PETROLOGY AND PETROFABRICS
RANDVILLE DOLOMITE IN THE FELCH
TROUGH, DICKINSON COUNTY, M

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ABSTRACT

PETROLOGY AND PETROFABRICS OF THE RANDVILLE DOLOMITE IN THE FELCH MOUNTAIN TROUGH, DICKINSON COUNTY, MICHIGAN

by Donald A. Dryden

Samples were taken of the Randville Dolomite where it outcropped in the Felch Mountain trough between Felch and Randville in Dickinson County, Michigan. The Randville is of Huronian Age and has been metamorphosed to a dolomitic marble. Ten outcrops were used from which thirteen specimens were taken. Four specimens were taken from one outcrop to standardize areal deviation.

Each outcrop, from which a specimen was taken, was mapped at a scale of 1" = 10'. The maps show specimen locations plus joint attitudes and locations.

Twenty-six thin-sections were prepared from the 13 samples and were studied under a petrographic microscope. The results showed that dolomite was the major constituent of the marble with tremolite, diopside and talc as major accessory minerals.

The thin-sections were also used to do a petrofabric analysis on the dolomitic marble. Standard orientation procedures were used.

Donald A. Dryden

Orientation analysis of 9530, C-axes of dolomite grains from twenty-four thin-sections revealed a weak fabric pattern with maximum orientations lying normal to the regional structural strike (north-northeast) or paralleling the direction of the deforming force.

A statistical analysis, using a correlation coefficient as a measure of preferred orientation, substantiated the findings and interpretations of the petrofabrics work.

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By

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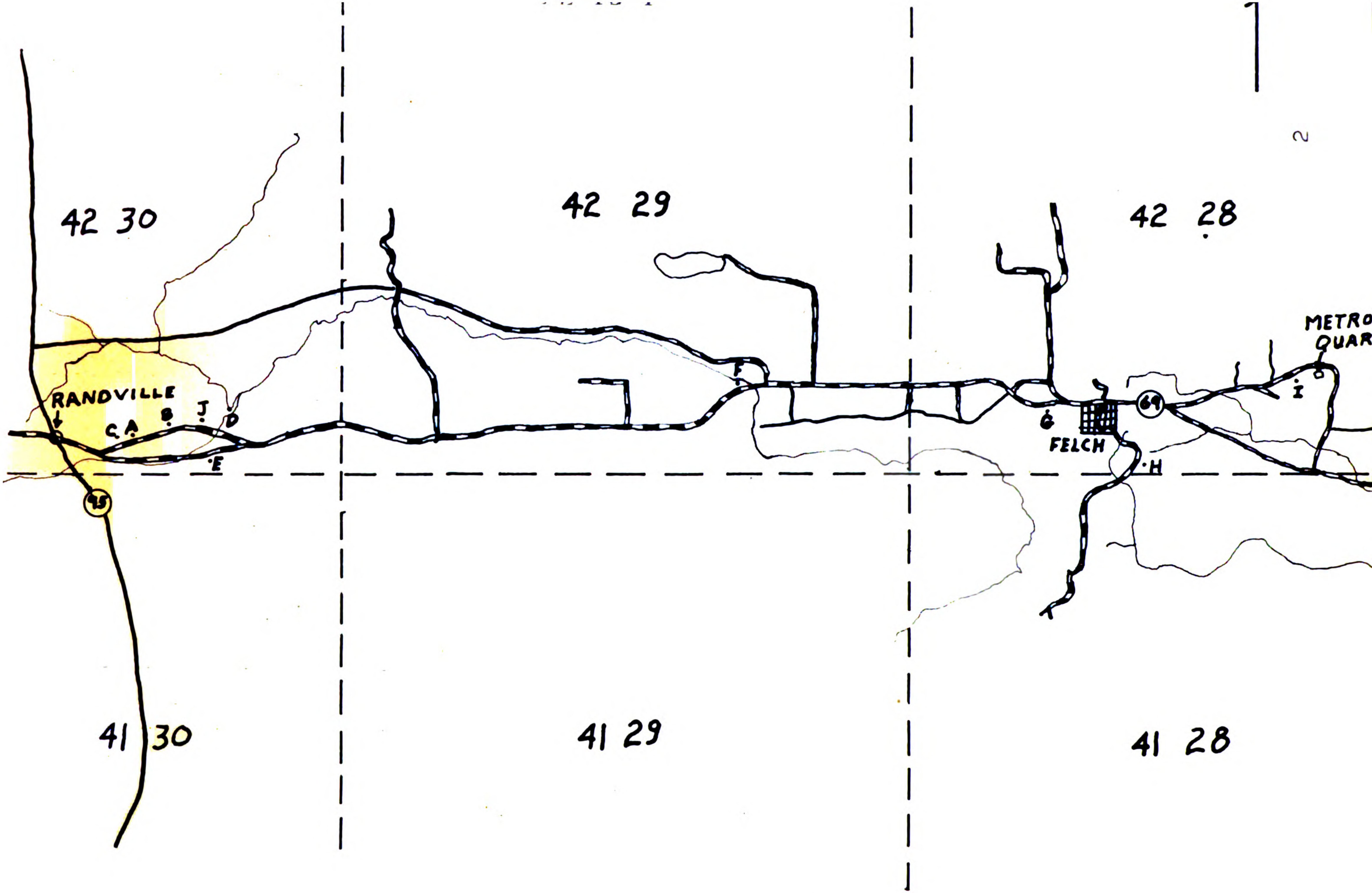
INTRODUCTION

The Felch Mountain trough is a fairly narrow structure running roughly east and west between the villages of Felch on the east and Randville on the west in Dickinson County, in the western part of the northern peninsula of Michigan. Geologically, it is a syncline of Precambrian metamorphosed sediments and igneous intrusions.

Although the relief is not great, the area is still rather rugged topographically. This is due in large part to the glacial debris and alternation of weak and resistant rocks forming abrupt changes in relief. Furthermore swamps, heavy forest and thick underbrush hinder field study. The West Branch of the Sturgeon River, formed between the low steep-sided knolls, intervening swamps and occasional steep-sided valleys, meanders nearly the length of the trough. The area of greatest relief and elevation is in the Felch Mountain area itself.

This report concerns an area which is over 13 miles long and includes the southern portion of T. 42N, R.'s 28, 29, and 30W. The map on page 2, Plate #1, shows the locations of the outcrops from which samples were taken. The samples


42 30
42 29
42 28
METRO
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RANDVILLE
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D
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69
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came from ten outcrops already located by the United States Geologic Survey. Detailed sketches of these outcrops, showing the location of samples and joint attitudes were taken at a scale of 1" = 10' (in pocket). Four oriented samples were taken from outcrop "E" which were used to standardize areal deviation.

The outcrops from which samples were taken consisted of dolomitic marble, some metamorphosed more than others. All outcrops were massive so that strike and dip of beds could not be observed.

The field work on the area was done in late June and early July of 1960. Petrofabric and petrographic examinations were then made of twenty-six thin sections taken from thirteen samples. Of primary concern was the orientation of the dolomite crystals of the marble in relation to the structural geology and, the correlation of these findings with those of Solberg (1958), who did a similar study on rocks exposed in the Metronite quarry at the eastern end of the trough. Of secondary nature was the study of the petrography and metamorphism of the dolomite.

GEOLOGIC SETTING

Until recently, little geologic data concerning the trough was available. In 1961, Professional Paper 310 (Geology of Central Dickinson County, Michigan), was released. This work, compiled primarily from works of James, Clark, Lamey and Pettijohn, is partly concerned with the area studied in this problem.

Earlier works are incomplete or only partially cover the area. Some of the better works are: 1) Progress report briefly outlining the regional geology, by C. E. Dutton (1950), 2) A portion of a paper by H. L. James (1955), on regional metamorphism in Northern Michigan, 3) An older work by Van Hise and Leith (1911) on the geology of the Lake Superior region. Other monographs pertaining to the area are available. Bailey and Smythe (1899) is perhaps the best, as it includes previous works in the area.

Stratigraphy

The Felch trough is underlain almost entirely by metamorphosed Animikie metasediments. These rocks are of Middle Precambrian age and in most stratigraphic successions are included as part of the Huronian series. Table I gives the

TABLE 1

(AFTER LAMEY GEOLOGICAL SURVEY PROFESSIONAL PAPER 310)

Middle Precambrian:	
Post-Animikie	Granite pegmatite.
	Massive granite.
	Metadiabase and metagabbro.
Animikie series:	
Baraga group	Badwater greenstone.
	Michigamme slate.
	Hemlock formation.
Unconformity.	
Menominee group	Vulcan iron-formation.
	Felch formation (includes schists of at least four types, believed to be correlative).
Unconformity.	
Chocolay group	Randville dolomite.
	Sturgeon quartzite (includes schist below and above vitreous quartzite).
	Fern Creek formation.
Unconformity.	
Lower Precambrian rocks:	
"Algoman"(?)	Gneissic granite.
Dickinson group	Six-mile Lake amphibolite.
	Solberg schist and Skunk Creek Member.
	East Branch arkose.
Unconformity.	
Pre-Dickinson	Granite gneiss.

probable stratigraphic succession of the Middle Precambrian in the Felch Mountain District as interpreted by Lamey (1961). The sedimentary rocks, as well as the younger metadiabase, are cut by granite and granite pegmatite dikes.

Structure

Although the local structure has been interpreted by a few workers, the best is perhaps the oldest by Van Hise (1911). It is a very general but accepted report.

"The structure is an east-west synclinorium constituting a narrow strip nowhere more than 1 1/2 miles and usually less than a mile wide, which as a whole runs over 13 miles. Although the general structure is synclinal, a single fold of simple type has nowhere been found to occupy the whole cross-section of the Algonkian formation, but usually two or more synclines occur, separated by anticlines, which may have different degrees and directions of plunge and different strikes, complicated besides, both, by subordinate folds and by faults" (p. 302).

It might be well to note here that all of the local synclines have a northeast to east trend.

The Randville Dolomite outcrops over a larger part of the trough's surface than any other member of the succession. It is probable that the thickness of the formation is not uniform, but increases from east to west.

PETROGRAPHY AND PETROLOGY

The major rock unit of study is a dolomitic marble with the formational name of Randville Dolomite and of lower Huronian Age. The Randville has certain mineral assemblages and characteristics that identify it. Here it will be called "dolomitic marble" or "Randville formation."

Detailed study of the marble was limited to samples taken along a fourteen-mile east-west strike at varying distances from each other. Where there were not enough outcrops the spacing was as far apart as five and one-half miles. The dolomite outcrops are identifiable by their massive knobbish form and the gray to black weathering surface.

Field study supplemented the thin section observation. There is no visible foliation. Megascopically, dolomite is the main constituent of the marble, with tremolite occurring in most samples in varying quantities. Talc, diopside, and quartz are present in minor amounts in many samples, with diopside becoming the main constituent in sample "F".

Samples "E" and "H" were taken from outcrops on the south side of the trough and the rest were taken from outcrops believed to be on the north side.

TABLE II

MODAL ANALYSIS OF DOLOMITIC MARBLE

Analysis	Sample A	B	C	D	E_1	E_2	E_3	E_4	F	G	H	I	J
Dolomite	92.4	75.6	95.4	66.95	91.1	86.4	92.4	96.53	--	100.00	82.96	88.91	67.62
Tremolite	7.4	22.5	1.0	3.08	0.3	12.8	X	0.24	11.9	X	11.08	6.70	30.10
Talc	--	X	X	0.14	8.1	0.8	7.6	2.77	--	--	5.11	3.31	--
Diopside	X	0.7	X	28.11	--	--	--	--	88.1	X	X	X	2.27
Quartz	--	--	3.6	--	0.5	--	--	0.47	X	--	0.85	0.29	--
Opaque (Pyrite)	X	1.3	X	1.72	--	--	--	--	X	X	X	0.79	X
TOTAL	98.8	100.1	100.0	100.00	100.0	100.0	100.0	100.01	100.00	100.00	100.00	100.00	99.99

X = trace

Dolomite. Texturally, the rock is granoblastic. The grain size ranges from 0.1 mm. to 0.83 mm. with the average of all samples being 0.24 mm. Samples from the Felch district seem to have much larger crystals than the samples from the western end of the trough.

Dolomite makes up 86% of the marble in all sections, except "F" which has completely changed to diopside and tremolite. In half of the samples it makes up over 90% of the rock.

The dolomite in thin section shows typical characteristics, such as high order white interference color and marked change in relief upon rotation of the stage. The average index of refraction of N_e and N_o for the dolomite is 1.664. To help identify the dolomite, interference figures were taken on many of the crystals that stayed gray to dark on 360° rotation of the stage. There are many of these in each slide except ones from sample "F." Figures 1 and 2, Plate II show the dolomite with some crystals exhibiting characteristic pressure twinning with crossed nicols and under plain light.

When using the universal stage and recording the orientation of the optic C-axes, it was noted that the isotropic sections could be distinguished by a lower order interference color (brighter).

In many cases, crystals of dolomite are enclosed by tremolite. Plate III, Figures 3 and 4 from sample "E_2" show a good example of this.

In other cases the dolomite seems to be corroded or clouded by iron and silica (Figure 5, Plate IV). This is especially true when in contact with amphiboles or if there is a lot of amphibole in the rock.

Thin section study revealed no foliation.

Tremolite. The tremolite for the most part occurs in aggregates of subhedral blades, although many individual blades are present throughout the series of samples. Some of the blades were as long as 1.00 mm. and 0.15 mm. in width, the average being much smaller. Sample F revealed excellent long blades (Figures 7 and 8, Plate V). Although the tremolite is bladed, no preferred orientation appeared.

The greenish white or gray bladed tremolite was megascopically visible in nearly all sections and obviously had some iron content. It is easy to recognize on the weathered surface of the outcrops as it stands out in relief against the surrounding dolomite which has been weathered away by solution. Diopside, which also stands out, was mistaken for it occasionally.

It was found after microscopic examination that samples A, B, E_2, H, I and J were fairly high in tremolite content, especially B and J. As stated before, some of what was thought to be tremolite when studied megascopically, was later found to be basal sections of diopside when examined under the microscope.

The tremolite was identified by its blade-like form, its 16^o-20^o extinction angle and distinguished by the biaxial negative interference figure. From diopside's biaxial positive figure, high (39^o) extinction angle and short stubby crystal habit.

When tremolite was cut across a basal section, it showed remarkably well formed 56^o and 124^o cleavage (Plate VI). This is in contrast with diopside's nearly 90^o cleavage.

Diopside. The diopside is an accessory mineral in most samples but in sample "F" it is the main constituent. Its crystal habit is short and stubby and some very large individuals appear, especially in the "F" specimen, where one crystal is 10.00 mm. long and 3.50 mm. wide.

In this particular sample the dolomite is completely replaced by tremolite and diopside, the diopside making up 88.1% of the rock. The identification of the pyroxene has already been discussed in previous paragraphs.

Megascopically it can be identified in samples "D" and "F" as very flat basal partings which seem to have a greenish core and a more cream colored rim. Some good diopside (90°) cleavage can be seen in Figure 11, Plate VII, taken from outcrop "F."

Talc. Talc is another accessory mineral which appears in minor amounts in most sections, especially the "E" series. Megascopically, the talc can be found in soft small segregations in the rock and can be picked out by a knife blade. When this is done the talc appears very fibrous (probably pseudomorphous of tremolite) - (Dana, 1932), but when rolled between the finger-tips it breaks down readily into a soft smooth powder.

