT, VICINITY OF TORCH LAKE QUARRY.
200 QUARTZ C-AXES; GRAIN SIZE ≥ 3 mm. CONTOURS 3-2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE
POLE OF THE FAULT.

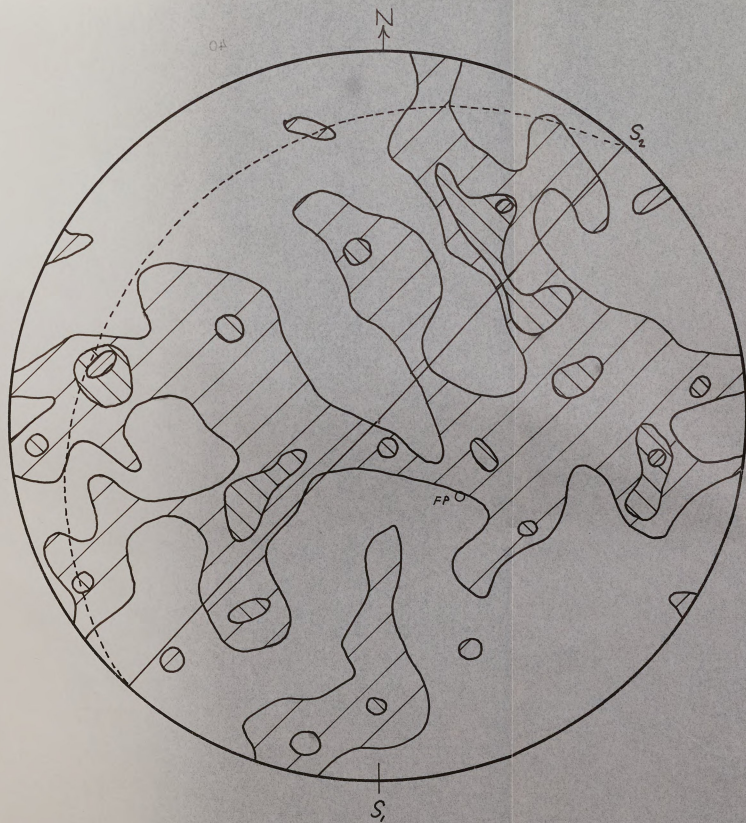
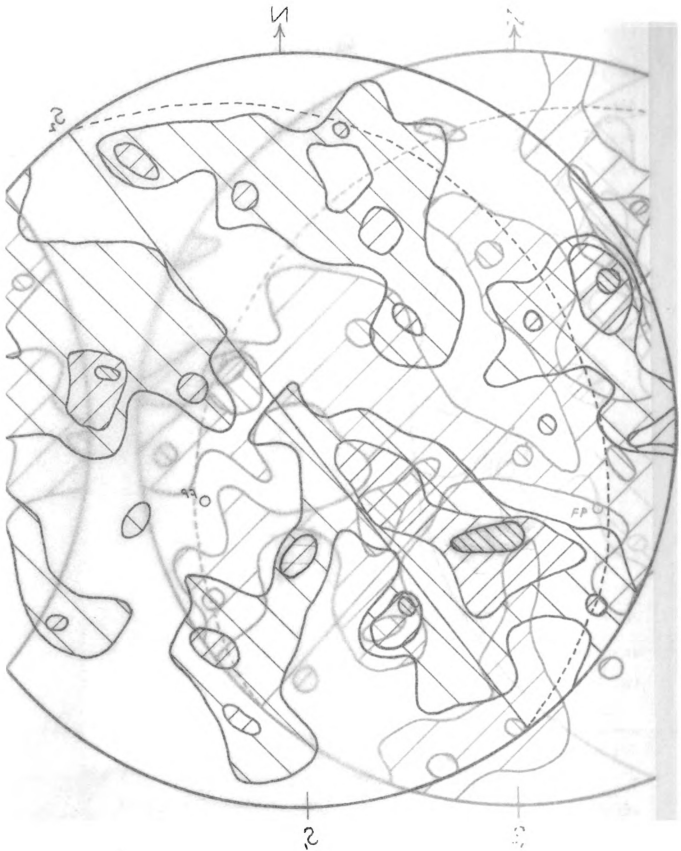


FIGURE 44. SAMPLE 22, VERTICAL CUT, VICINITY OF TORCH LAKE QUARRY.
200 QUARTZ C-AXES; GRAIN SIZE .1-3 mm. CONTOURS 3-2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE
POLE OF THE FAULT.

FIGURE 43. Sample 55, Vertical cut vicinity of Torch Lake Quarry.
 500 Quartz C-axis; Grain size 2-3 mm. Contours 5-10
 is the bedding plane. 2 is the fault plane. FP is the
 pole of the fault.



to be highly deformed it is conceivable that the observed dips are overturned dips and that the sandstone, rather than being horizontal has been pushed into a recumbant fold by forces associated with the faulting.

Sample 4 was taken from the base of the Hungarian Falls. This area is located approximately 1,300 feet from the fault, which trends N35E, and dips 25NW. The orientation of the sample is N35W, 4NE.

The fabric diagram (Figure 41) for the small grains shows a rather pronounced AB girdle, and also a tendency for a BC girdle, the main concentration (6%) being nearly perpendicular to the plane of the fault. There is no girdle in the bedding plane and, therefore, no indication of a sedimentary fabric. The evidence of a sedimentary imbrication is also lacking in the diagram of the large grains (Figure 42). The large grains also show the development of a weak AB girdle, although the highest maxima do not lie exactly in the fault plane. One could imagine a weak BC girdle and also, perhaps, a tendency for a girdle in the AC plane.

Vicinity of Torch Lake Quarry

Sample 22 was taken very close to the fault contact, which is not exposed at this location. The outcrop, undulating and massive, is located approximately 1/4 mile southwest of Douglass Houghton Falls. (Figure 3). The sandstone does not appear to be deformed, other than its

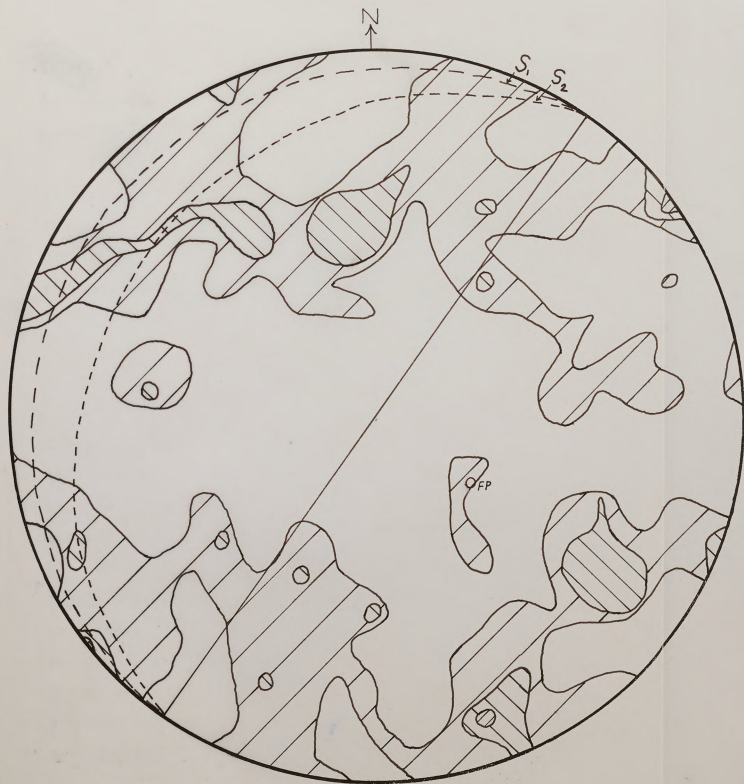


FIGURE 45. SAMPLE 3, HORIZONTAL CUT, TORCH LAKE QUARRY, 200 QUARTZ C-AXES; GRAIN SIZE ≥ 3 mm. CONTOURS 3-2-1%. S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

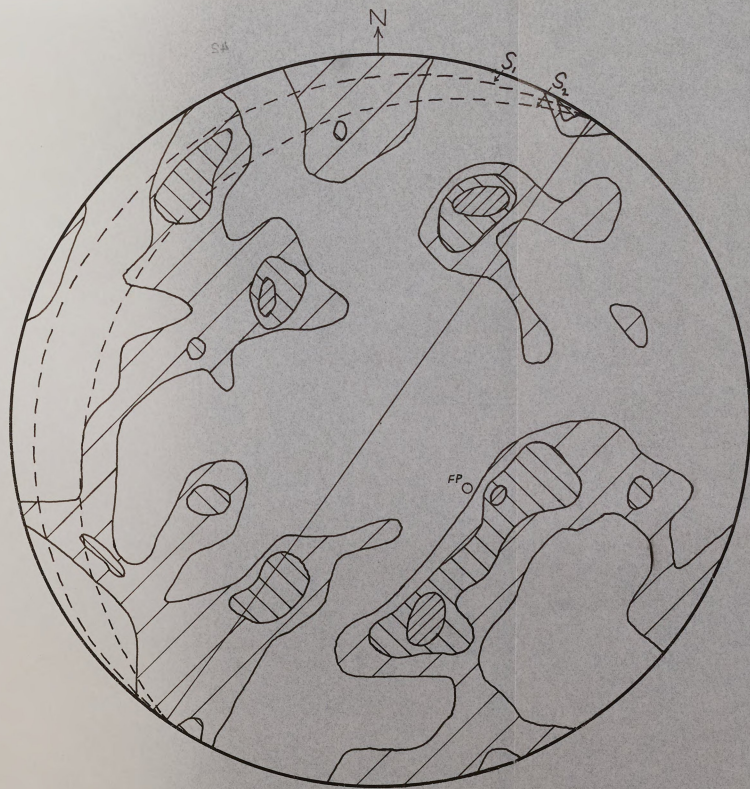


FIGURE 46. SAMPLE 3, HORIZONTAL CUT, TORCH LAKE QUARRY, 200 QUARTZ C-AXES; GRAIN SIZE 1-3mm. CONTOURS 3-2-1%. S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