Microscopically, the talc appears in plates which give the "birds-eye" effect, a sort of speckled appearance to the bright green and yellow interference colors. Also many of the plates seem to bend. It can be identified by its optic angle (6-30°) and association with magnesium bearing minerals. In some sections it occurs as a very fine grained, scaly aggregate which looks like sericite. This and some individual plates are shown on Plate VII, Figure 12.

Other minerals associated with the dolomite are rare. Quartz is found in only four samples. It runs in veinlets in one or two places which would suggest secondary injections, yet in other places it appears to be native to the rock before metamorphism, i.e., quartz which has not been used to change the dolomite to pyroxene. The quartz is fine grained and is associated with pyroxenes and amphiboles, as pictured in Figures 13 and 14, Plate VIII.

An opaque mineral, identified as pyrite in all cases, is found in nearly every thin section. The pyrite appears to have partly replaced some of the silicates.

Interpretation. Through thin-section examination, it appears that the marble has experienced complete recrystallization, for none of the constituents are present in their original form. This is indicated by the large grain size, blades of tremolite, grains of diopside and other minerals foreign to an original dolomite. Although the original dolomite was probably impure, containing such elements as silica and iron as some of its impurities.

It seems in many places as though only the original constituents were used in the recrystallization. Yet in others, some quartz and perhaps pyrite appear to have been introduced by granite pegmatites, as suggested by stringers of quartz with pyrite in association with it. This might be the case in outcrop "I," where granite dikes appear nearby and free quartz is evident on the weathered surface of the outcrop (outcrop map in pocket). Other free quartz may have crystallized later than the general metamorphism, by hydrothermal action, as suggested by Lamey (1961).

Frequent and multiple twinning shows that the dolomite was affected by the folding. Hawkins (1949) reported that twinning in dolomite is found only where stress and strain of deformation occur and Fairbairn (1954) concluded that twins develop only in grains of restricted orientation.

Tremolite is present in varying amounts in every slide. Tremolite is a metamorphic mineral and is usually restricted to metamorphosed limestones or limy sediments (Moorehouse, 1959) which proves that there has been recrystallization due to some type of metamorphism.

In a few cases, some of the tremolite has in turn altered to talc. Here the tremolite has probably been subjected to hydrothermal alteration. It is a common alteration of non-aluminous magnesium silicates, like tremolite (Dana, 1932).

In sample "F," the major constituent is diopside which is a minor constituent in other samples. The diopside is believed to be an alteration of the dolomitic marble, but there is no direct evidence of this as there are not any remnants of marble left. From observing other slides, such as "D," it appears that the diopside is a direct alteration of the dolomite.

Diopside is a common constituent of hornfels and metamorphosed dolomite and limestone (Moorehouse, 1959). Since the outcrop is found on the north side of the trough and since there are no hornfels or other carbonates found in the trough, it is safe to assume the outcrop is the altered Randville.

Why the dolomite is more altered at "F" than at other points is not hard to explain once the outcrop map is viewed. It will be noticed at the south end of the main outcrop is a pegmatite knob. The direction the dike trends is questionable, but Lamey (1961) has observed that most of the pegmatite dikes trend nearly northward. From this pegmatite would come the heat and large amounts of quartz needed to alter the complete outcrop.

The course grained texture of samples "G" and "H" which were collected from outcrops near the village limits of Felch (Table III) is also of interest. None of the other dolomitic samples even approach the average grain size of "G" and "H." "I," which is in the same vicinity of these two has very large grains also, but these large grains are surrounded by a matrix of fine grains which reduce the average grain size of the sample. It is thought that where metamorphism has progressed further, there is a general tendency toward an increase in grain size (Spock, 1953). This indicates that the eastern end of the trough received a higher degree of metamorphism than the western half.

TABLE III

GRAIN SIZE CHART

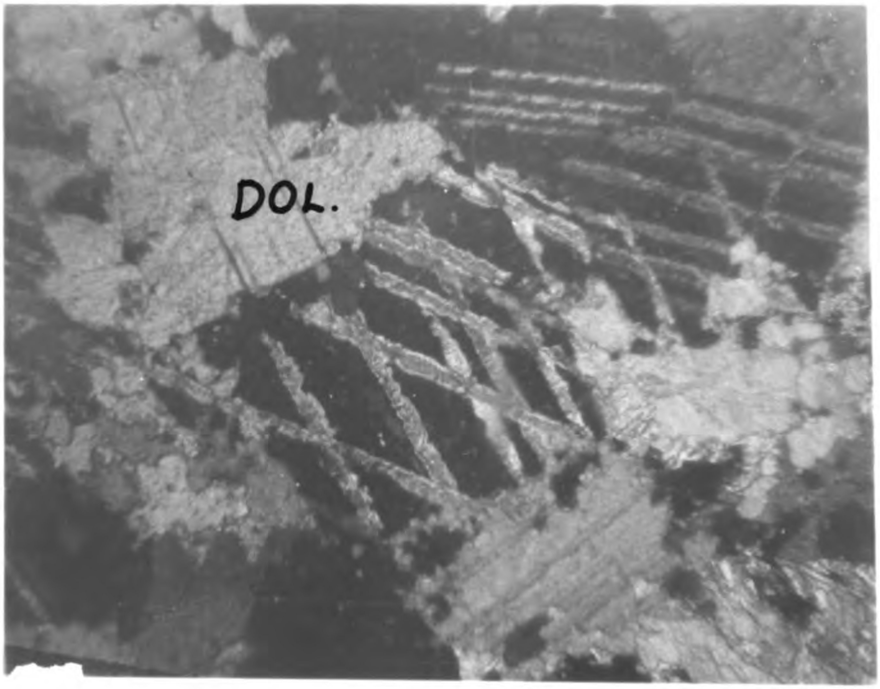
Sample	Average Size (mm.)
A	24.0
B	22.9
C	30.0
D	11.3
E_1	20.9
E_2	19.0
E_3	16.4
E_4	21.0
F	142.2
G	43.8
H	44.1
I	18.7
J	16.2

Average of all dolomite samples (excludes F) = 24.0

PLATE II

Figure 1. Photomicrograph of dolomite marble, showing pressure twinning taken from slide A_h. Crossed nicols, X90.

Figure 2. Photomicrograph of dolomite marble, showing pressure twinning taken from slide A_h. Plain light, X90.


DOL.

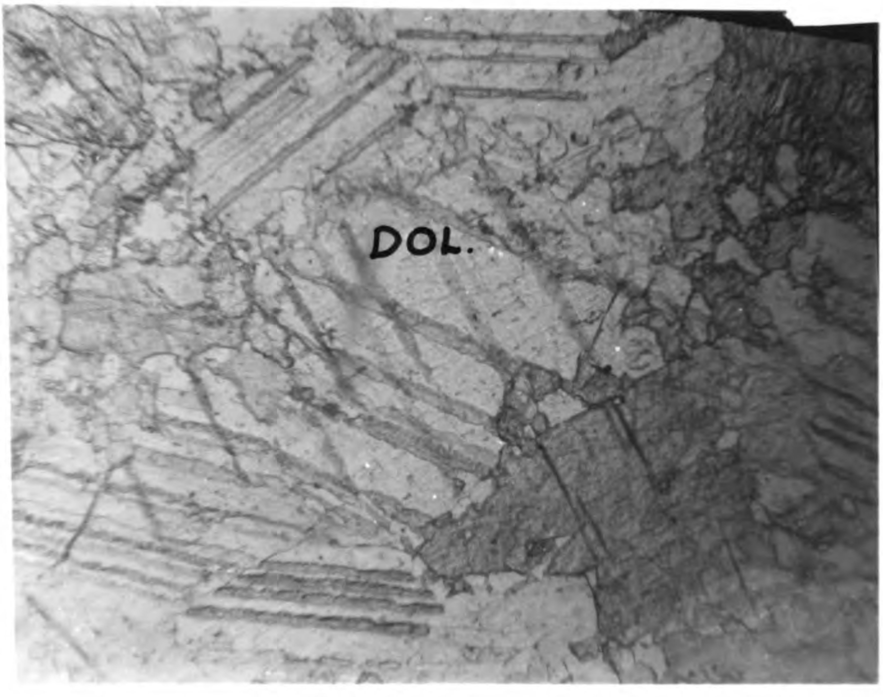
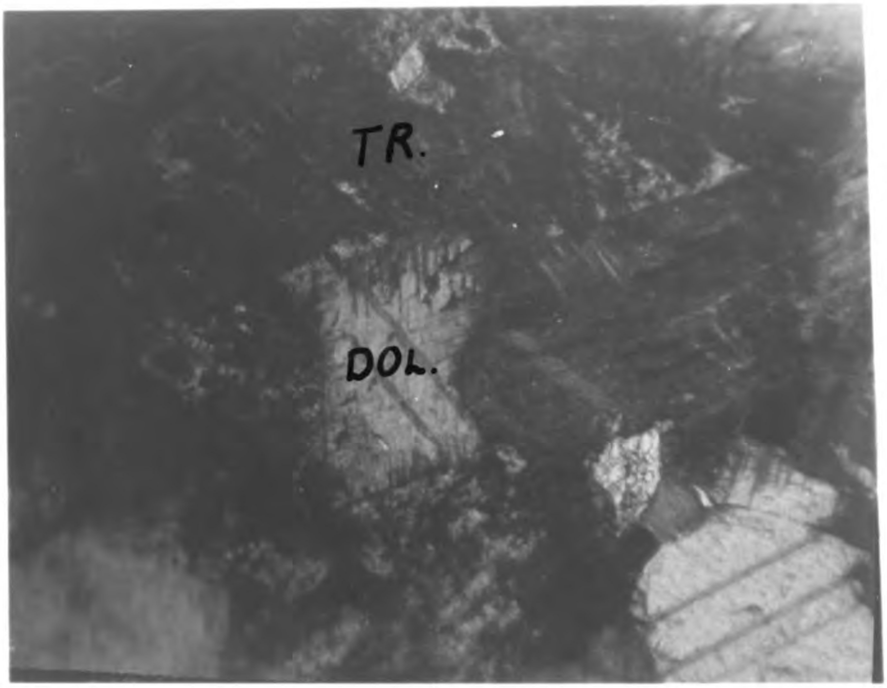

DOL.

PLATE III

Figure 3. Photomicrograph of dolomite marble and tremolite, showing tremolite surrounding dolomite and replacing it. Crossed nicols, X90.

Figure 4. Photomicrograph of dolomite marble and tremolite, showing tremolite surrounding dolomite and replacing it. Plain light, X90.


TR.
DOL.

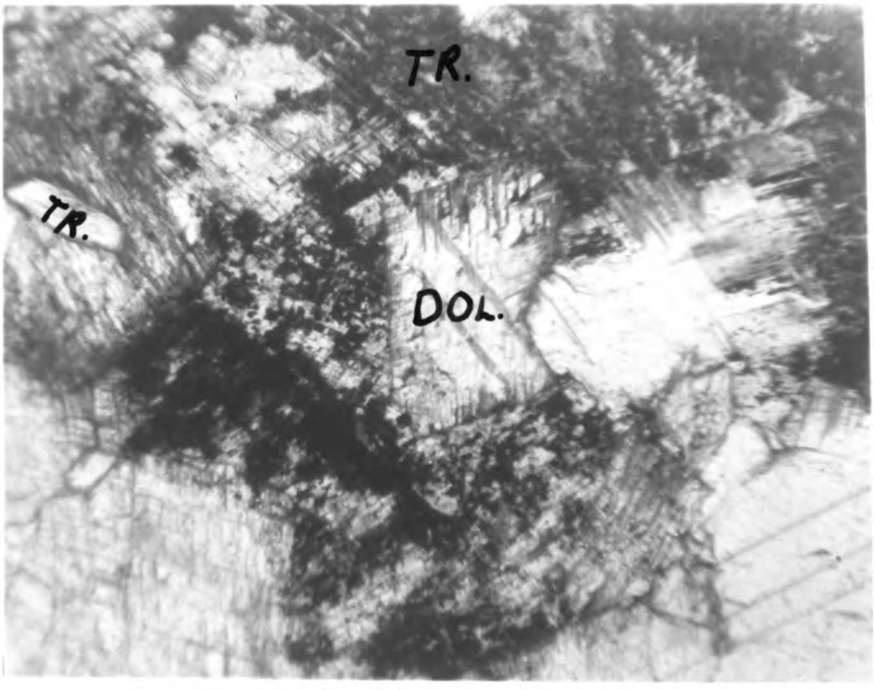
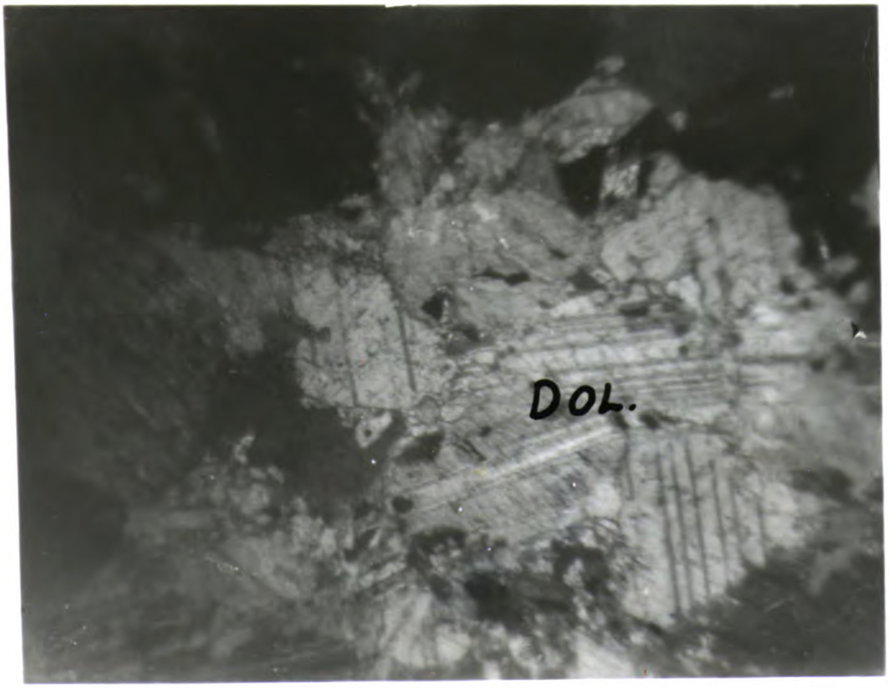

TR.
TR.
DOL.

PLATE IV

Figure 5. Photomicrograph of dolomite marble, showing clouded appearance from slide E_{2v}. Plain light, X90.

Figure 6. Photomicrograph of dolomite marble, showing twinned and untwinned grains under lower power objective. Crossed nicols, X35.

COR.
DOL.
DOL.