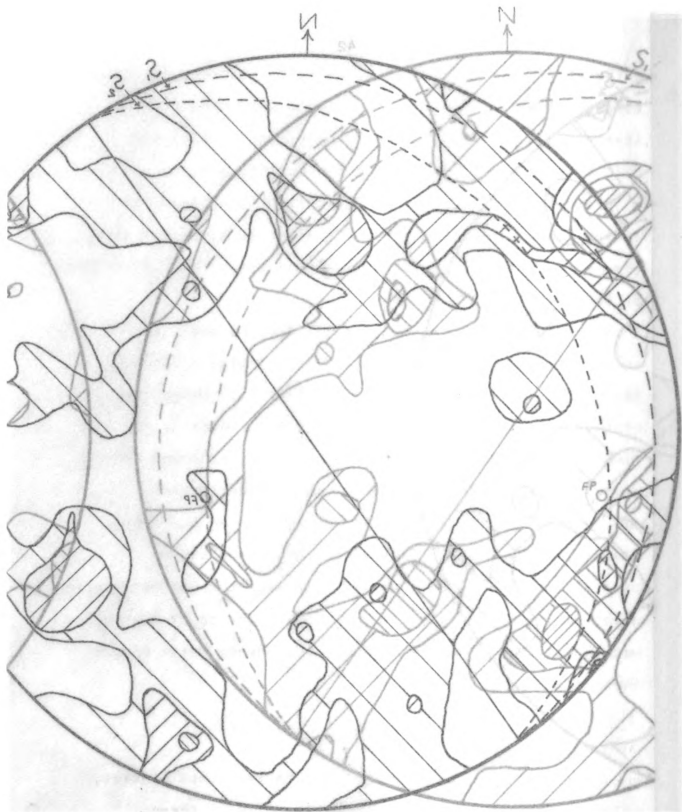


Figure 42. Sample 8, Horizontal cut Torch Lake Quarry, 500 Quartz C. Grain size 2-3mm. Contours 2-5 ft. 2 is the bedding plane. The fault plane is the face of the fault.

crinkled or undulatory appearance. Although it is difficult to determine, due to its massive nature, the outcrop appears to be essentially horizontal.

There is no well developed pattern in the fabric diagrams (Figures 43 and 44). There does seem to be an indication of an AB girdle, and also a suggestion of a girdle in the BC plane. The remainder of the fabric elements probably represent a slightly disturbed sedimentary girdle in the plane of the bedding.

Torch Lake Quarry

The Torch Lake Quarry lies about one mile south from Douglass Houghton Falls. (Figure 3). The sandstone in this area is massive and undulating with the dip ranging between $0 - 10^{\circ}$ to the northwest. The orientation of the sampled outcrop being N35E, 10NW.

No definite preferred orientation is present in the fabric diagrams (Figures 45 and 46). There is, however, an indication of a bedding plane girdle and an AB girdle, perhaps reinforcing each other. There is also a faint BC girdle which is broken and of low intensity. In Figure 46 however, the three percent maxima could be assumed to lie parallel to the BC plane.

M 26 Near the Town of Mason

The outcrop sampled lies along Highway M 26, west of the town of Mason. (Figure 3). Here the sandstone is essentially horizontal and lies approximately 1.5 miles

the same time, the fact that the system is not a simple one, and that the results are not always the same, is a fact that must be taken into account.

The first of these facts is that the system is not a simple one, and that the results are not always the same. This is because the system is a complex one, and the results are determined by a number of factors. The second fact is that the system is not a simple one, and that the results are not always the same. This is because the system is a complex one, and the results are determined by a number of factors. The third fact is that the system is not a simple one, and that the results are not always the same. This is because the system is a complex one, and the results are determined by a number of factors.

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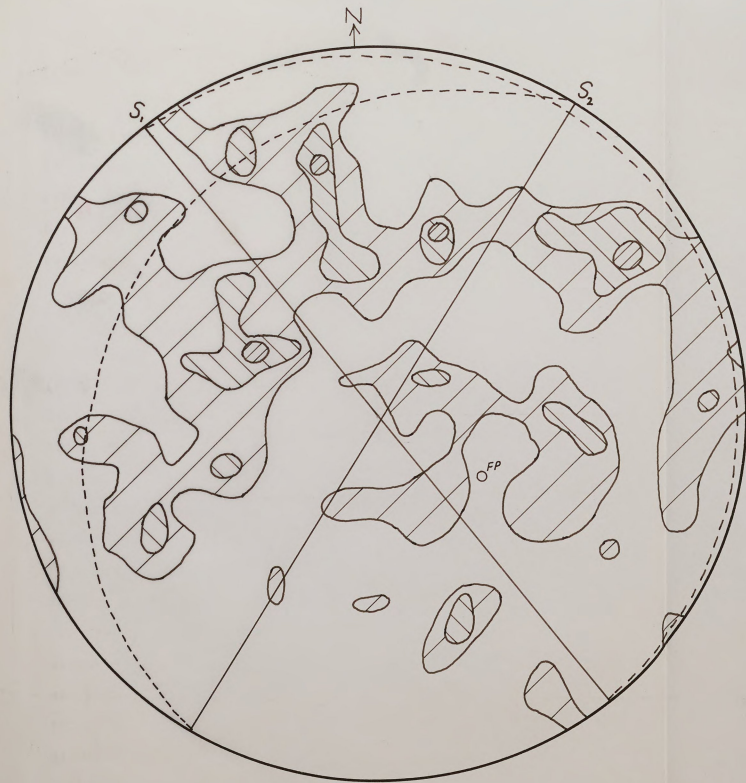


FIGURE 41. SAMPLE 4, VERTICAL CUT, HUNGARIAN FALLS, MASSIVE FACIES.
200 QUARTZ C-AXES; GRAIN SIZE 2-3mm. CONTOURS 3-2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE
POLE OF THE FAULT.

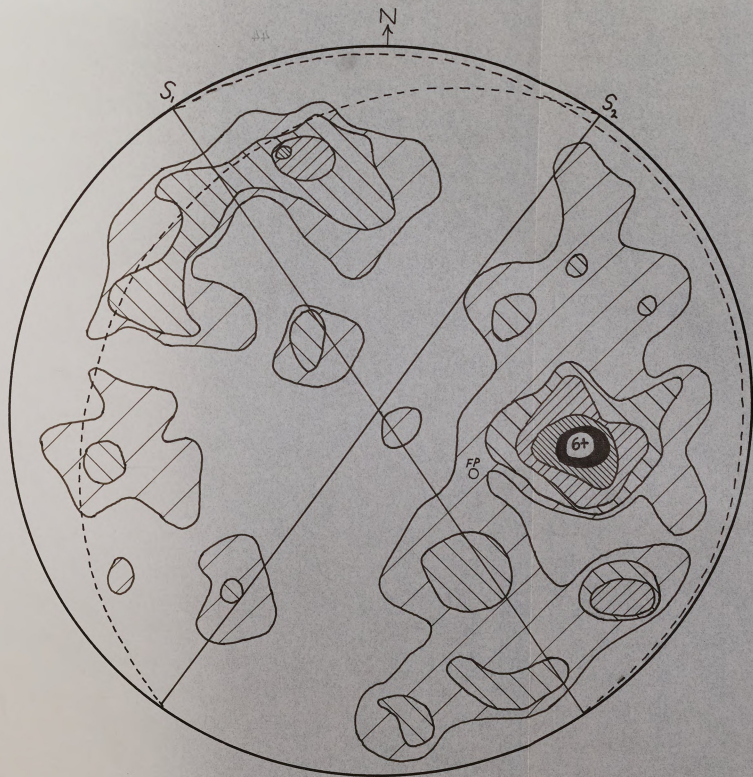


FIGURE 42. SAMPLE 4, VERTICAL CUT HUNGARIAN FALLS, MASSIVE FACIES.
200 QUARTZ C-AXES; GRAIN SIZE 1-3mm. CONTOURS 6-5-4-3-2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE
POLE OF THE FAULT.



Figure 4. Sample 4 Vertical cut Hungarian Falls Massive Facies.
500 Quartz C-axis; Grain size 3-5 mm. Contours 3-5-10
is the bedding plane. 2 is the fault plane. FP is the face
pole of the fault.

from the fault contact.

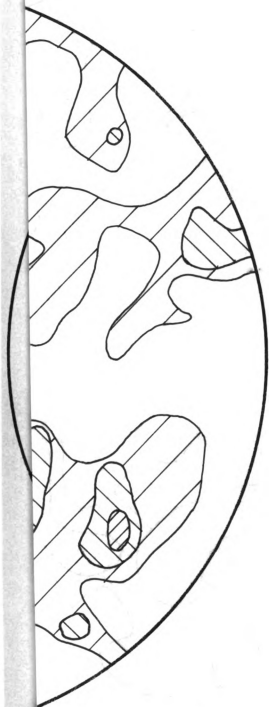
The fabric diagrams (Figures 47 and 48) show a tendency toward a BC girdle and a concentration parallel to the plane of the fault (AB girdle). The AB girdle could be partially sedimentary and perhaps there has again been a reinforcement of the sedimentary fabric by forces associated with the faulting.

Jacobsville

Sample 21 was taken near the town of Jacobsville (Figure 2). Here the sandstone forms an outcrop which rises approximately 35 feet above the lake. The bedding is horizontal and massive. The sample was taken for use as a standard in determining the effect of the faulting on the orientation of the quartz grains. It was assumed by the author that since the sandstone in this area is undeformed, if a fabric is present it would be the original sedimentary fabric and not one caused by the faulting.

The results of cross-stratification studies in the Jacobsville by Hamblin (1958) indicate that the direction of sediment transport in this area was west-northwest. If this direction is assumed, then a maximum or girdle plunging northwest, or downstream, would be expected on the petrofabric diagram due to the orientation of the long axes of quartz grains in the direction of stream flow.

The fabric diagrams (Figures 49 and 50) seem to indicate a rather poorly defined girdle dipping northwestward



26 NEAR MASON.
 n. CONTOURS 3-2-1%
 PLANE. FP IS THE

46

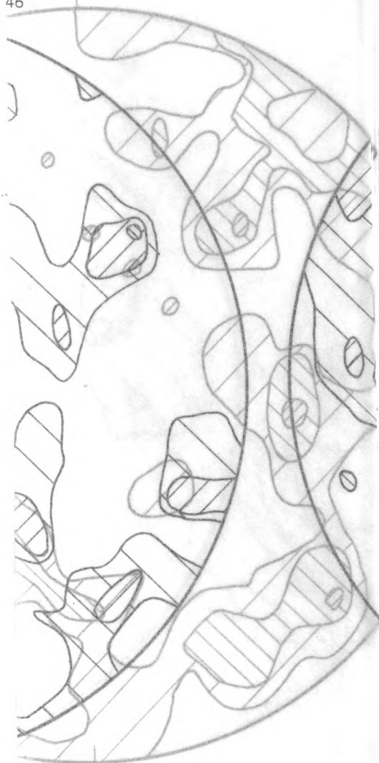


FIGURE 2. 8739087
 190005
 187812
 FACE FOR

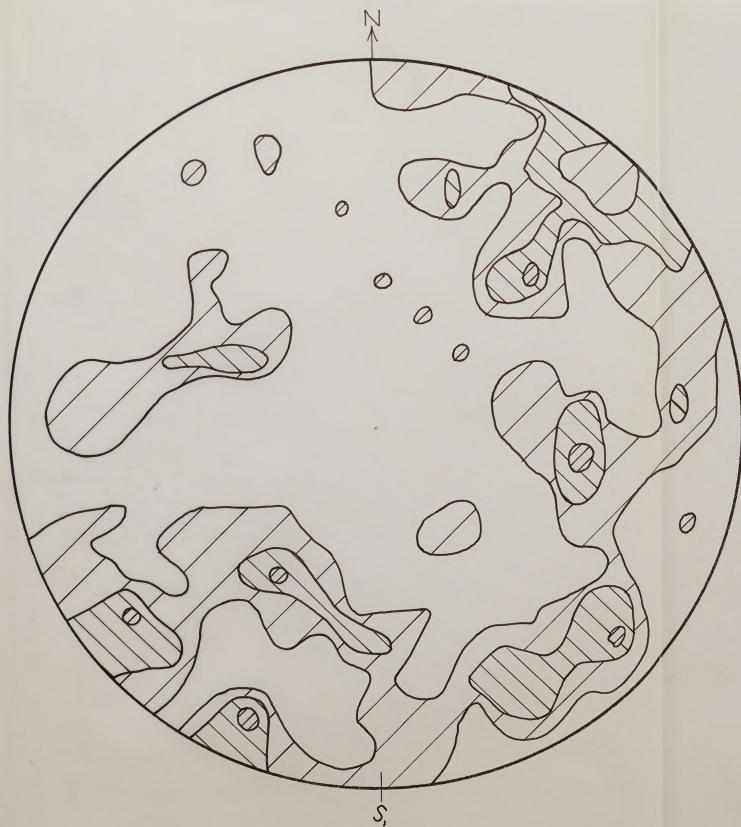


FIGURE 47. SAMPLE 7, HORIZONTAL CUT, HIGHWAY M-26 NEAR MASON.
200 QUARTZ C-AXES; GRAIN SIZE 7-3mm. CONTOURS 3-2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE
FACE POLE OF THE FAULT.

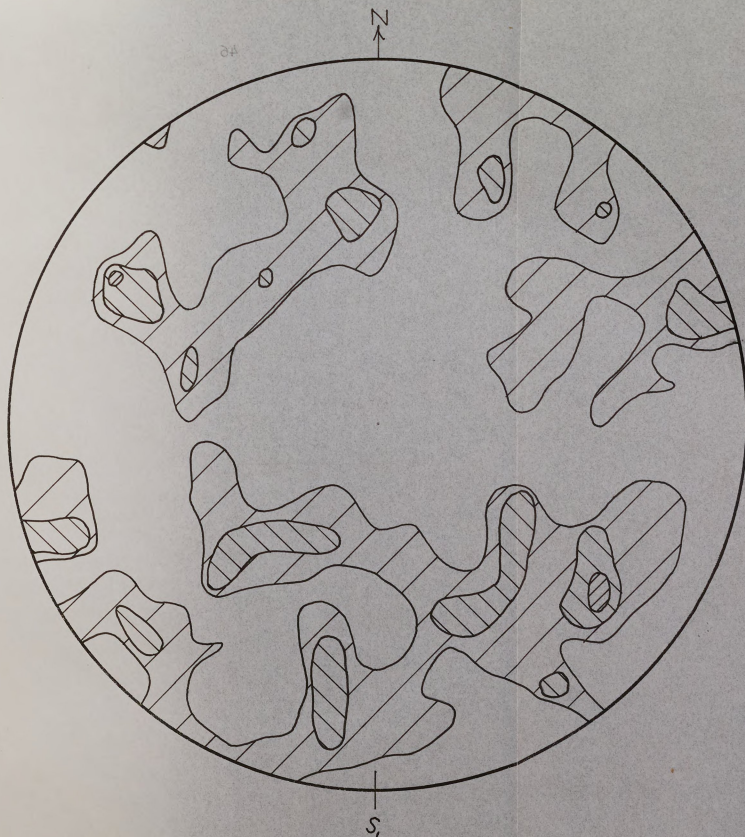


FIGURE 48. SAMPLE 7, HORIZONTAL CUT, HIGHWAY M-26 NEAR MASON.
200 QUARTZ C-AXES; GRAIN SIZE 1-3mm. CONTOURS 3-2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE
FACE POLE OF THE FAULT.

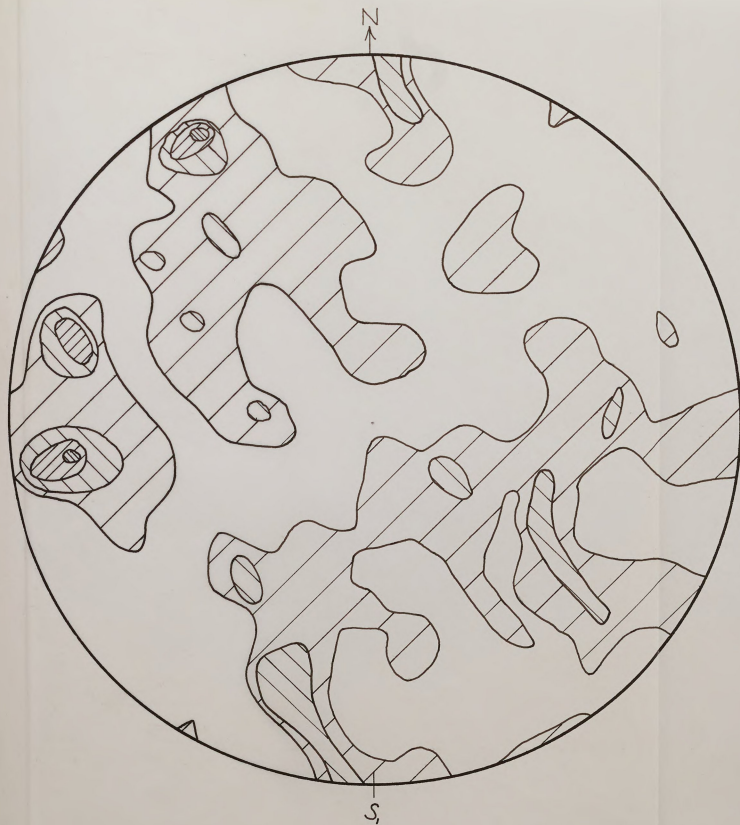


FIGURE 49. SAMPLE 21, VERTICAL CUT, JACOBSVILLE, REDSILTSTONE FACIES, 200 QUARTZ C-AXES; GRAIN SIZE ≥ 3 mm, CONTOURS 4-3-2-1%. S_1 IS THE BEDDING PLANE, S_2 IS THE FAULT PLANE, F.P. IS THE FACE POLE OF THE FAULT.