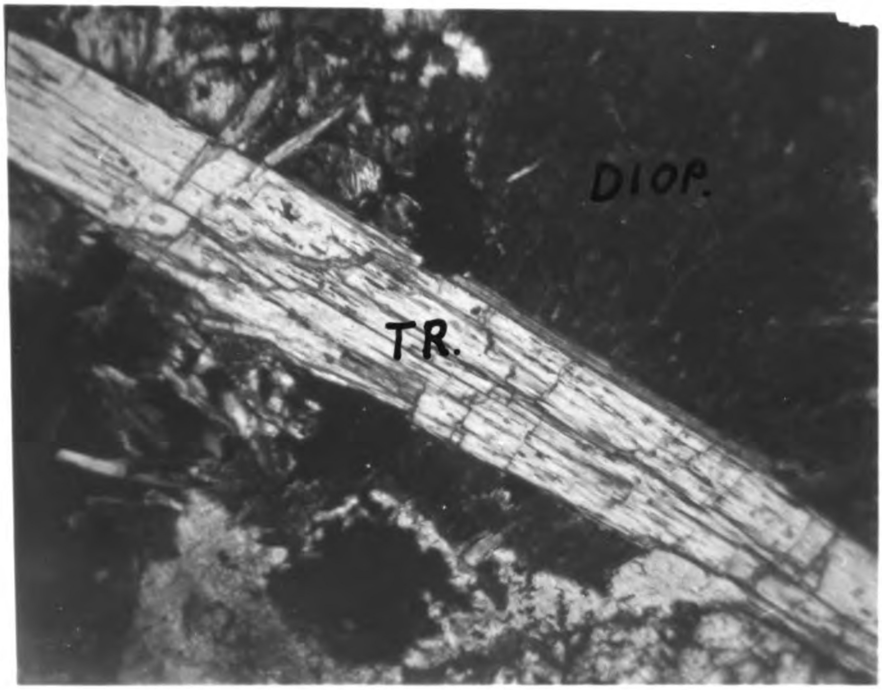


DOL.

PLATE V

Figure 7. Photomicrograph of tremolite in diopside, showing long bladed tremolite. Crossed nicols, X70.

Figure 8. Photomicrograph of tremolite in diopside, showing long bladed tremolite. Plain light, X70.


DIOP.
TR.

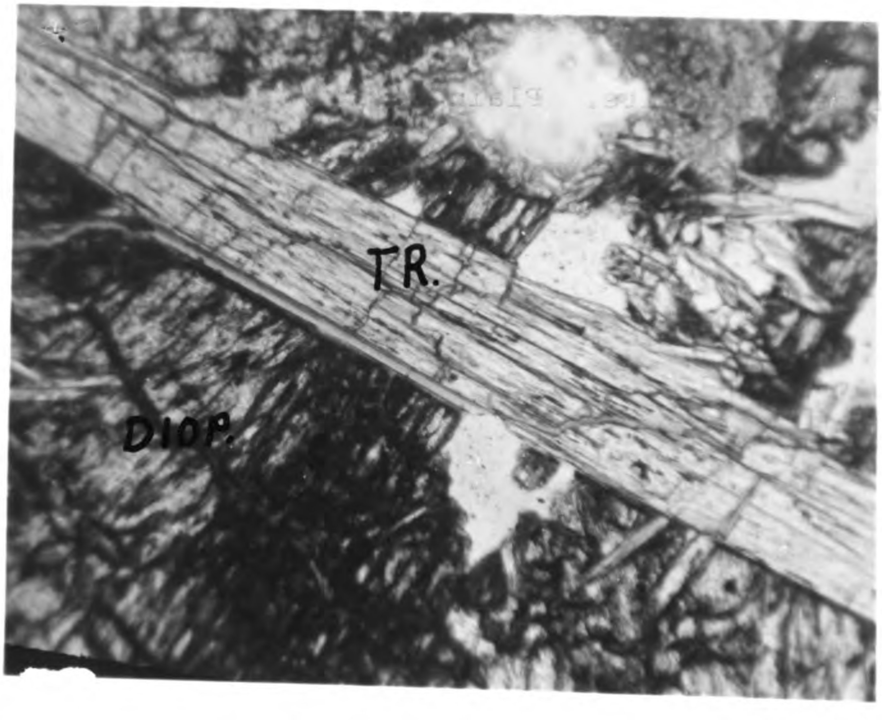
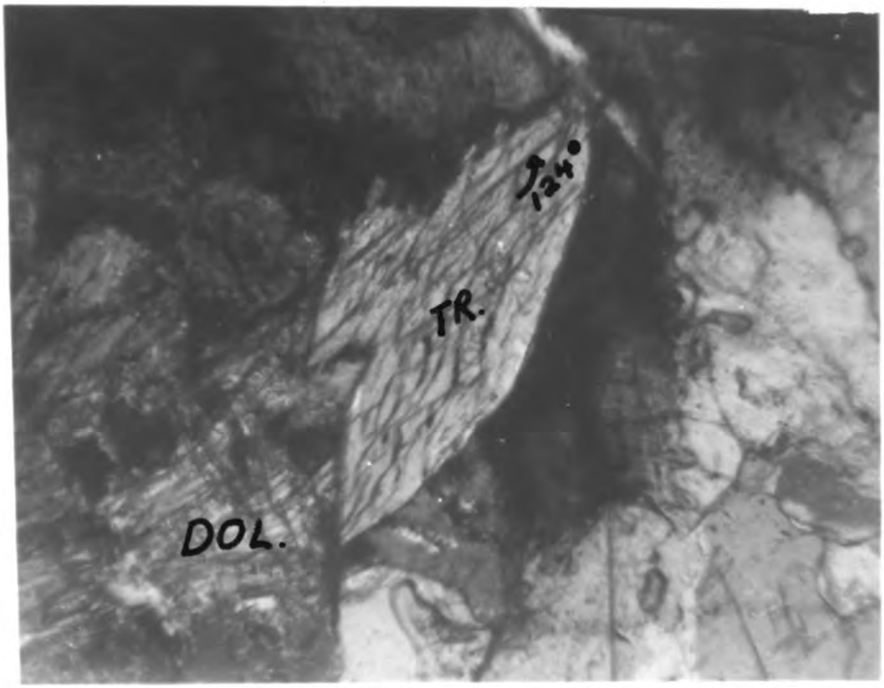

TR.
DIOP.

PLATE VI

Figure 9. Photomicrograph of tremolite in dolomite, showing a basal section of tremolite exhibiting excellent amphibole cleavage. Crossed nicols, X90.

Figure 10. Photomicrograph of tremolite in dolomite, showing a basal section of tremolite exhibiting excellent amphibole cleavage. Plain light, X90.


124°
TR.
DOL.

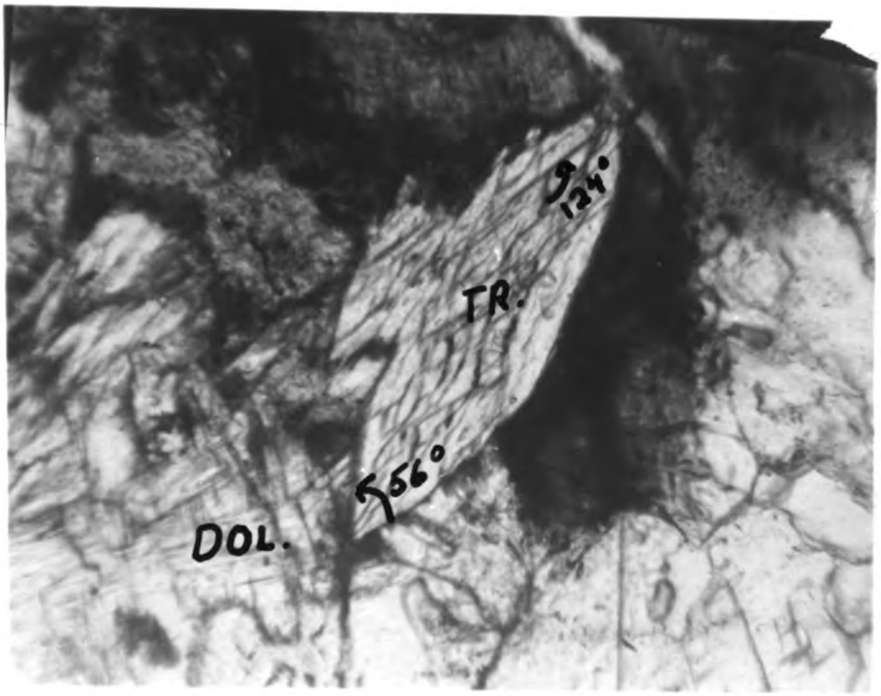

124°
TR.
56°
DOL.

PLATE VII

Figure 11. Photomicrograph of diopside, showing 90 degree pyroxene cleavage. Crossed nicols, X90.

Figure 12. Photomicrograph of talc in marble, showing single plate edges of talc along with fine grained scaly aggregates of talc which resemble sericite. Crossed nicols, X90.


90°
DIOP.

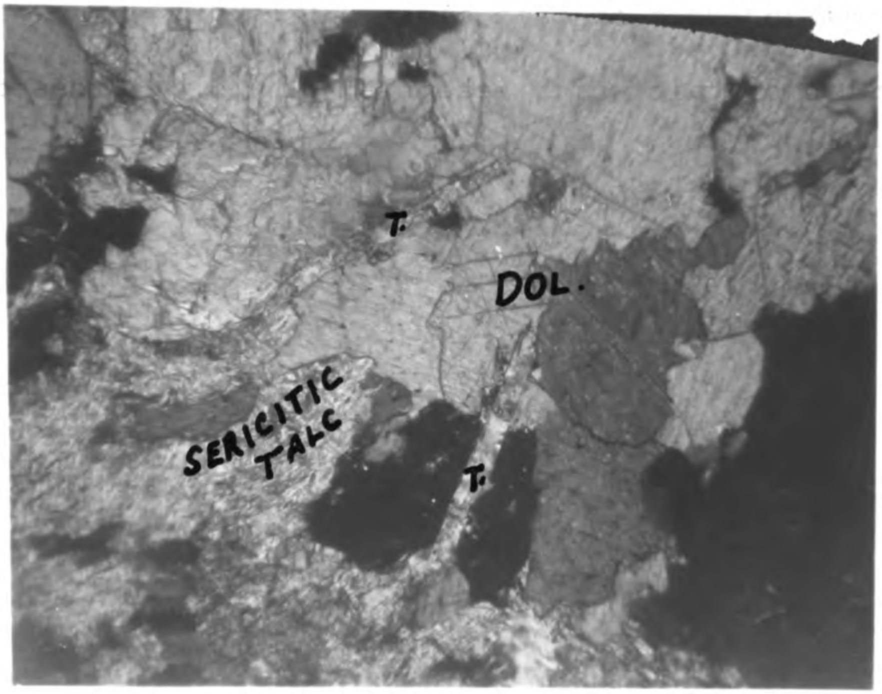
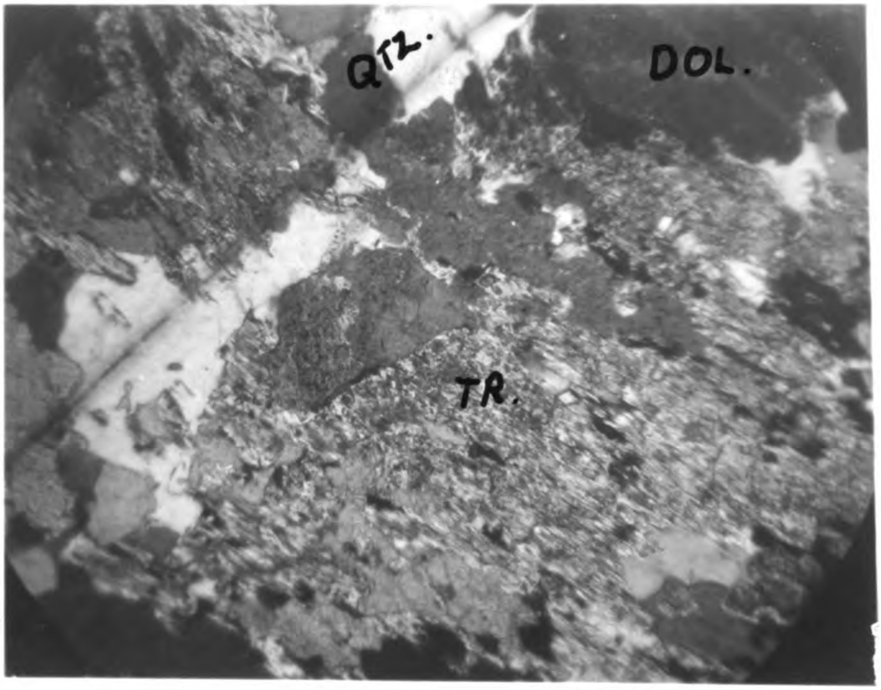
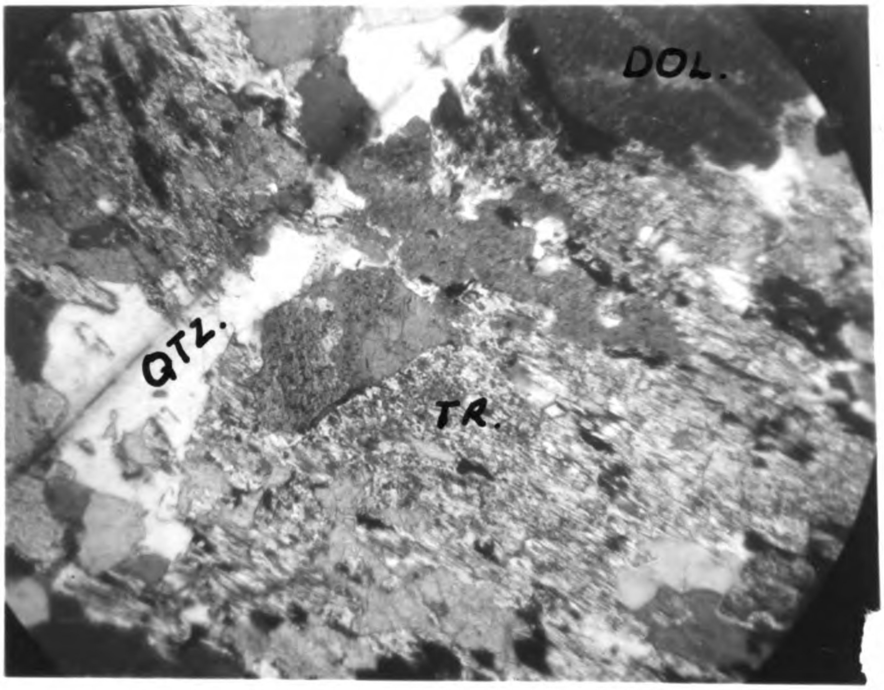

T.
DOL.
SERICITIC TALC
T.

PLATE VIII

Figure 13. Photomicrograph of quartz in dolomite marble and tremolite, showing stringers of quartz with dolomite replaced by tremolite, taken from slide C_h. Crossed nicols, X70.

Figure 14. Photomicrograph of quartz in dolomite marble and tremolite, showing stringers of quartz with dolomite replaced by tremolite, taken from slide C_h. Plain light, X70.


QTZ.
DOL.
TR.


DOL.
QTZ.
TR.

PETROFABRICS

A petrofabric analysis was run on twelve of the thirteen rock samples, to determine if there was any significant preferred fabric orientation. This study was necessary, because the rocks showed no megascopic or microscopic fabric orientation. A Brunton compass was used to orient the samples in the field. Since the magnetic declination in the area is less than one degree off true north, the samples were oriented with respect to magnetic north.

Locations of all specimens studied are shown on the map on page two. The attitude of each specimen was marked on the rock sample with red lead pencil and later scratched in with a knife blade. All location and geographic directions were noted in a field notebook.

Of the thirteen specimens taken, only sample "F" did not have a petrofabric study made on it. As mentioned previously, this sample has completely altered to diopside and amphiboles which are biaxial. A biaxial mineral must be measured by a five-axis universal stage. A microscope to use with the five axis stage was not available in the Geology Department at Michigan State University; consequently the "F" sample was discarded for petrofabric use.