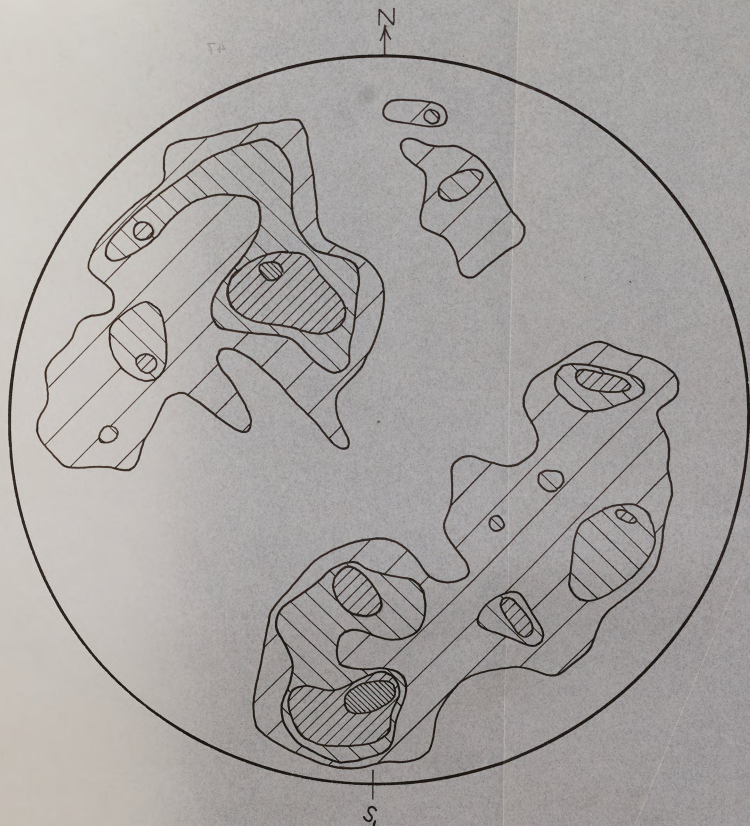


FIGURE 50. SAMPLE 21, VERTICAL CUT, JACOBSVILLE, REDSILTSTONE FACIES, 200 QUARTZ C-AXES; GRAIN SIZE 1-3 mm, CONTOURS 4-3-2-1%. S_1 IS THE BEDDING PLANE, S_2 IS THE FAULT PLANE, F.P. IS THE FACE POLE OF THE FAULT.

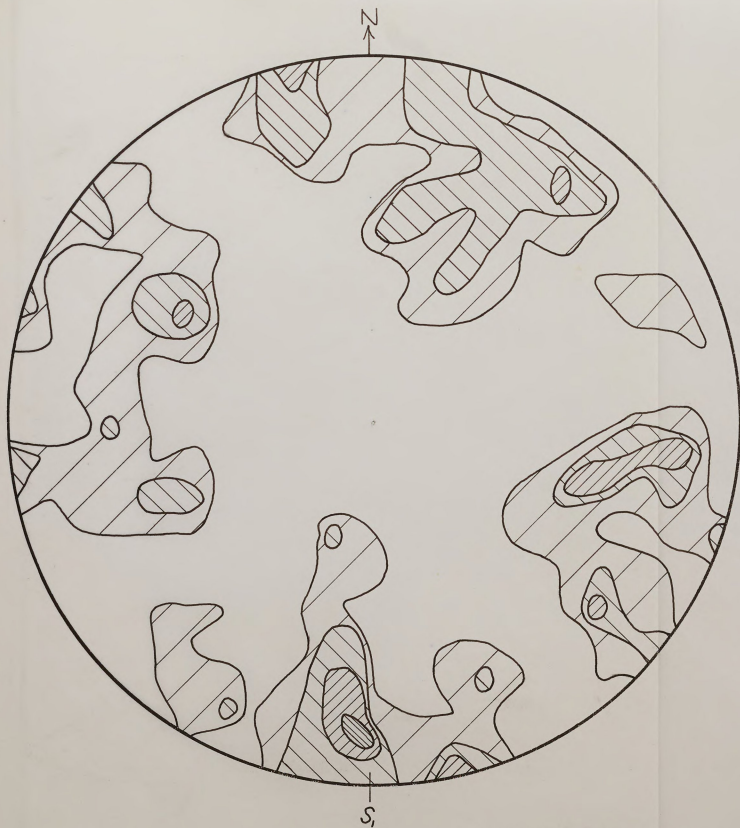


FIGURE 51. SAMPLE 21, HORIZONTAL CUT, JACOBSVILLE, RED SILTSTONE FACIES. 200 QUARTZ C-AXES; GRAIN SIZE $> 3\text{mm}$, CONTOURS 4-3-2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

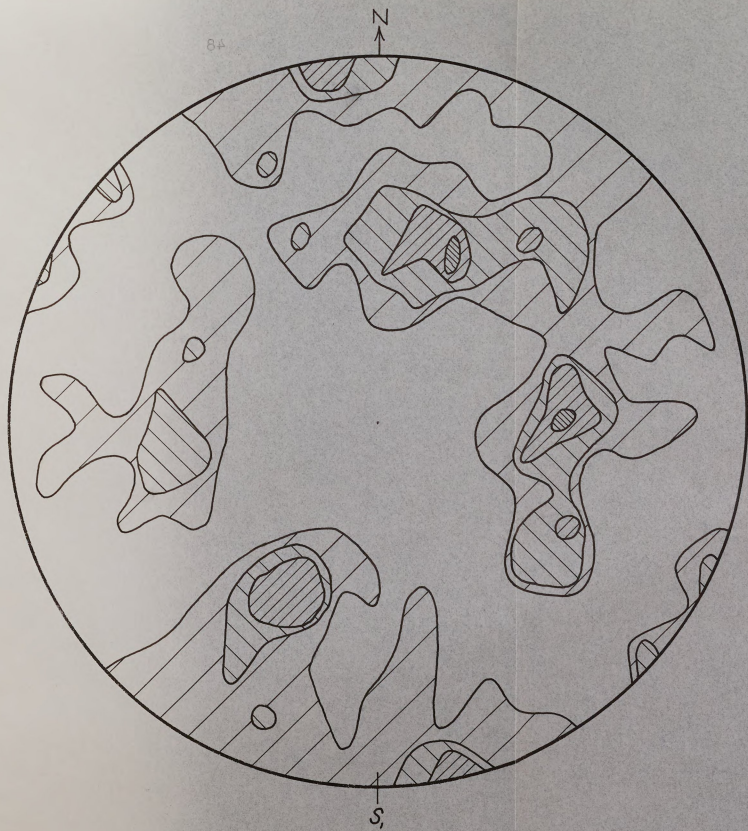


FIGURE 52. SAMPLE 21, HORIZONTAL CUT, JACOBSVILLE, RED SILTSTONE FACIES. 200 QUARTZ C-AXES; GRAIN SIZE $1-3\text{mm}$, CONTOURS 4-3-2-1%
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

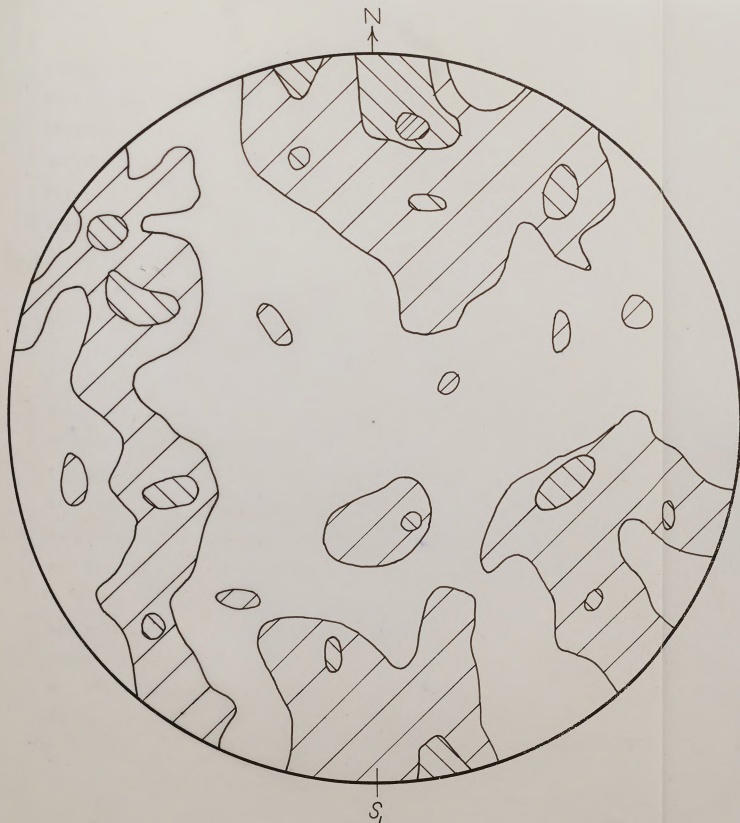


FIGURE 53. SAMPLE 21, COMBINED DIAGRAM, JACOBSVILLE, RED SILTSTONE FACIES.
400 QUARTZ C-AXES; GRAIN SIZE 2-3mm. CONTOURS 3-2-1%.
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE
POLE OF THE FAULT.

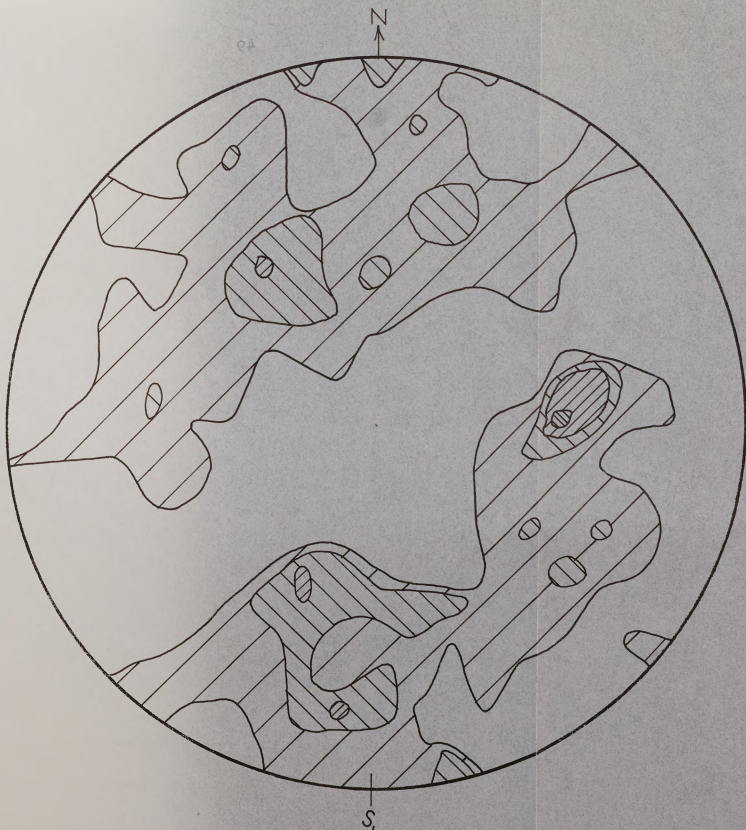
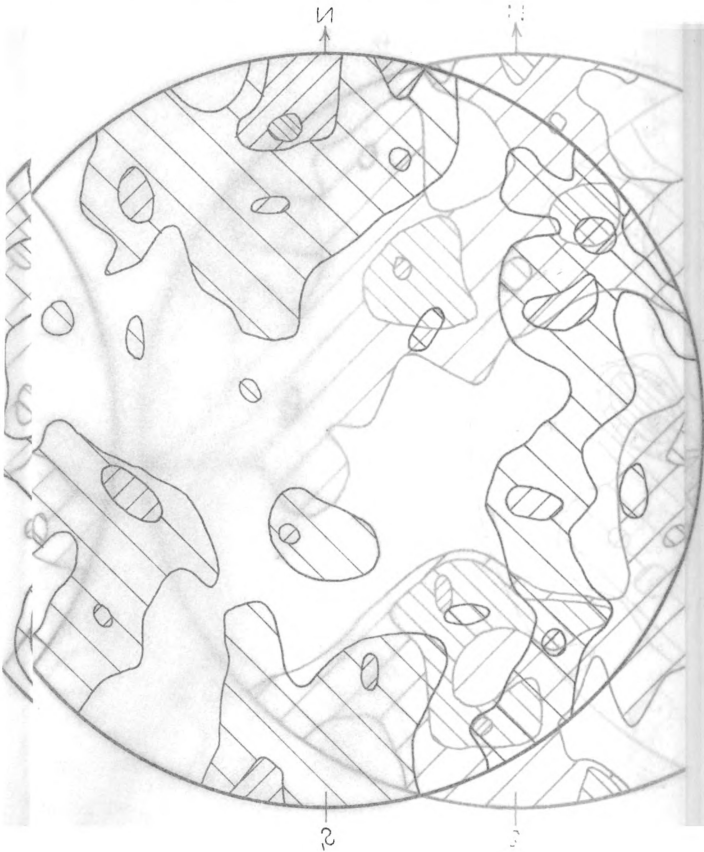


FIGURE 54. SAMPLE 21, COMBINED DIAGRAM, JACOBSVILLE, RED SILTSTONE FACIES.
400 QUARTZ C-AXES; GRAIN SIZE .1-3mm. CONTOURS 4-3-2-1%.
 S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE
POLE OF THE FAULT.

FIGURE 23. Sample 51, Combined Dismal-Jacobsville Red Silstone F.
400 QUARTZ CRYSTALS, GRAIN SIZE 2.5 mm. CONTOURS 3-5-T, 4-5-
... IS THE BEDDING PLANE. 2 IS THE FAULT PLANE. P IS THE POLE OF THE
POLE OF THE FAULT.



between $20 - 50^{\circ}$ and defined by three, four, and five percent maxima. Figures 51 and 52 also show this girdle tendency, however, there seems to be two quite well defined highs in Figure 52 situated opposite each other. Figure 51 shows a concentration of grains plunging at a low angle to the east-southeast. The combined diagrams (Figures 53 and 54) again exhibit a tendency for a dipping girdle with the main concentration in Figure 54 in the eastern portion of the diagram.

It is the authors opinion that the diagrams do suggest a girdle dipping in a west-northwesterly direction. The other concentrations could be explained as common sedimentary fabric patterns in which there is a tendency for a single or double maximum in the plane of the bedding, situated either parallel or transverse to the prevailing current direction (Figures 51 and 52). Another common sedimentary fabric is a girdle in the plane of the bedding.

These fabric diagrams probably show a combination of sedimentary fabric patterns. It is also possible that these patterns have been disrupted somewhat by forces associated with the faulting even at this distance from the fault contact.

Algoma Mine

The Algoma mine area is located 1.5 miles east of Mass, Michigan in Sec. 3, T. 50, R. 38 W. (Figure 2). Sample 6 was taken from massive and very friable sandstone

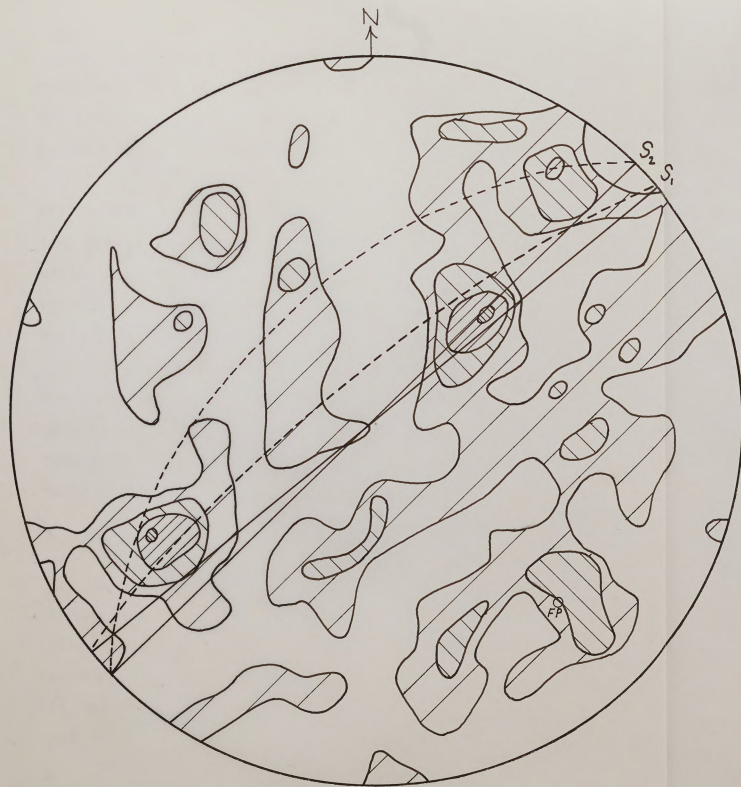


FIGURE 55. SAMPLE 6, VERTICAL CUT, ALGOMAH MINE AREA. 200 QUARTZ C-AXES; GRAIN SIZE $> 3\text{mm}$. CONTOURS 4-3-2-1%. S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