Because the rocks had no obvious megascopic foliation, a section perpendicular to the trend of the regional structure was taken. Since the trough runs nearly east-west, a vertical north-south section was taken and a horizontal section was also studied. As twelve samples are being studied, this gives a total of 24 thin sections prepared for petrofabric examination.

Two hundred grains of dolomite in each section were studied, except for H-vertical, in which only 130 grains could be used. Orientation of the C-crystallographic axis (the optic axis) of each grain was determined. Because dolomite is a uniaxial mineral a four-axis universal stage was attached to an ordinary polarizing microscope and standard orientation procedures used.

In measuring a uniaxial crystal, either the optic axis is oriented parallel to the microscope axis (N_o) or the plane perpendicular to the optic axis is oriented in a vertical position parallel to N-S (N_e).

Both attachment and orientation procedures are outlined in Fairbairn (1954). The universal stage readings were plotted directly upon measurement on a Schmidt equal-area net.

Because carbonates are highly birefringent, a correction must be made when plotting them. The corrections are obtainable from Plate 8 in Emmons (1943), using the index for the hemisphere and the low index for the carbonate. The correction is used for plotting N_e only as N_o is not affected, since for readings of less than fifty degrees there is no appreciable error for N_o. But as the N-S reading of N_e gets larger, the correction also increases. The N-S readings were adjusted as follows: 19-23 = 1^o, 24-27 = 1 $1/2^o$, 28-33 = 2^o, 34-38 = 2 $1/2^o$, and 39-43 = 3^o. All corrections were made to decrease the readings. For example, if a N-S reading was 21, it was adjusted to 20 and plotted on the lower hemisphere of a Schmidt equal-area net, as were all points.

After the points were plotted, they were rotated to a horizontal plane and a composite diagram was compiled from points of the two sections of each sample, giving twelve composites in all. Concentrations of the C-axis were determined by standard center and peripheral counters of 1.0 cm. radius. These composites were contoured and then studied.

ANALYSIS OF RESULTS

It will be noticed that in most of the diagrams a north-south girdle is evident. The girdle consisting of a supposed direction of movement ("A") and a normal to the cleavage or beds ("C") (Billings, 1954).

Sample A, Figure 15, shows one 4% maximum bearing N 22° W and plunging 24 degrees northwest, another larger one striking approximately the same as the first maximum but lying nearly horizontal, while the last 4% high is very small and trending N-S horizontal. The attitudes of these maxima are essentially normal to the regional structure. A weak "A-C" girdle is present, but not nearly as strong or evident as in most other diagrams.

Figure 16 pictures 400 contoured C-axes from sample "B." Notice the stronger "A-C" orientation in this diagram. Two strong three per cent maxima are seen, both striking the same direction (N 26° W) but are plunging in opposite directions. One plunges 21 degrees to the northwest and the other plunges 20 degrees to the southeast. Again, as in sample "A," this is normal to the regional structure.

Four hundred oriented optic axes taken from two thin sections of sample "C" are shown in Figure 17. Once more a strong "A-C" girdle is evident running north-south, but a high 5% maximum is found in the northeast quadrant of the diagram. It bears N 14° E and plunges 18° to northeast. This is contrary to local structure and might be attributed to being taken from an outcrop at the western terminal of the trough.

Figure 18 is a composite diagram of two slides from sample "D." This diagram has a very strong "A-C" girdle culminating in a north-south three per cent maximum which plunges 58 degrees to the south. This finding is in conjunction with the local geology in that the optic axes parallel the direction of compression.

As has been stated before, four specimens were taken of outcrop "E" as a standard of areal deviation. Figure 19, 20, 21, and 22 show composite diagrams of 400 grains each for specimens E_1, E_2, E_3, and E_4 respectively. A marked resemblance will be seen when the four diagrams are compared. Each has a strong "A-C" girdle and the highs in each are situated in approximately the same positions. A two and three per cent maximum can be seen in the N-S, "A-C" girdle; two per cent highs are visible in all northeast quadrants, all northwest quadrants and all southwest quadrants.

Specimen "E_1," has north-south 3 per cent highs, plunging 25 and 55 degrees to the north which is parallel to the supposed direction of the deforming force.

Figure 21 exhibits two 3 per cent highs, one trending north-south and plunging 31 degrees to the north and another bearing N 26° W with a plunge of 30 degrees to the northwest. Again both conform to the regional geology.

Three different highs, all small, are observed in the E_3 specimen. Two strike north-south, but plunge in opposite directions; one 50 degrees north, the other 56 degrees south. Since these are found in the "A-C" concentration, they are parallel to the maximum deforming stress. The third also coincides with the deforming stress as it bears N 56° W plunging 60 degrees to the northwest.

For the most part E_4 conforms to the local structure also. As is shown, four 3 per cent highs are recorded, three of which are normal or nearly normal to the synclinal axis. One strikes N 22° W with a plunge of 23 degrees to the southeast. Once more two of the highs trend north-south, one plunges 20 degrees south, and the other is normal to the "A" axis. The remaining high strikes N 14° E and plunges 19 degrees to the northeast. This deviation will be of little concern, as it is over-shadowed by the significance of the other three maxima.

Overall, the diagrams from outcrop "E" fit the regional picture of being oriented normal to the axis of the trough.

Figure 23, of sample "G" depicts 400 C-axes contoured on a composite diagram. The "A-C" girdle is again very evident with another 3 per cent maximum in the southeast quadrant. The high bears N 24° W and plunges 25 degrees to the southeast. Once more, we see the orientation trending parallel to the folding thrust.

From outcrop "H," 330 C-axes were plotted from two thin-sections and are shown in Figure 24. The "A-C" girdle is not so distinct in this diagram as in previous ones and a 3 per cent high exists in the southwest quadrant. The other maximum which strikes N 28° W and plunges 54 degrees northwest, may depend upon regional structures. The first mentioned high bears N 69° E, plunging 64 degrees to the southwest and seems independent of local structures, but may be influenced by either of two faults adjacent to the quarry from which the sample was taken. One fault strikes WNW and the other bears to the NE.

A dolomite axis diagram of sample "I" (Figure 25) represents 400 contoured C-axes. Again, an "A-C" girdle is evident with a 3 per cent maximum striking N 28° E and plunging 20 degrees southwest. This northeast bearing and southwest plunge is probably independent of any regional structure. Outcrop I is directly west of the Felch Metronite Quarry and is most likely influenced by the granite dikes mentioned by Solberg (1958). The free quartz stringers found in the "I" thin-sections help substantiate this belief.

In sample "J," Figure 26, the "A-C" girdle appears to disappear with only remnants remaining. Preferred orientation is apparent with a small but strong 5 per cent maximum that strikes north-south and plunges 21 degrees to the north. This clearly complies with the regional structure.

There is a weak but consistant dolomite orientation in nearly all samples. Assuming the regional east-northeast strike, the orientation of nearly all diagrams is dependent upon regional structure; as the maximum orientations trend roughly north-northwest and plunge from 60 to 20 degrees and average 37 degrees in the same direction. The strong "A-C" girdle present in every diagram is also north-trending.

The conclusion reached is that the preferred orientation is essentially normal to the regional strike. Therefore, the deforming stress and preferred orientation parallel one another, which means the deforming force must have come from the northwest or southeast. It is stated by Turner (1952), that it is conceivable that recrystallization of marble under simple compression may yield a fabric with strong preferred orientation of C-axis parallel to the direction of maximum compressive stress.

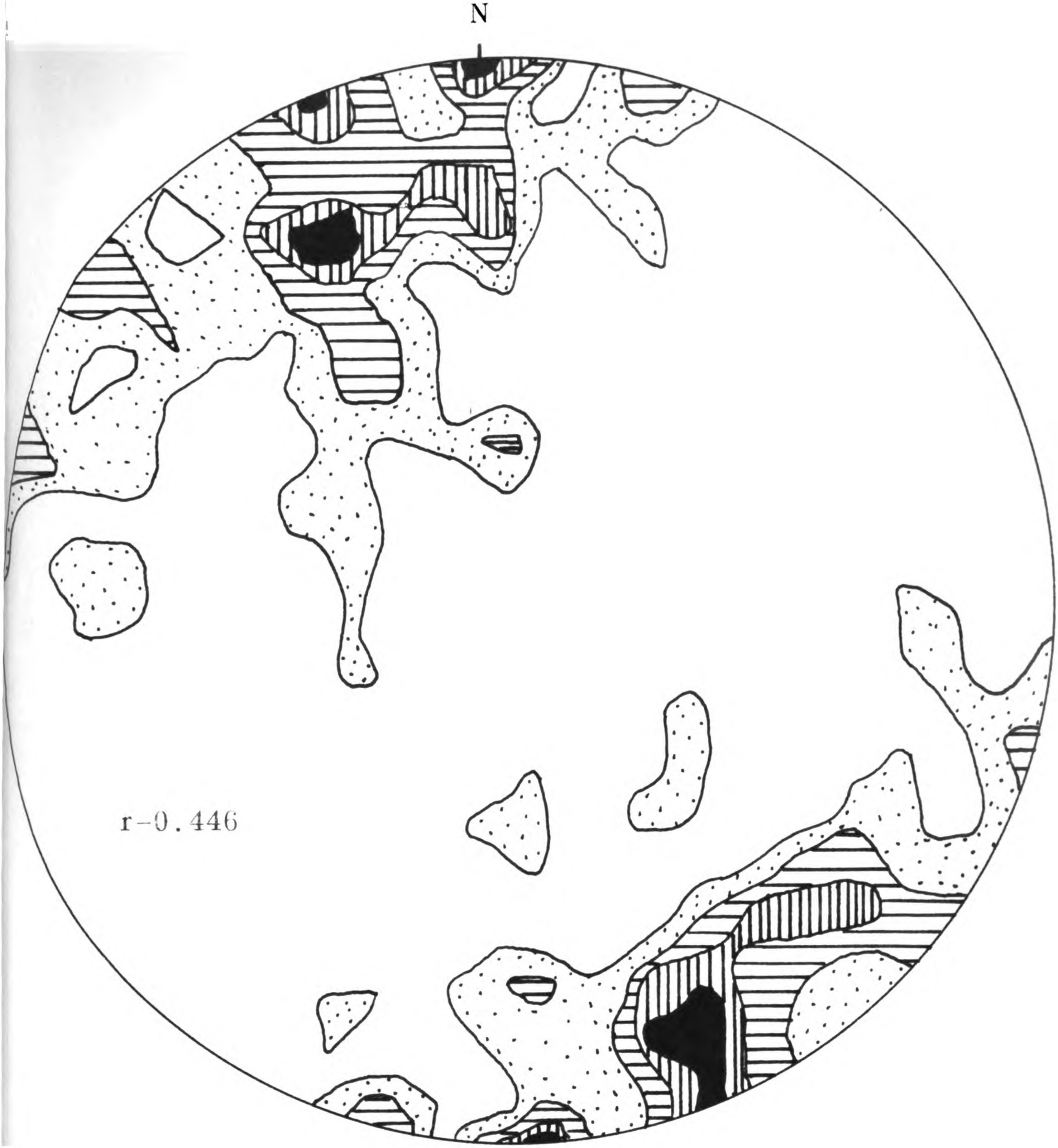


Figure 15. 400 dolomite axes from sample A contours 4-3-2-1 percent, plotted on the lower hemisphere of a Schmidt equal-area net.

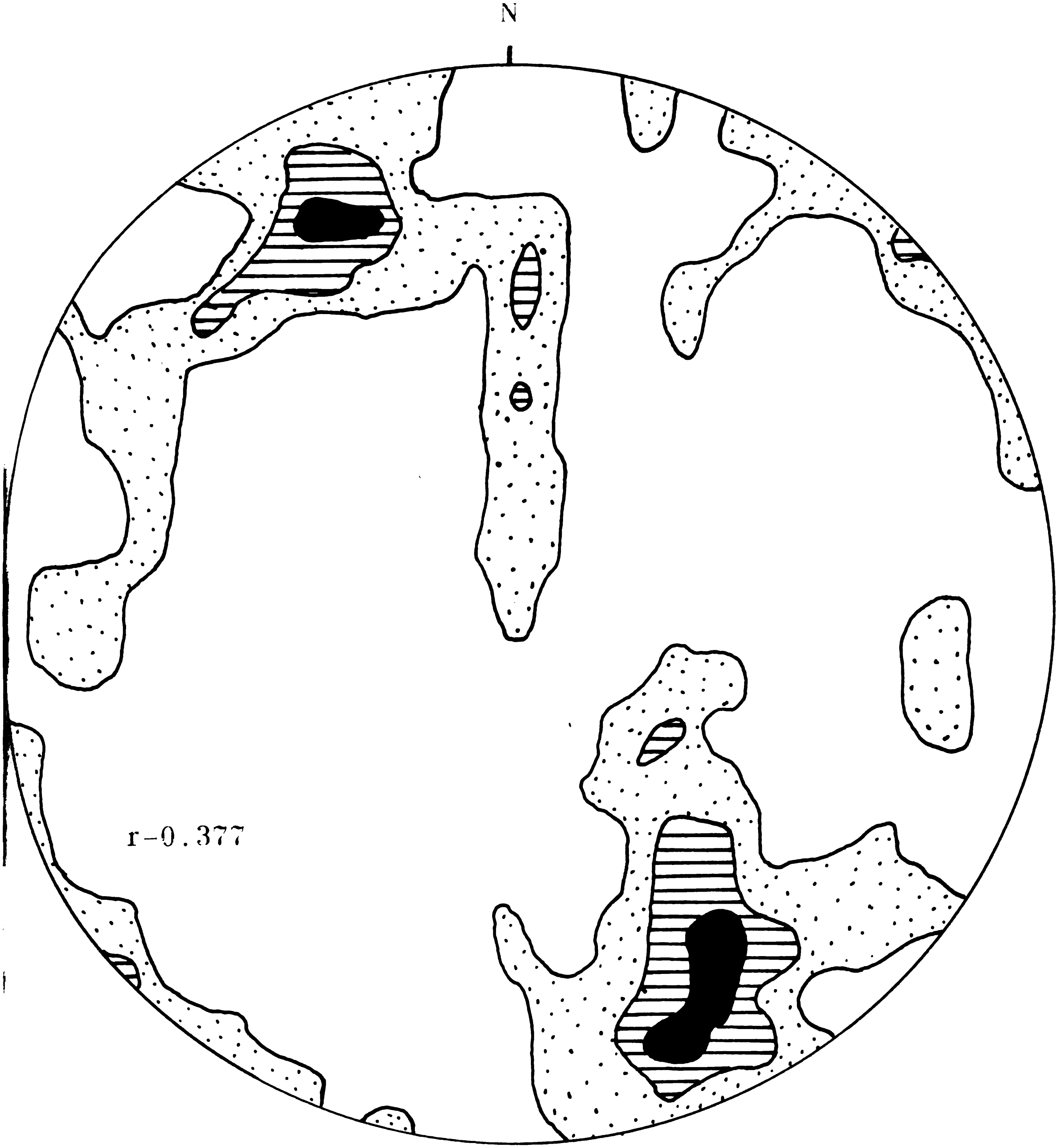


Figure 16. 400 dolomite axes from sample B contours 3-2-1 percent, plotted on the lower hemisphere of a Schmidt equal-area net.

Figure 17. 400 dolomite axes from sample C contours 5-4-3-2-1 percent, plotted on the lower hemisphere of a Schmidt equal-area net.