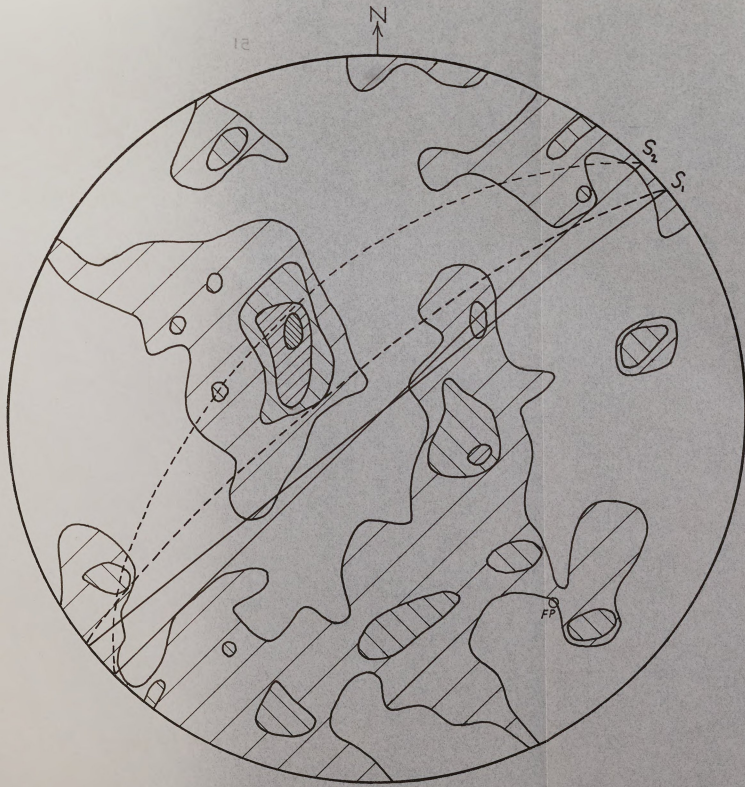


FIGURE 56. SAMPLE 6, VERTICAL CUT, ALGOMAH MINE AREA. 200 QUARTZ C-AXES; GRAIN SIZE $1-3\text{mm}$. CONTOURS 4-3-2-1%. S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

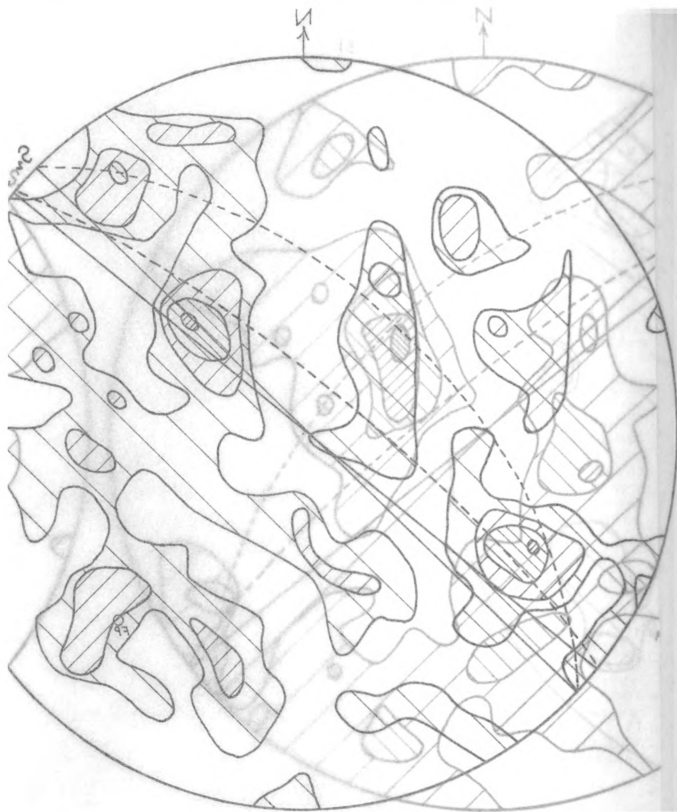


Figure 2. Sample 6, Vertical cut through Mine Area, 500 Quartz C
Grain Size 2-5 mm Contours 4-8-5-1%. 2 is the Bedrock
Plane. 2' is the Fault Plane. 1 is the Face of the 2

outcropping near the Algomah mine and only a few feet from the fault contact. Although massive, the sandstone appears to weather along a plane that has the orientation N50W, 80NW.

The fabric diagrams (Figures 55 and 56) show a fairly well defined girdle in the bedding plane and a somewhat less apparent AB girdle. Maxima of one to two percent define a girdle parallel to the BC plane. There is, perhaps, also the suggestion of an AC girdle, especially noticable in Figure 56.

Petrographic studies by the author indicate that this sandstone is almost identical in composition to known Jacobsville outcropping in the type section, and also to that outcropping at Victoria Falls, as described by Hamblin (1958).

Tobacco River

Sample 20 was taken from an outcrop in the Tobacco River, which runs east across Keweenaw County (Figure 2). This location is approximately seven miles from the fault contact. The outcrop has a slight northwesterly dip. It is composed of white sandstone and has a siliceous cement.

The fabric diagram (Figure 57) shows a tendency for a bedding plane and AB girdle. A weak BC girdle can also be defined.



FIGURE 51. SAMPLE 20, HORIZONTAL CUT, TOBACCO RIVER, 200 QUARTZ C-AXES; GRAIN SIZE APPROXIMATELY .2mm. CONTOURS 4-3-2-1-0. S_1 IS THE BEDDING PLANE. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

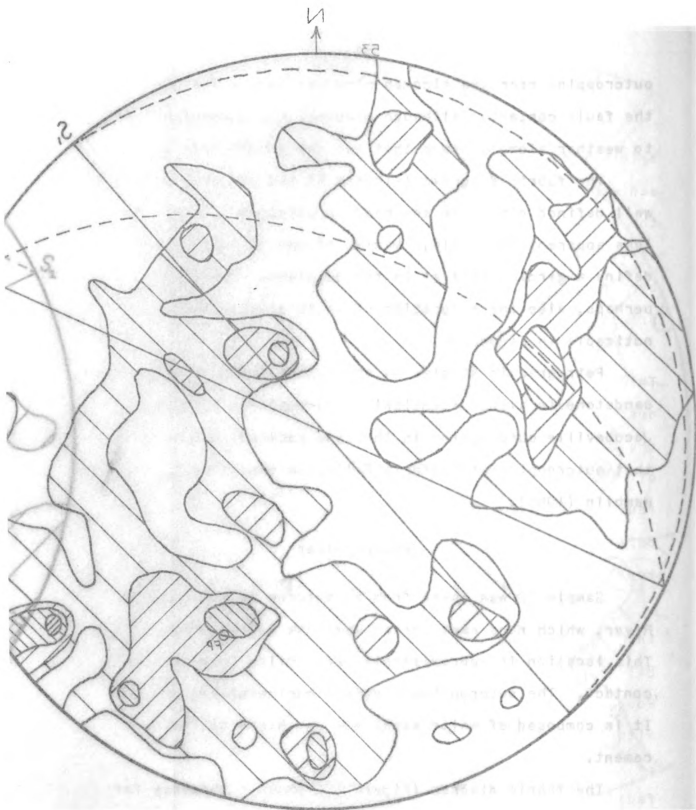


Figure 27. Sample 50, Horizontal cut, Tobacco River, 500 Quartz Cr. Grain size approximately 5 mm. Contours 4-5-10-20 is the bedding plane. 2 is the fault plane. 3 is the face of the

CONCLUSION

Three, and possible four patterns of preferred orientation are found in the sampled area. One is a sedimentary pattern defined by a girdle lying nearly in the plane of the bedding. It is probably a combination of sedimentary fabrics which may have been slightly disturbed by forces associated with the faulting or with tilting prior to the major faulting.

The second fabric is the suggestion of an AB girdle. This girdle would be expected as the long or c-axes of the quartz grains would tend to align themselves parallel to the direction of movement or perpendicular to the direction of greatest stress. In many cases where the bedding and fault planes are nearly parallel this girdle is very well defined. Probably the sedimentary and tectonic fabrics tend to reinforce each other.

The third pattern is that of a BC girdle. In many cases this girdle is of low intensity but the trend is visible. Balk (1952) found the development of a BC girdle in the Poughquag quartzite, Dutchess County, New York, in a similar situation of thrust faulting. This girdle would be expected as the result of dilation on a direction parallel to the fault, resulting in recrystallization along joint or incipient joint planes formed perpendicular to the fault plane.

A possible fourth pattern can be distinguished in

some diagrams. This is an AC girdle, perhaps similar to that found by Higgins (1947) in the Sturgeon quartzite, Dickenson County, Michigan. Higgins feels that this orientation is related to rotational shear about a vertical axis related to the faulting. He correlates the shear with differential movement of adjacent fault blocks.

It is also possible that tension resulting from a rapid change in the plunge of the fold axis would cause tension joints to develop parallel to the AC plane. There would be a tendency for recrystallization on this plane in response to reduced pressure.

The maximum concentration on diagrams for horizontal, slightly deformed, and highly deformed outcrops were combined and plotted. The resulting patterns for large and small grains in the highly deformed areas lying within approximately 600 feet of the fault contact (Figures 58 and 59) show fairly well defined AB and BC girdles. The orientation of the fault is about the same for all of the areas, the average orientation being N25E, 30NW. The fault plane and face pole are shown on the diagrams.

In the diagrams for the less deformed appearing areas (Figures 60 and 61), at distances greater than 600 feet from the fault contact, the AB and BC girdles are not as well defined. There is, however, the suggestion of a weak girdle in the AC plane. The combined horizontal maxima (Figure 62) lie in a fairly well defined girdle nearly parallel to the bedding plane.

The study shows that there is an original depositional fabric present in the sandstone. This fabric has been disturbed by forces associated with the faulting, and a tectonic fabric has been overprinted on the sedimentary fabric in the form of fairly well defined AB and BC girdles. The presence of this tectonic fabric indicates that the major movement along the Keweenaw fault was definitely post-Jacobsville, and that the contact between the basalt and the sandstone does not represent an unconformity with the sandstone being deposited against the fault scarp sometime after the major thrusting.

Although there is the development of a tectonic fabric, the exact nature of the deformation of the sandstone is not indicated by the petrofabric study. Ripple marks from the Natural Wall, collected by Dr. Harold Stonehouse (2), indicate that the top of the formation is to the southeast. This means that the Wall was formed by the thrusting of originally horizontal beds upward into a vertical position, and is not a situation of reverse drag. There is also evidence, in the form of overturned cross bedding, that the sandstone at the Hungarian Falls has been thrust into a recumbent fold by the faulting, instead of being relatively undeformed as was previously believed.

Detailed field work, which was beyond the scope of this thesis, is needed to interpret fully the exact nature and extent of the deformation of the Jacobsville sandstone by forces associated with the faulting.

2) Stonehouse, Dr. Harold, Personal Communication, 1969.

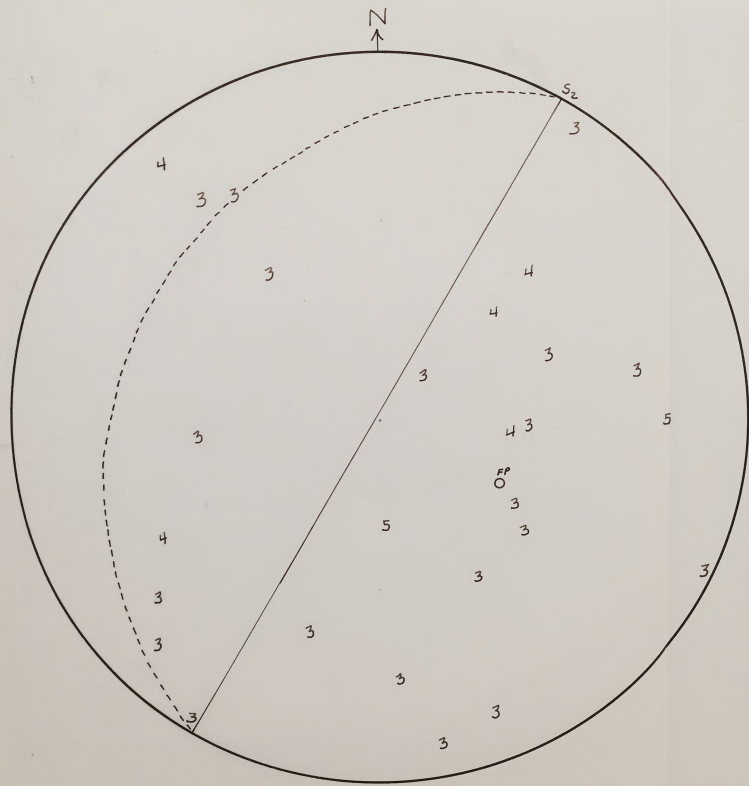


FIGURE 58 COMBINED MAXIMA FROM HIGHLY DEFORMED AREAS, WITHIN 600 FEET OF FAULT CONTACT. GRAIN SIZE $> 3\text{mm}$. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

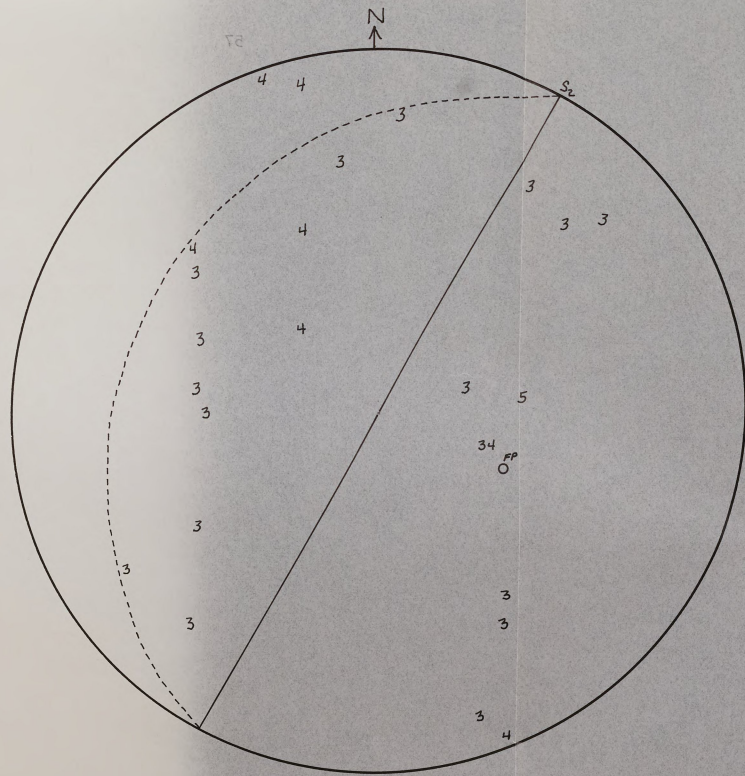


FIGURE 59. COMBINED MAXIMA FROM HIGHLY DEFORMED AREAS, WITHIN 600 FEET OF FAULT CONTACT. GRAIN SIZE $1-3\text{mm}$. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

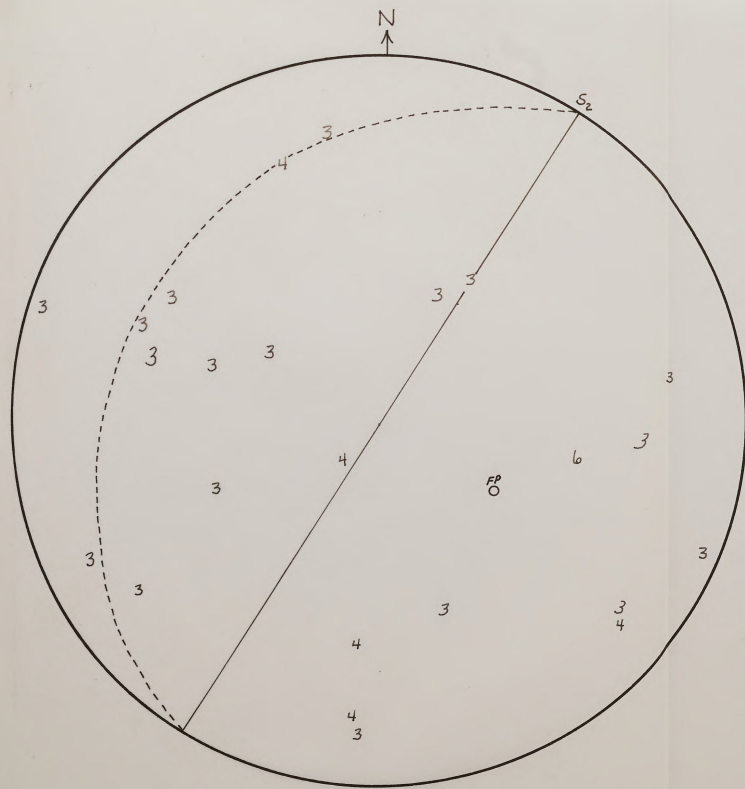


FIGURE 60. COMBINED MAXIMA FOR AREAS SHOWING SOME DEFORMATION. GRAIN SIZE > 3 mm. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

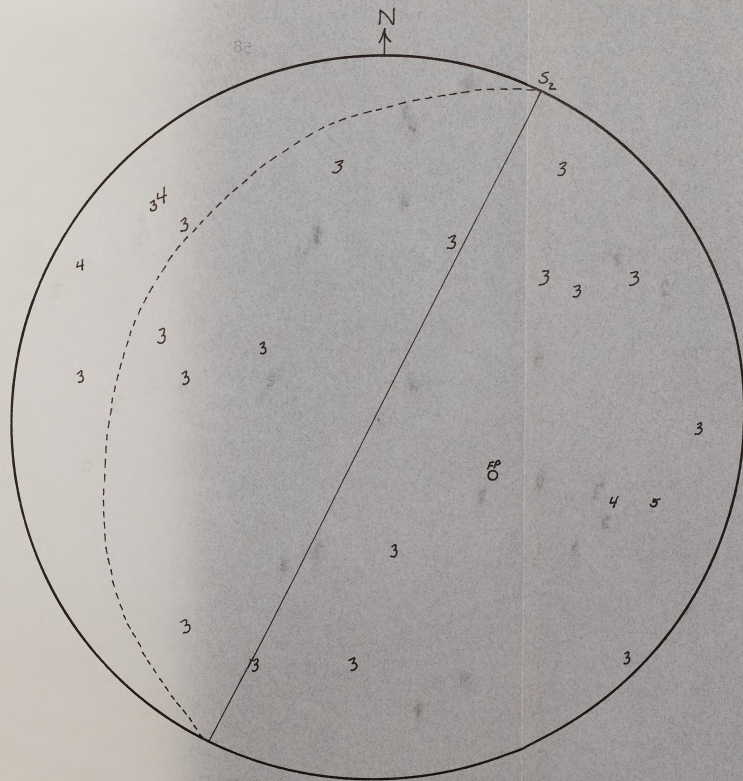


FIGURE 61. COMBINED MAXIMA FOR AREAS SHOWING SOME DEFORMATION. GRAIN SIZE > 3 mm. S_2 IS THE FAULT PLANE. FP IS THE FACE POLE OF THE FAULT.