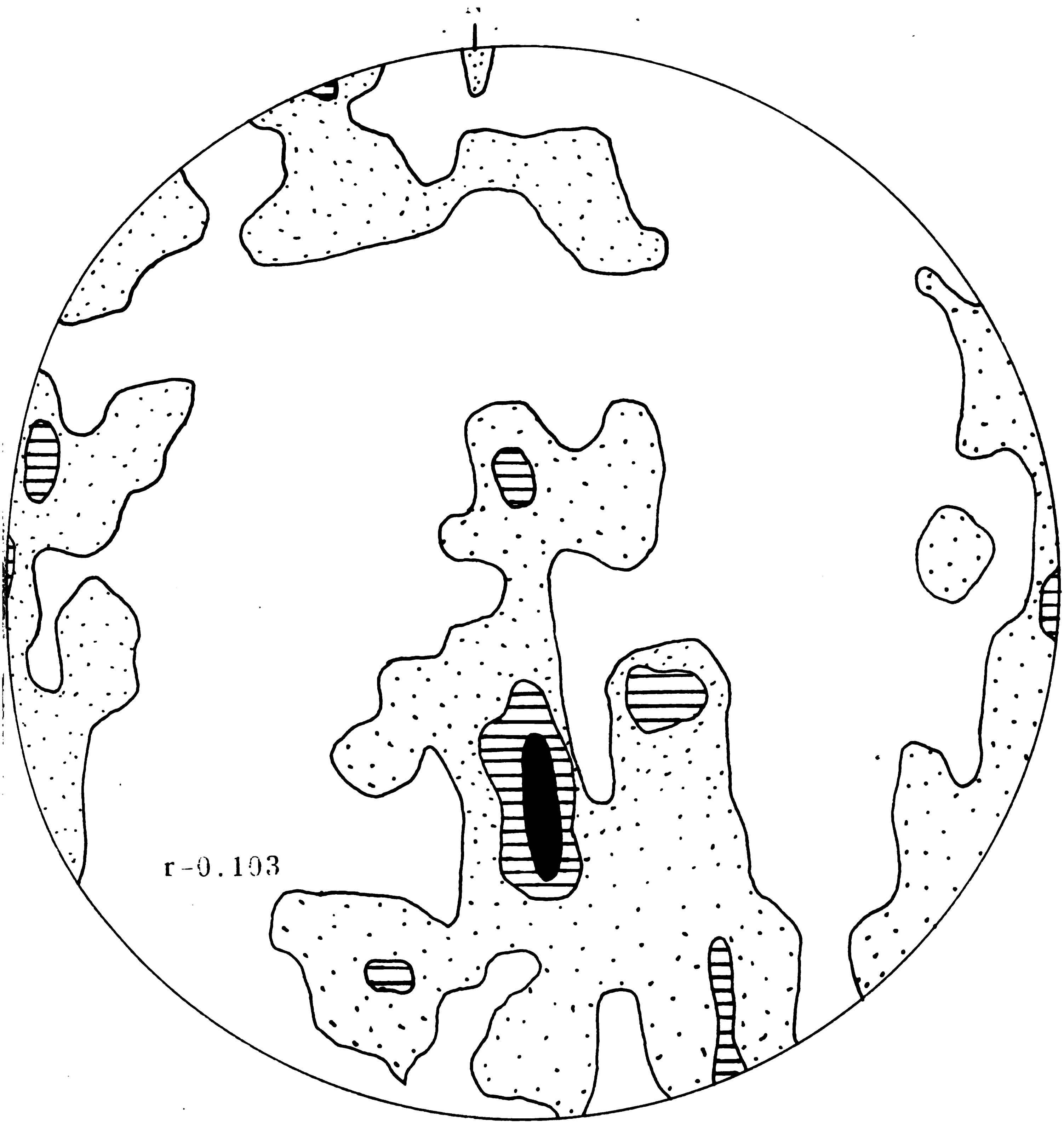


Figure 18. 400 dolomite axes from sample D contours 3-2-1 percent, plotted on the lower hemisphere of a Schmidt equal-area net.

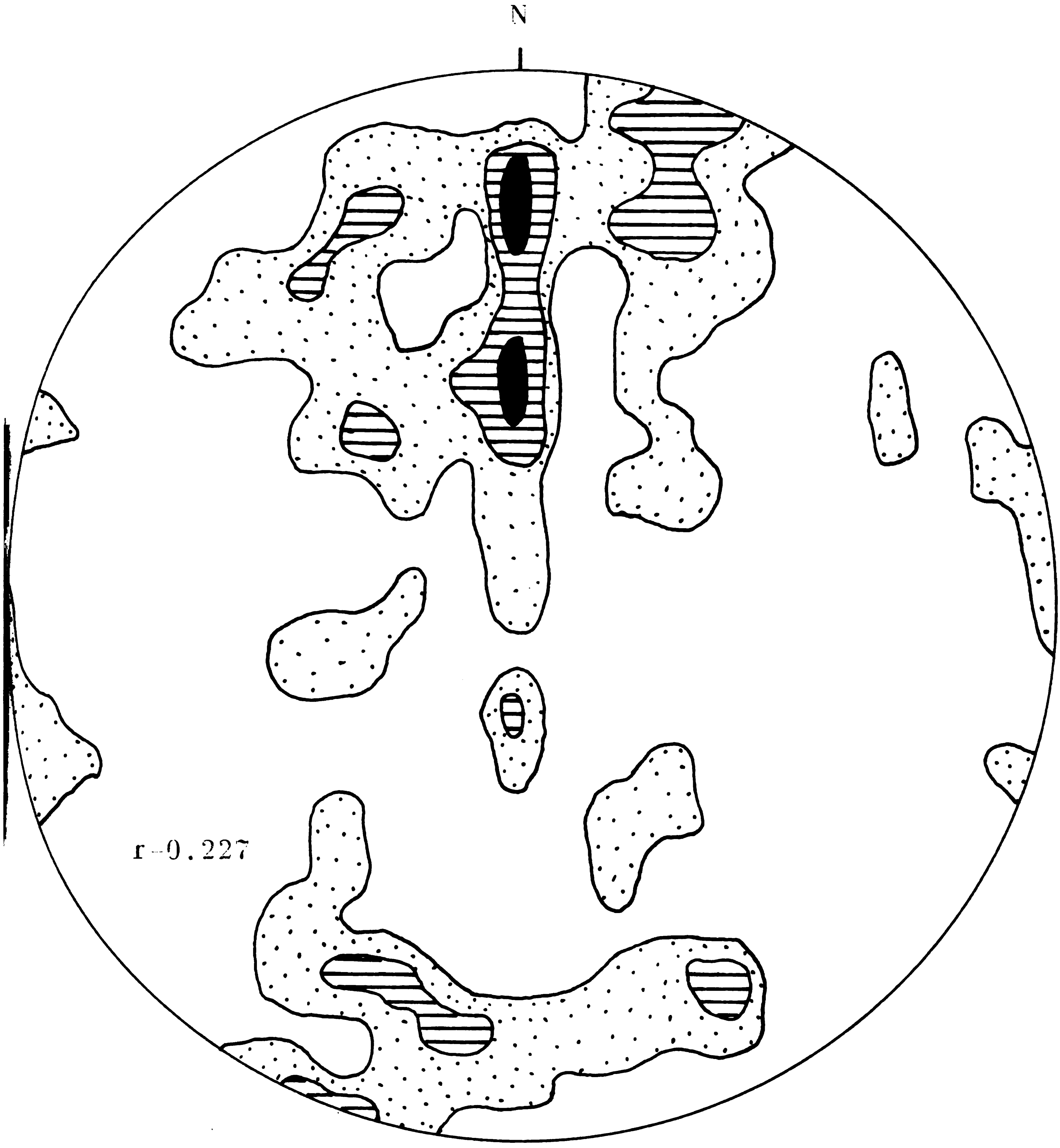


Figure 19. 400 dolomite axes from sample E_1 contours 3-2-1 percent, plotted on the lower hemisphere of a Schmidt equal-area net.

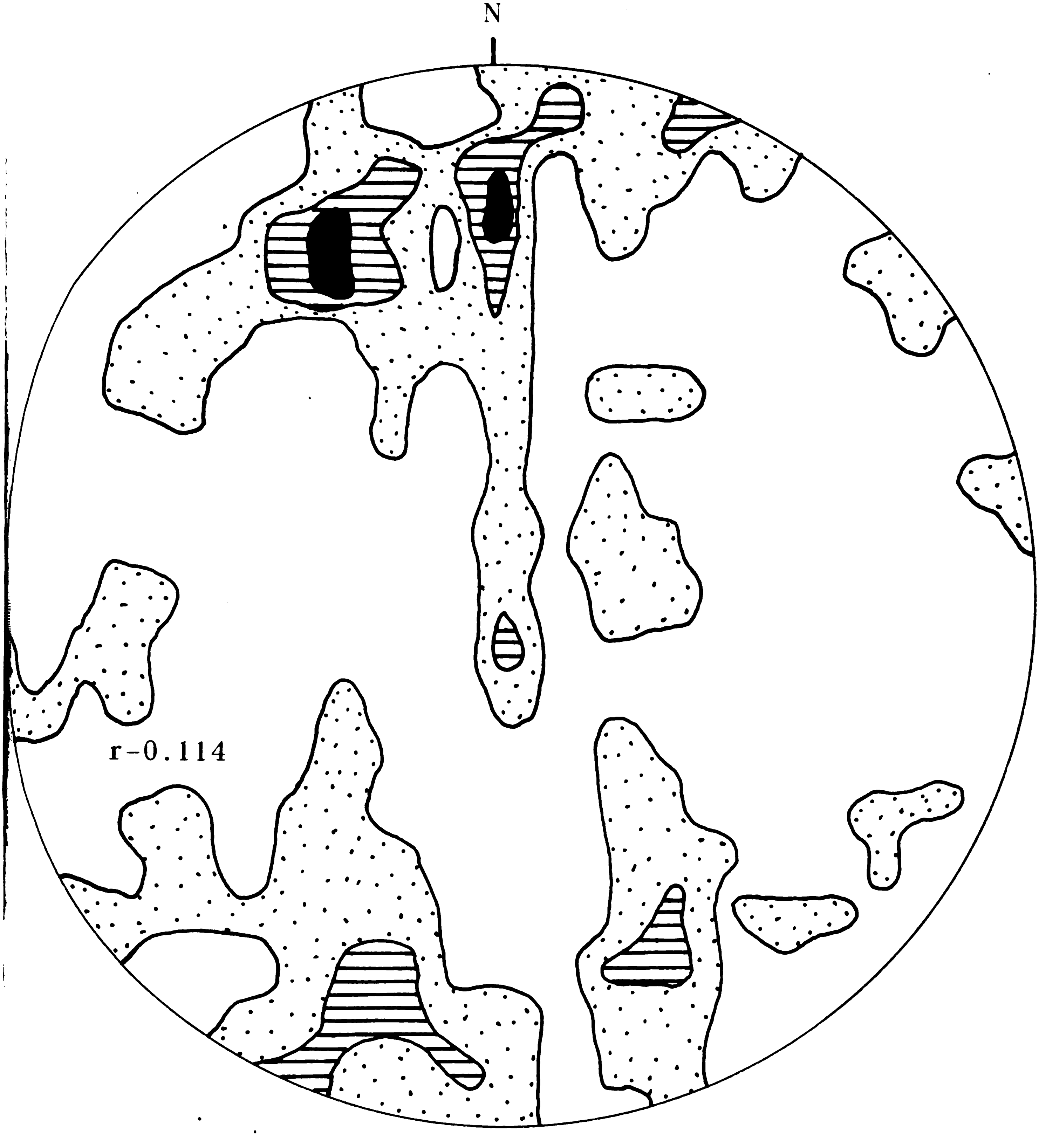


Figure 20. 400 dolomite axes from sample E_2 contours 3-2-1 percent, plotted on the lower hemisphere of a Schmidt equal-area net.

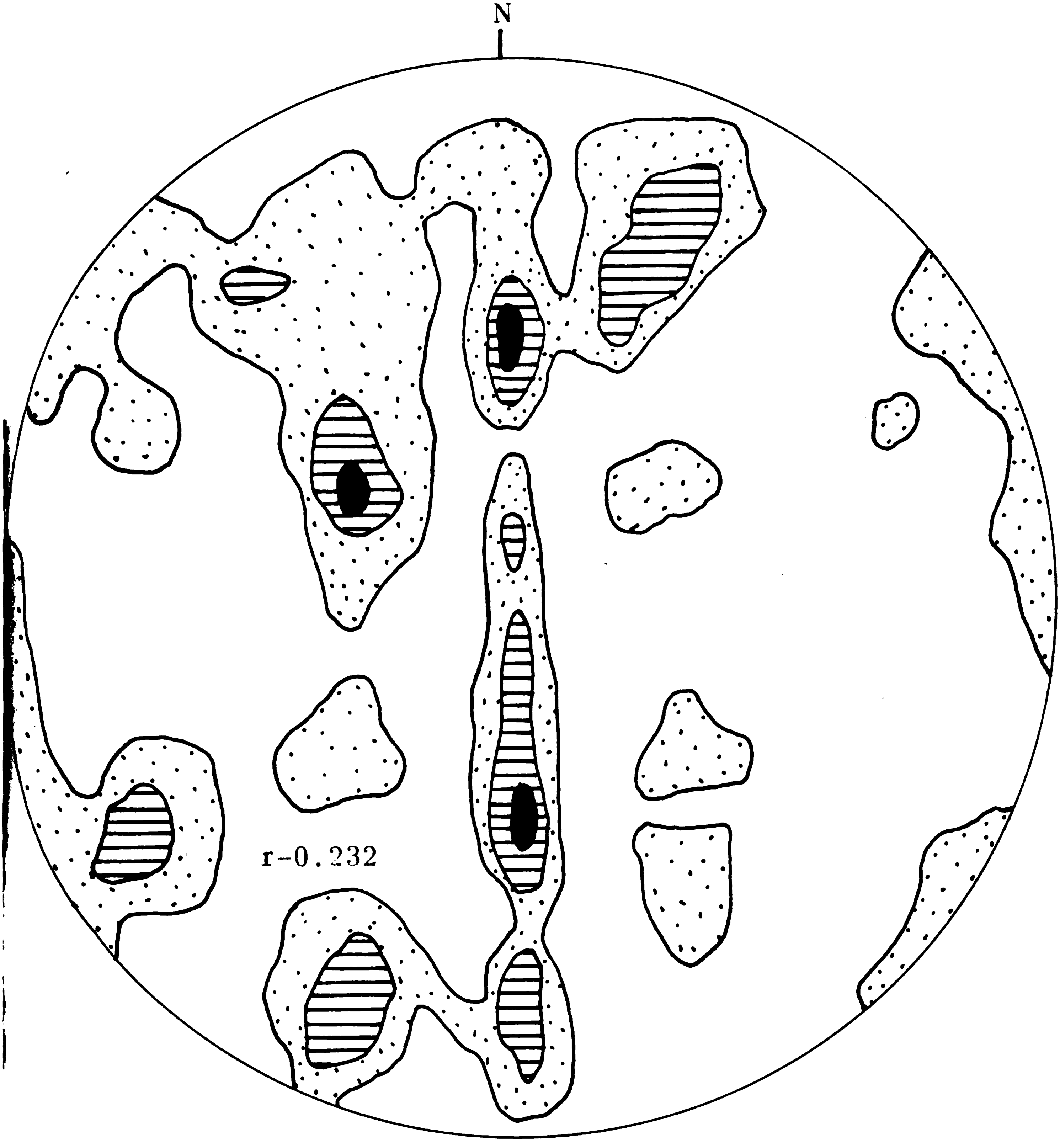


Figure 21. 400 dolomite axes from sample E_3 contours 3-2-1 percent, plotted on the lower hemisphere of a Schmidt equal-area net.

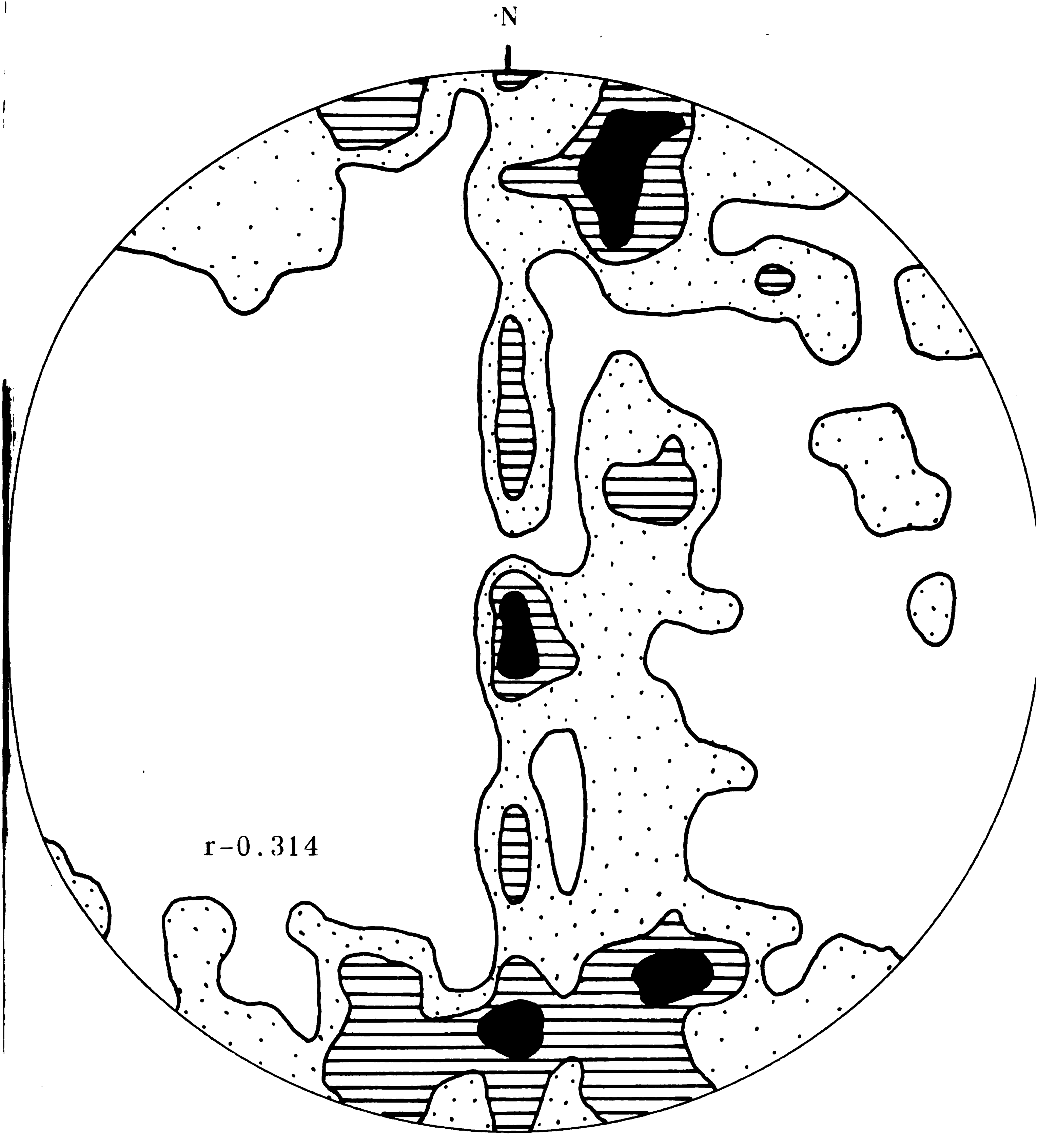


Figure 22. 400 dolomite axes from sample E_4 contours 3-2-1 percent, plotted on the lower hemisphere of a Schmidt equal-area net.

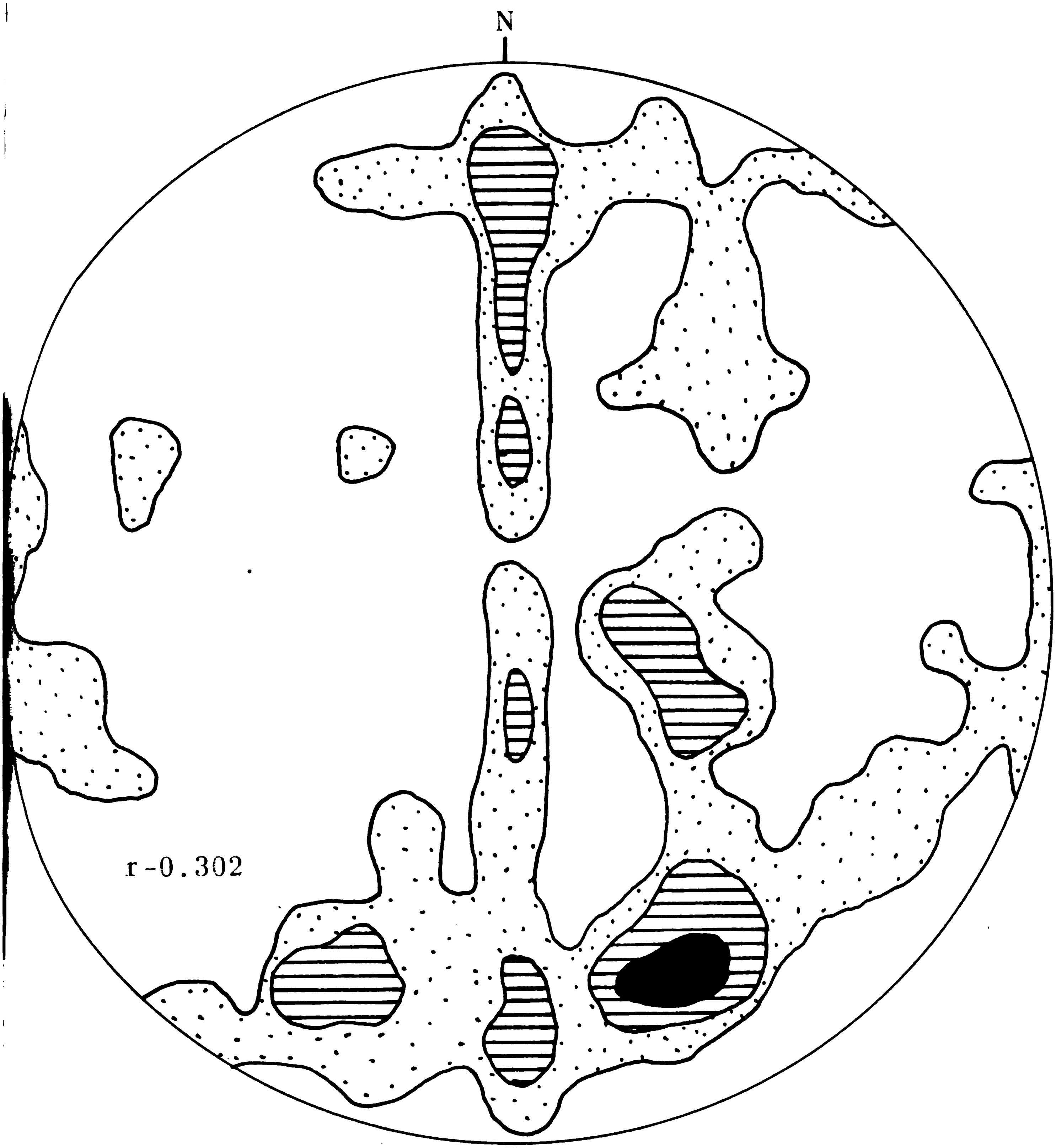


Figure 23. 400 dolomite axes from sample G contours 3-2-1 percent, plotted on the lower hemisphere of a Schmidt equal-area net.

Figure 24. 330 dolomite axes from sample H contours 3-2.1-1.2 percent, plotted on the lower hemisphere of a Schmidt equal-area net.

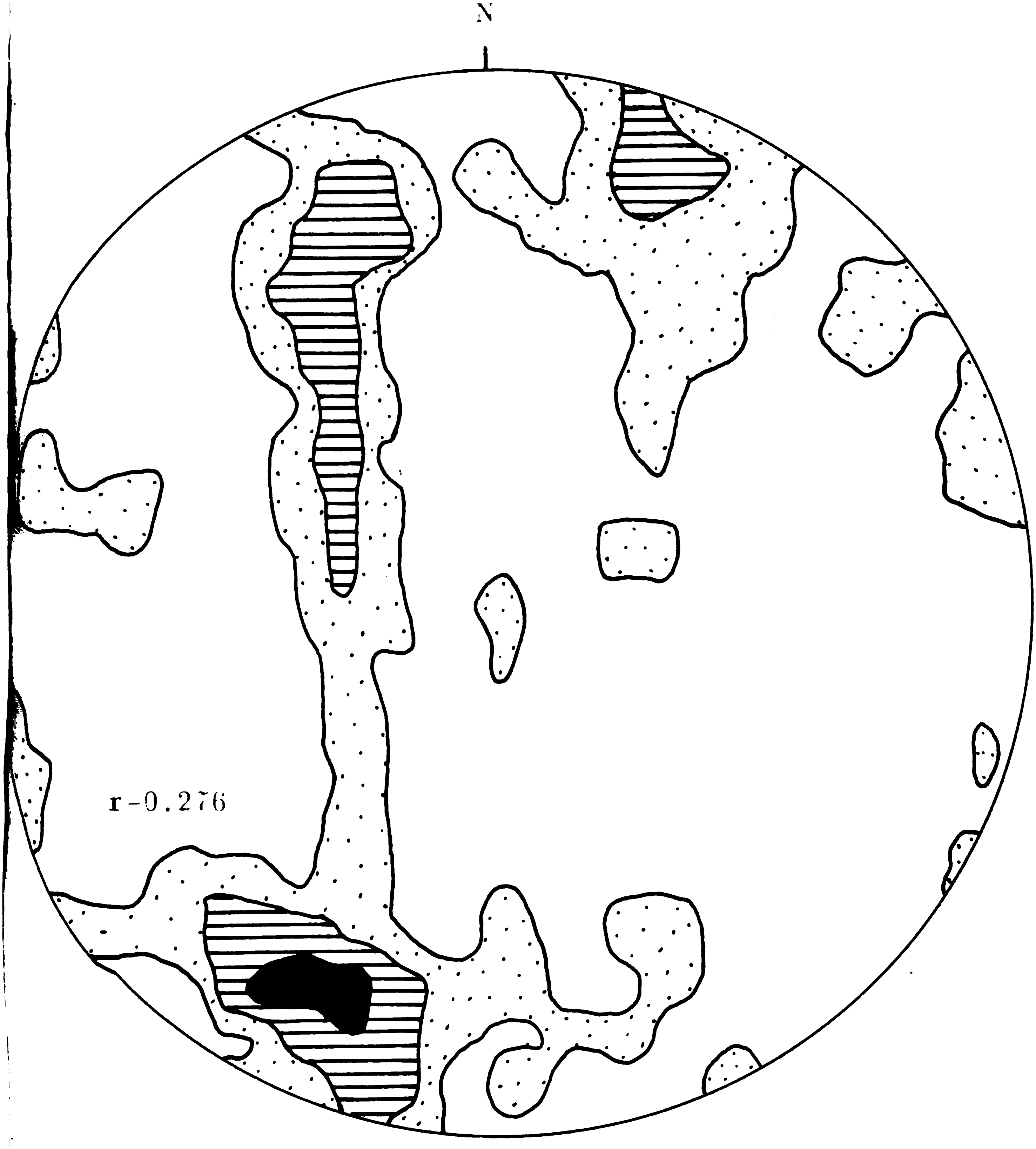


Figure 25. 400 dolomite axes from sample I contours 3-2-1 percent, plotted on the lower hemisphere of a Schmidt equal-area net.

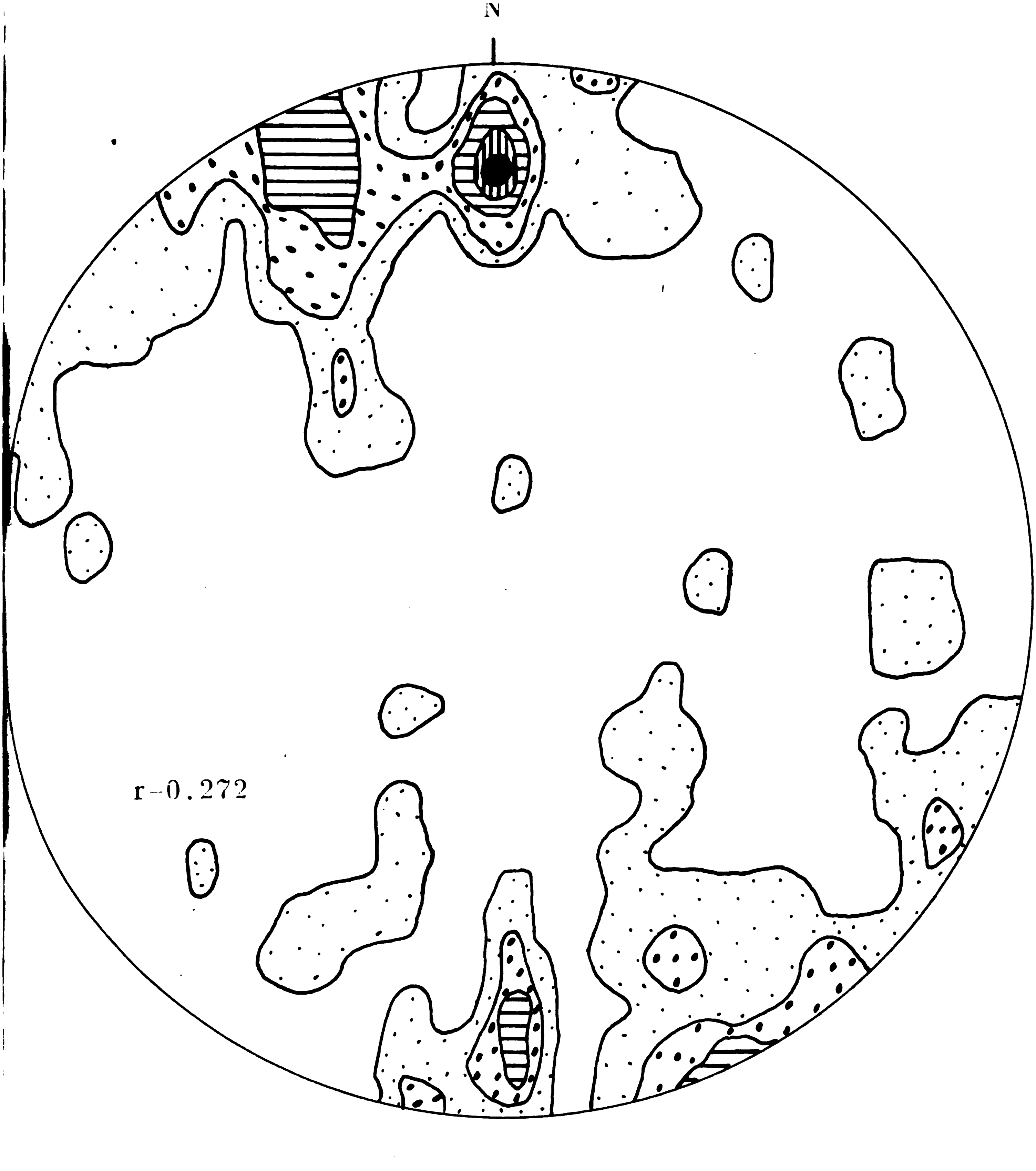


Figure 26. 400 dolomite axes from sample J contours 5-4-3-2-1 percent, plotted on the lower hemisphere of a Schmidt equal-area net.