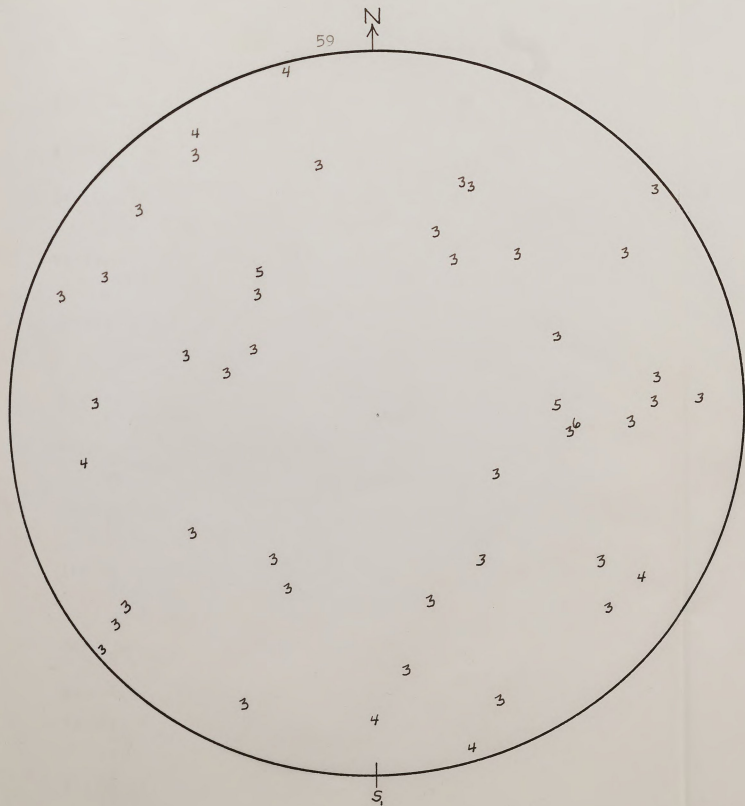
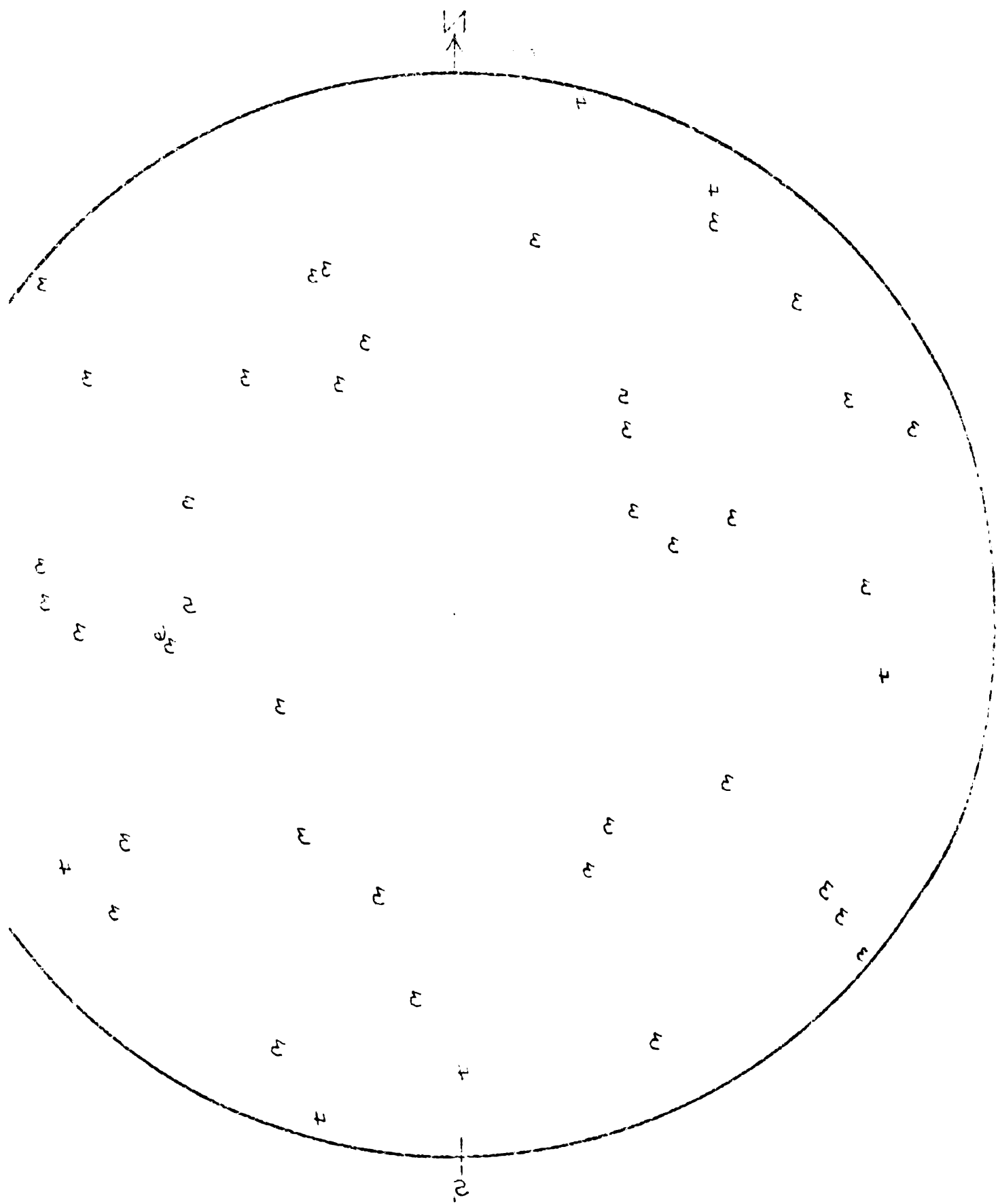


FIGURE 62. COMBINED MAXIMA FOR HORIZONTAL STRATA.

FIGURE 2. Combined Maxima for Horizontal Strata.

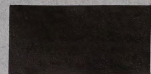


BIBLIOGRAPHY

- Balk, Robert, 1952, Fabric of quartzites near thrust faults: Jour. Geology, v. 60, p. 415-435.
- Billings, M. P., 1954, Structural geology, 2d Edition: New Jersey, Prentice-Hall, Inc., 490 p.
- Denning, R. M., 1949, The petrology of the Jacobsville sandstone, Lake Superior: unpublished M.S. thesis, Michigan College of Mining and Technology.
- Fairbairn, H. W., 1939, Hypothesis of quartz orientation in tectonites: Geol. Soc. America Bull., v. 50, p. 1475-1492.
- Griggs, David, and Bell, James F., 1938, Experiments bearing on the orientation of quartz in deformed rocks: Geol. Soc. America Bull., v. 49, p. 1723-1746.
- Hamblin, W. K., 1958, The Cambrian sandstones of northern Michigan: Michigan Geol. Survey, pub. 51, 146 p.
- Higgs, D. V., and Tunell, G., 1966, Angular relations of lines and planes: San Francisco, W. H. Freeman and Co., 43 p.
- Higgins, James W., 1949, Structural petrology of the Pine Creek area, Dickenson County, Michigan: Jour. Geology, v. 55, p. 476-496.
- Irving, R. D., and Chamberlin, T. C., 1885, Observations on the junction between the Eastern sandstone and the Keweenaw series on Keweenaw Point, Lake Superior: U. S. Geol. Survey Bull. 23, 124 p.
- Pettijohn, F. J., 1957, Sedimentary rocks, 2d Edition: New York, Harper and Bros., 718 p.
- Stonehouse, Dr. Harold B., 1969, Personal Communication.
- Turner, F. J., and Weiss, L. E., 1963, Structural analysis of metamorphic tectonites: New York, McGraw-Hill, 620 p.
- Vistelius, Andrew B., 1966, Structural diagrams: New York, Pergamon Press, 178 p.

APPENDIX A
Key to Petrofabric Diagrams

KEY TO
PETROFABRIC DIAGRAMS



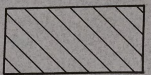
5-6 %



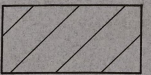
4-5 %



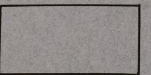
3-4 %



2-3 %



1-2 %



0-1 %