STATISTICAL ANALYSIS

Where orientations are "weak," it sometimes warrants a statistical test on the petrofabric diagrams to determine if the attached interpretations are valid. Considering the petrofabric diagrams done in this problem, we find that nine have only 3% maxima and only two have 5% maxima.

Therefore, because the majority of the maxima were weak, a statistical analysis was done on each diagram to help substantiate their preferred orientations.

In this case, a correlation coefficient will be used as a measure of preferred orientation. The correlation coefficient measures the degree of preferred orientation of the individual diagrams. It does not determine the nature of the fabric, it is used only as a comparison.

The coefficient of correlation (r) measures how the number of cells or points on one square correlates with the number of cells on each of the four squares nearest it; if there is a tendency for squares of equal densities to lie closer together in some parts of the diagram than in others, this correlation is significantly positive and interpreted as evidence of preferred orientation in the parent fabric.

In preparing this test a one per cent comparison grid was made, each square being 1.77 cm. on a side; the result is an array of 96 squares (Figure 27).

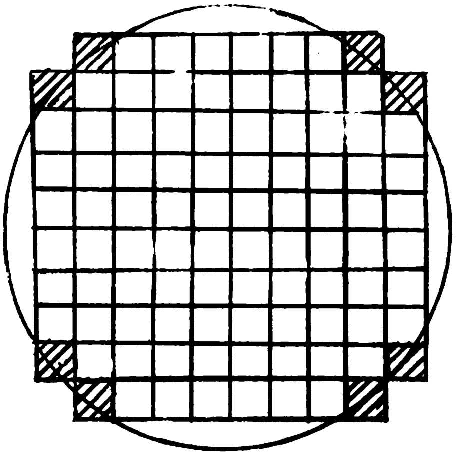


Figure 27. One per cent grid used in counting points for the computation of "r."

Procedures and computations needed to find the coefficient of correlation are found in Fairbairn (1954, pp. 317-321).

A two per cent grid was not used here, because all the diagrams averaged over 4 cells per square except "H" which averaged slightly over three.

Fairbairn states that if the average cell content is less than 3 or 4 per square, then it will be best to coarsen the grid (a two per cent grid).

He also remarks that in the absence of a formal analysis of the problem, it is suggested that the degrees of freedom for the test be set at one less than the number of squares in the grid. The test here involves 272 comparisons made on the above grid containing 96 squares, hence there will be 95 degrees of freedom. Also, it is customary to use the .05 and .01 significance levels. For 95 degrees of freedom the .01 level of "r" is 0.26 and the .05 level is 0.20.

Table IV gives the statistical findings for each point diagram besides each correlation coefficient being placed on its respective contoured fabric diagram. It may be noted here that "r" does not in any way indicate the location of the plotted maxima.

It is seen by Table IV, that the statistical analysis seems to validate the point diagrams. That is the diagrams with the higher per cent maxima have the highest coefficient of correlation and the ones with the lower per cent contours have a lower coefficient of "r."

"J" which has a 5% maximum and a low "r" seems to contradict this, but when diagram "J" is looked at more closely it is seen that the 5 per cent and 4 per cent maxima are smaller than the maxima in the other diagrams. So the 3 per cent high is the more valid one for the diagram and this would more readily coincide with the coefficient of correlation found for this diagram.

It will also be noticed that nine of the twelve diagrams reached the .05 significance level with seven of these reaching the .01 level.

TABLE IV

Outcrop	Maximum Contour (Per Cent)	Coefficient of Correlation (r)	Significance Level
A	4	0.446	.01
B	3	0.377	.01
C	5	0.415	.01
D	3	0.103	*
E_1	3	0.227	.05
E_2	3	0.114	*
E_3	3	0.232	.05
E_4	3	0.314	.01
G	3	0.302	.01
H	3	0.068	*
I	3	0.276	.01
J	5	0.272	.01

*Did not reach .05 level.

SUMMARY

After field and laboratory study, including megascopic and microscopic work, certain conclusions have been reached:

1. Through thin-section study, it appears the original dolomite has undergone complete reconstruction. The character of the accessory minerals indicates that in most cases the altered rock is a reconstruction of the original impure dolomite. In some outcrops, elements have been introduced to the dolomite from pegmatite dikes and hydrothermal solutions.

2. The Felch Trough area is frequented by pegmatite dikes and other intrusions, suggesting that they originated from a deep-seated magmatic mass that may have caused widespread regional metamorphism throughout the area at an earlier date. To crystallize minerals, such as diopside and tremolite from a dolomite silica must have been introduced and heat must have been an important agent of metamorphism. Due to the abundant pressure twinning, it is acknowledged that pressure had also played an important role.

3. Outcrops from the east end of the syncline have much larger grains. Seeing that temperature and pressure are of primary importance, these large grains were likely caused by increased heat and pressure in the eastern section of the trough. Heating, squeezing and flowing of the dolomite might accompany the increased heat and pressure, suggesting a possible thickening of the marble from east to west. This theory is not proven here, but is merely submitted as a possibility.

4. Petrofabrically, the point diagrams show a consistant but weak preferred orientation. This orientation is normal to the regional structure and parallel to the deforming stress, assuming a north-northeast regional trend.

5. Statistical analysis supplements the finding and interpretations of the composite petrofabric diagrams.

6. As this problem is an extrapolation of Solberg's Master of Science thesis, it can be said that the two compare favorably. The Metronite Quarry, where his study was made, is located east of outcrop "I" a short distance and is shown on the locations map (page 2). The mineral assemblages

and their respective per cents are in accord with most of the outcrops used in this thesis. Also Solberg's fabric diagrams comply with the regional structure. Altogether his study, if used as another outcrop, supplements the other findings of this thesis.

The only place that I would differ with Solberg is in the identification of some minor minerals.

PLATE IX

Figure 28. Photograph of active quarry at outcrop "B," showing where oriented specimen was taken plus joint face (N 46° E, 43° SE).

Figure 29. Photograph of outcrop "B," showing joint surface within quarry (N 61° W, 85° SW).

AUG 1962

AUG 1962

PLATE X

Figure 30. Photograph of inactive quarry at outcrop "C," taken at oriented specimen and looking east.

Figure 31. Photograph of quarry "C," looking across quarry at oriented specimen. Note parallel fractures.

AUG 1962

AUG 1962

PLATE XI

Figure 32. Photograph of outcrop "C," showing joint surface in marble (N 42° E, 77° SE).

Figure 33. Photograph at outcrop "C," showing joint surface at west end of quarry (N 15° E, 69° NW).

AUG 1962

AUG 1962

PLATE XII

Figure 34. Photograph of Rian Quarry at outcrop "H," looking across quarry at oriented specimen location.

Figure 35. Photograph of dolomite at Rian Quarry, showing close-up of oriented specimen location.

AUG 1962

AUG 1962

PLATE XIII

Figure 36. Photograph of wall in Rian Quarry, showing parallel joint surfaces (N 22° W, 72° SW).

Figure 37. Photograph of marble at outcrop "H," showing joint surface in dolomitic marble (N 60° W, 86° NE).

AUG 1962

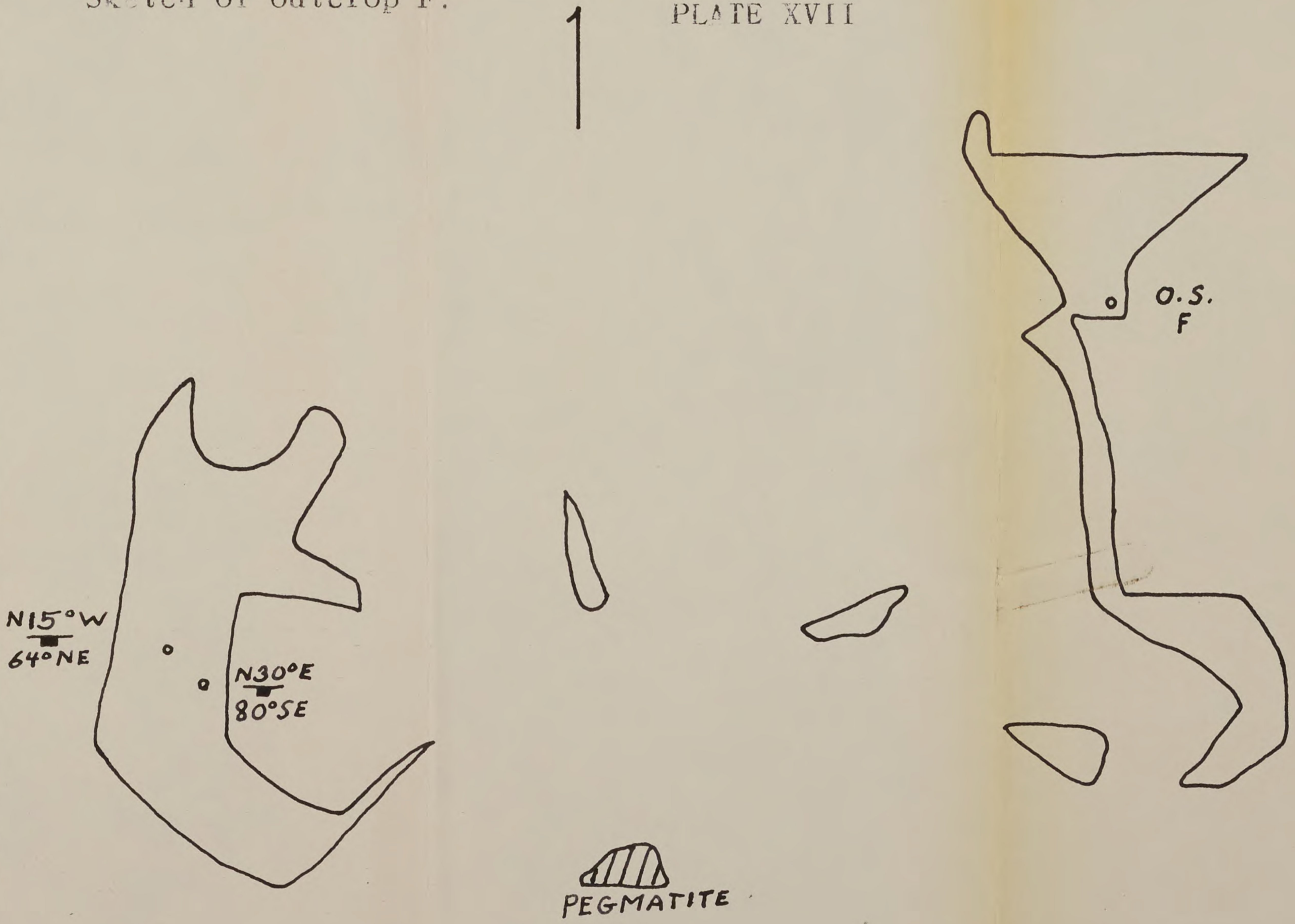
AUG 1962

Turner, F. J., and Verhoogen, J. (1951); *Igneous and Metamorphic Petrology*, McGraw-Hill, Inc., New York.

Van Hise, C. L., and Leith, C. K. (1911); *The geology of the Lake Superior region*, USGS Mon. 52.

Sketch of outcrop F.

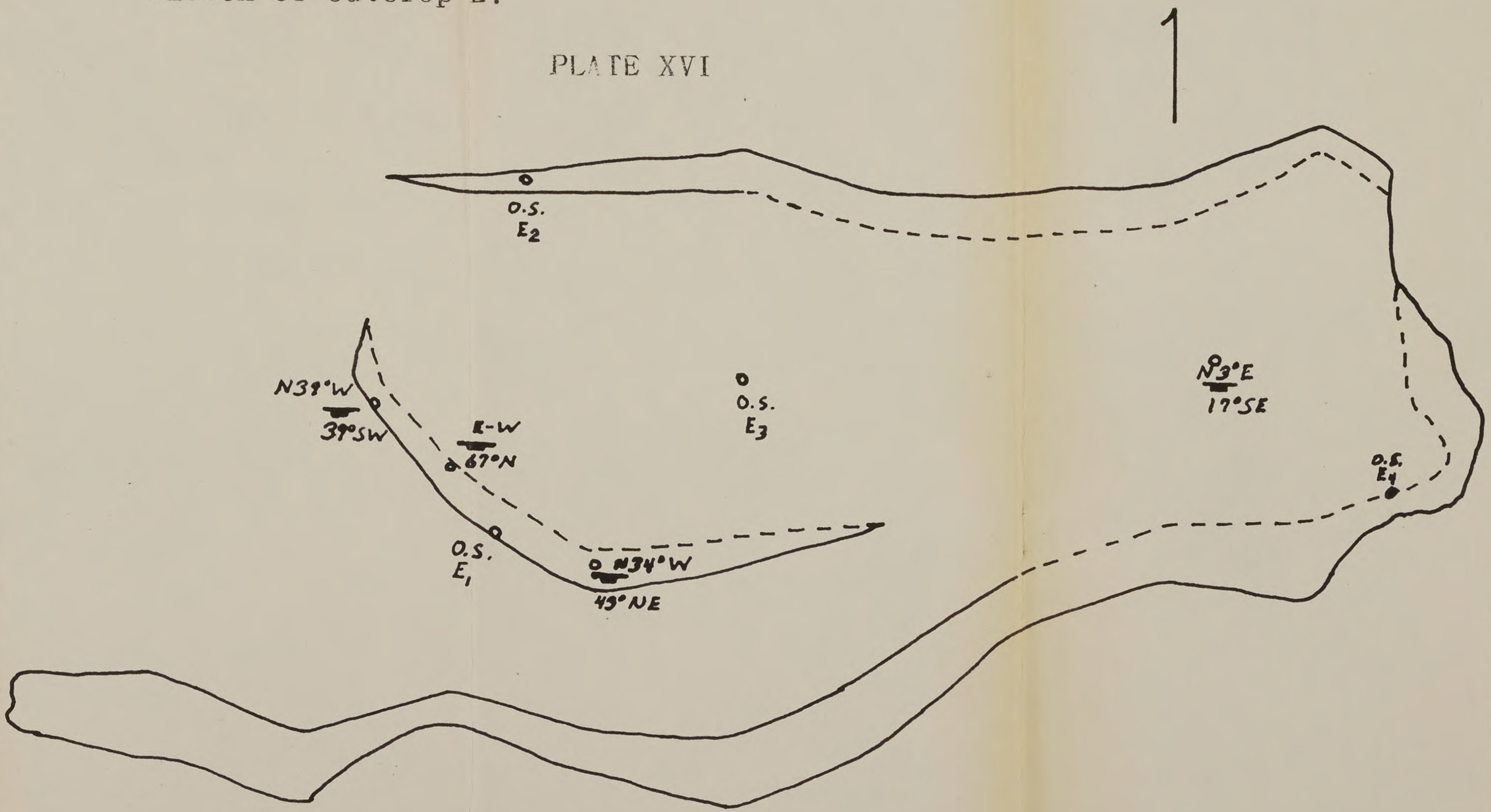
PLATE XVII



Scale - 1" = 10'

Sketch of outcrop E.

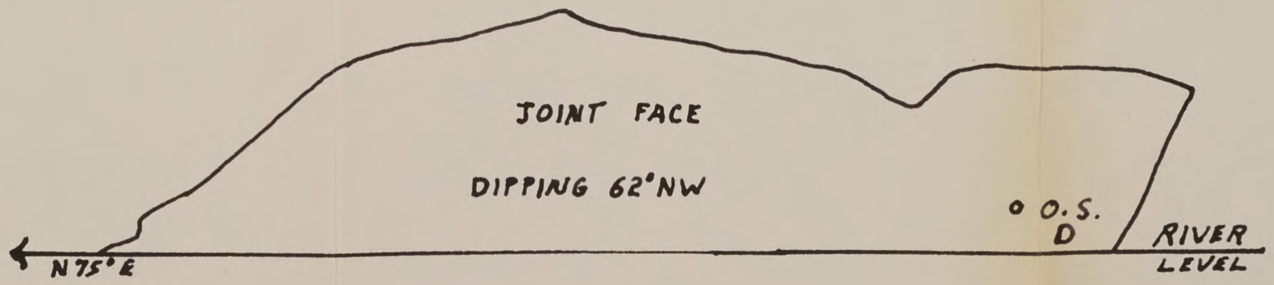
PLATE XVI



Scale-1" = 10'

Sketch of outcrop D.

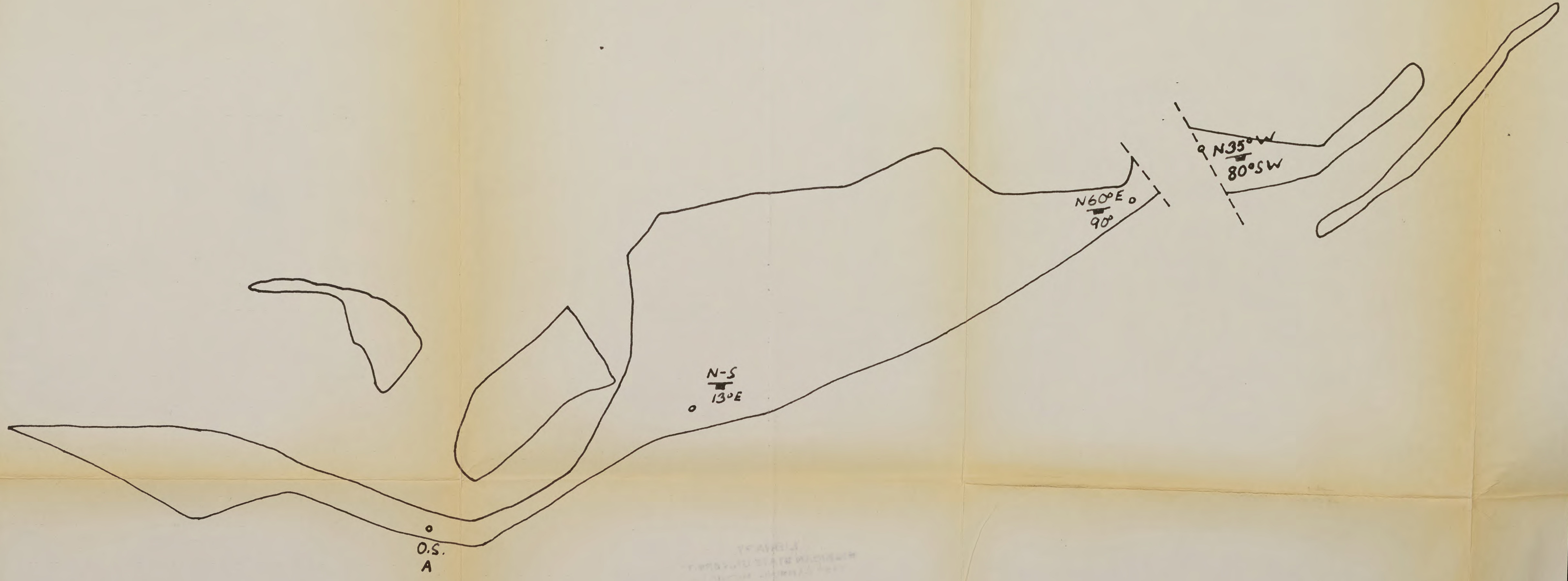
PLATE XV



Scale - 1" = 10'

Sketch of outcrop A.

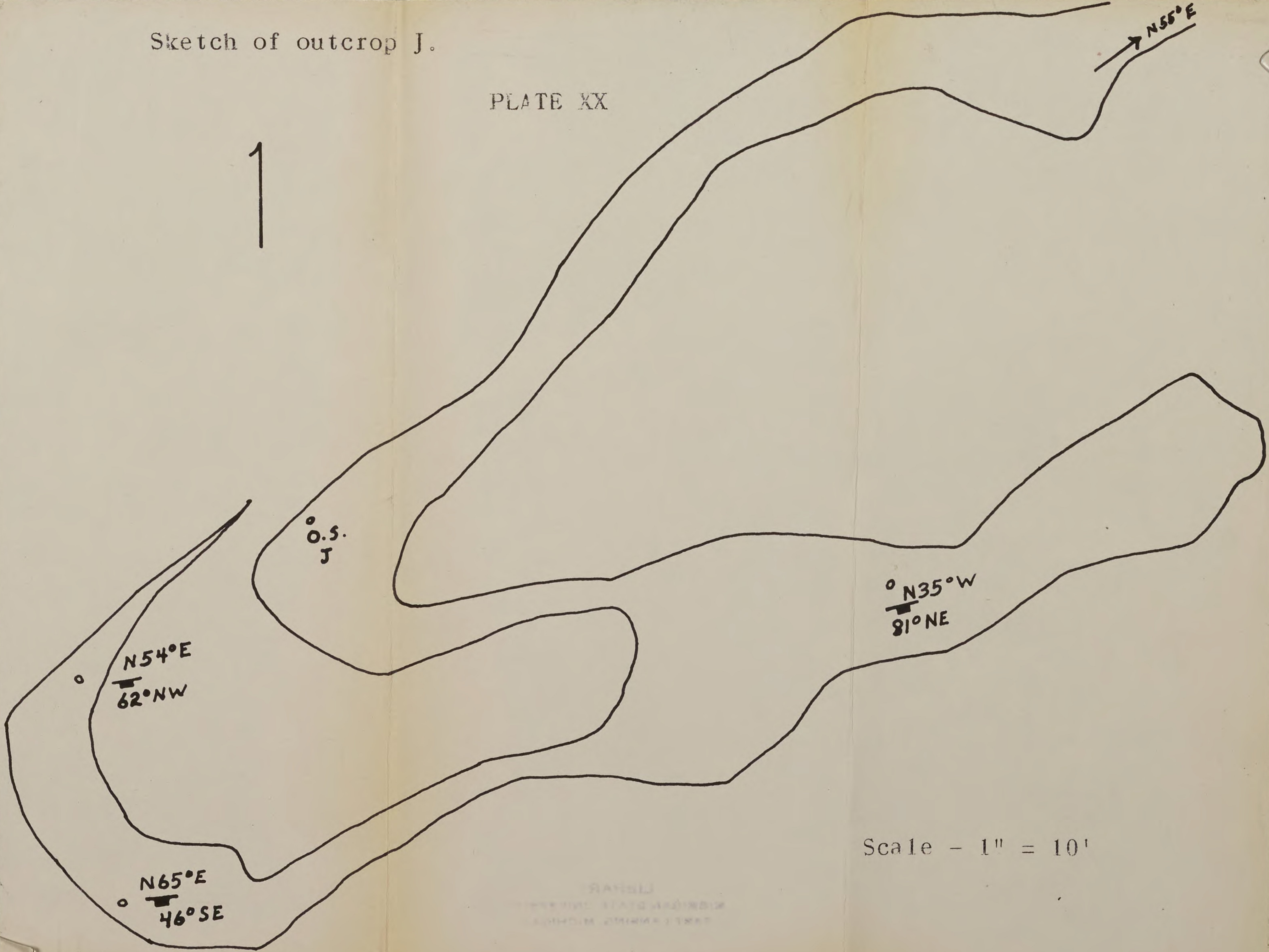
PLATE XIV



Scale - 1" = 10'

Sketch of outcrop J.

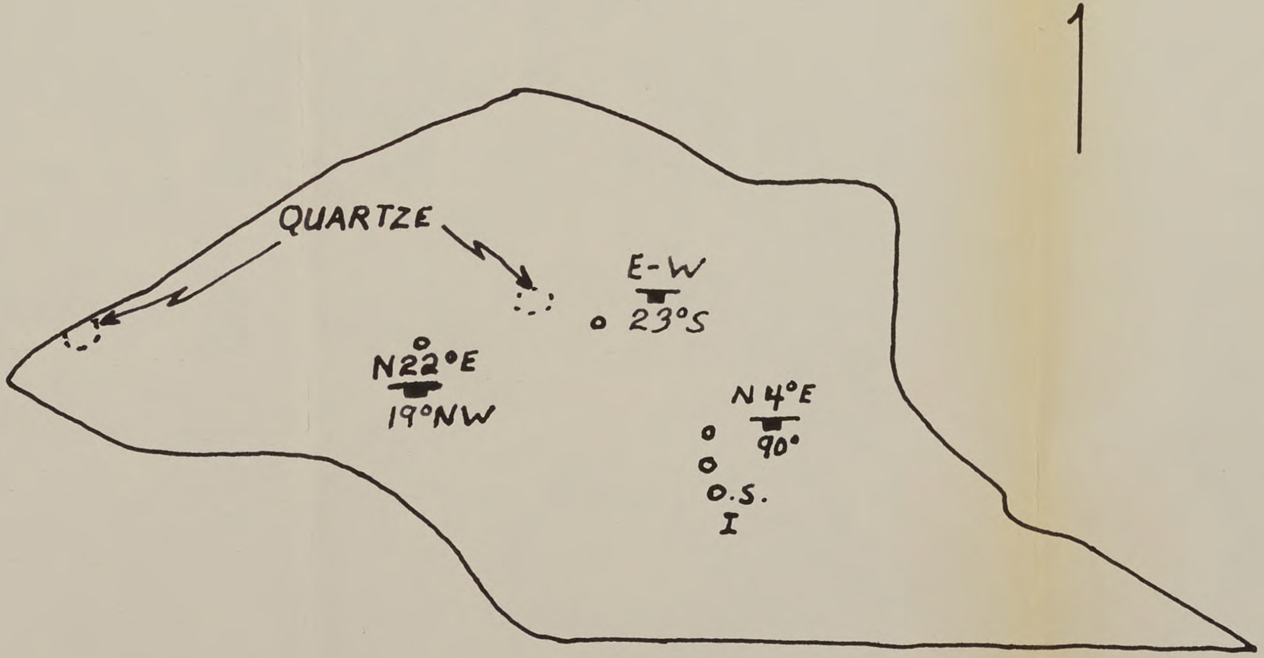
PLATE XX



Scale - 1" = 10'

Sketch of outcrop I.

PLATE XIX

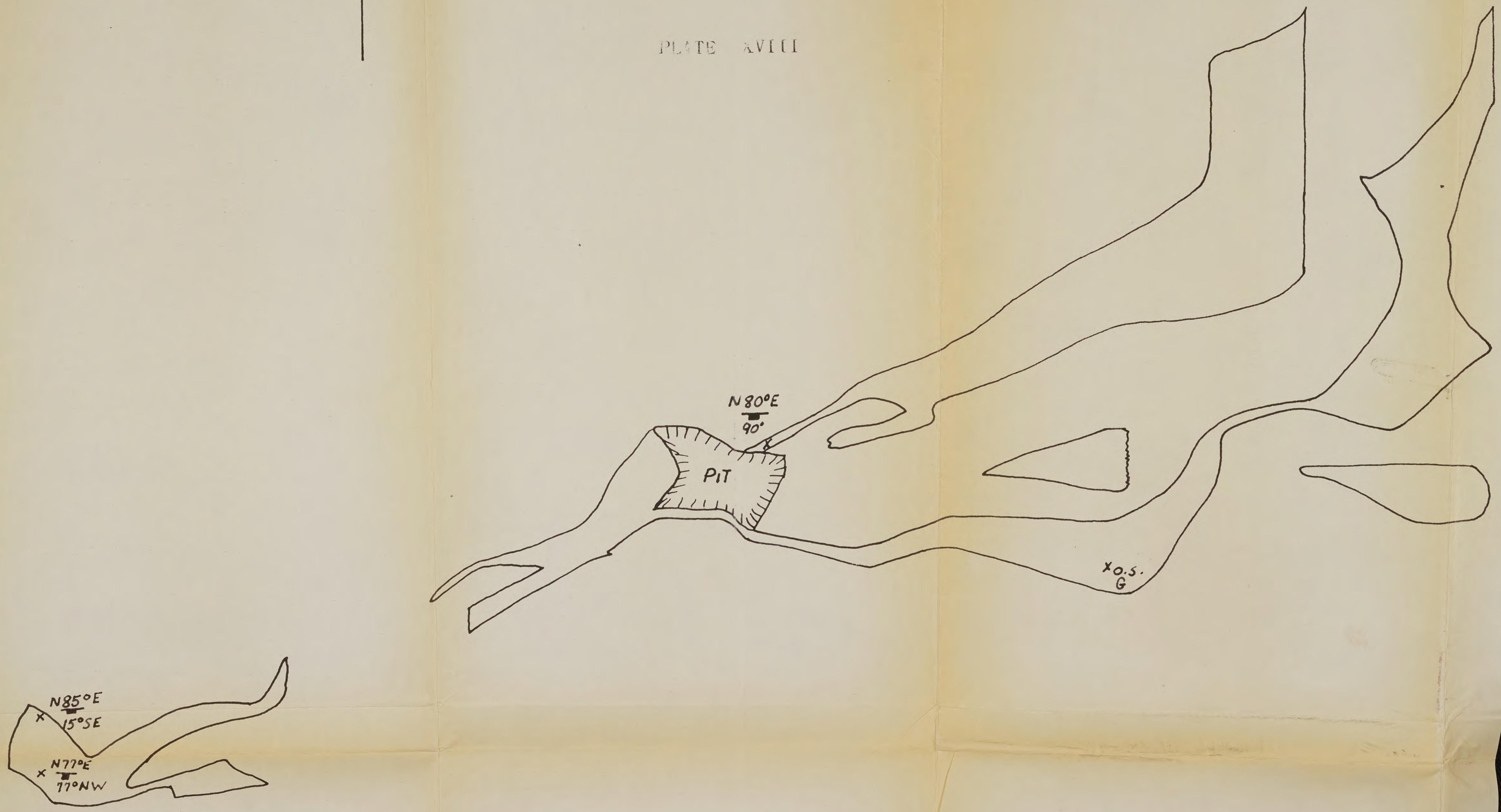


Scale - 1" = 10'

Sketch of outcrop G.

1

PLATE XVIII



Scale - 1" = 10'