PETROLOGY AND PETROFABRICS OF THE FELCH METRONITE QUARRY, DICKINSON COUNTY, MICHIGAN

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PETROLOGY AND PETROFABRICS OF THE FELCH METRONITE QUARRY, DICKINSON COUNTY, MICHIGAN

by

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ABSTRACT

The Felch Metronite Quarry constitutes a part of the Randville Dolomite located in the Precambrian complex of the Felch Mountain trough. The results of field observations supplemented by the analysis of twenty-two oriented thin sections are presented with brief interpretations of the rock units present.

Two rock units are present; dolomitic marble and granite dike. The older marble which represents the country rock is sedimentary in origin and has undergone later deformation and metamorphism. Granite intrusions represent the youngest rocks in the area. They are of igneous origin, their injection took place after deformation and metamorphism, and they are of post-Huronian age.

The major regional structure consists of an east-west trending syncline. Locally the marble follows a similar strike, while the dikes have an attitude of roughly N20°E, 65°NW. As a result of these intrusives, the marble in the footwall has undergone contact metamorphism.

Orientation analysis of the c-axes of over 900 quartz grains within the granite dike indicated a point maximum lying within the plane of dip and appears to be dependent upon structural features. A petrofabric study of 2460 c-axes of dolomite grains revealed a weak fabric pattern with maximum orientations lying normal to the regional structural strike or parallel to the deforming stress. Study of c-axes of grains

displaying multiple twinning in the dolomite revealed a fabric pattern confirming results that twins develop in areas of restricted orientation.

Dolomite re-orientation and/or obliteration resulted from post-deformational, postmetamorphic granite intrusions.

Correlation of coefficient gave a statistical measure of the degree of preferred orientation in the dolomite diagrams.

ACKNOWLEDGEMENTS

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INTRODUCTION

The Felch Metronite Quarry is located two miles east of Felch in Dickinson County, in the western part of the northern peninsula of Michigan. Geologically, the quarry lies at the eastern end of the Felch Mountain trough which is a syncline of Precambrian metamorphosed sediments and igneous intrusions. (Fig. 1 and map)

Topographically, the region consists of rock knobs, low rounded hills, and many intervening swamps. Although the maximum relief is not great, the region still presents a rather rugged topographic expression. With the exception of the large basic intrusive within the village of Felch, and the granite knobs to the north and south, most of the bedrock is covered by glacial material. The region is also thickly wooded with much underbrush and second growth.

The area covered in this report is limited to an outcrop within the Randville dolomite of Huronian age which is being quarried just east of Felch in section 26, T42N, R28W. The major rock unit exposed is a dolomitic marble which has a regional strike of east-northeast and an unknown dip, into which has been intruded post-Huronian granitic dikes that strike approximately north-northeast and dip steeply to the west-northwest.

This thesis reports findings of work done in the field and laboratory study. Oriented samples were collected in February of

1958. The area was first mapped in the spring of the same year and during early June was again visited to confirm earlier findings. Petrographic and petrofabric examinations were made of twenty-two thin sections cut from eleven samples. Of primary concern is the orientation of the dolomite in relation to the areal geology, and the influence the intruding granite dikes had upon any previous orientation of the marble. Of secondary nature is the study of the petrography, with petrological interpretations of dike-marble relationships.

GEOLOGIC SETTING

Little geologic literature concerning the Felch district is available. Most recent is a series of progress reports of work done by the United States Geological Survey in cooperation with the Michigan Geological Survey Division, Department of Conservation. The only publication is a progress report issued by C. E. Dutton in 1950, of work done in Iron and Dickinson Counties, briefly outlining the regional geology. Open file reports include detailed geologic studies of the Norway Lake area by L. D. Clark, the Calumet district by J. Freedman, and progress reports of portions of the Felch Mountain district by C. A. Lamey. H. L. James (1955) in his paper on regional metamorphism in Northern Michigan included portions of the Felch Mountain district.

An earlier work by Bailey and Smythe (Monograph 34), gives a short report on the Felch Mountain region which includes previous work in the area, general geology, and petrographic characteristics of the rock units. Papers issued by C. A. Lamey (1931, 1941) also cover the problem area.

Stratigraphy

Stratigraphically, four major rock units are recognized. In ascending order they are: 1) Sturgeon quartzite; 2) Randville dolomite; 3) Felch schist, and; 4) Vulcan iron-formation. All four of these

Post-Huronian intrusives				
PRECAMBRIAN	MIDDLE PRECAMBRIAN	HURONIAN	Menominee group	Vulcan iron-formation Felch schist
			minor uncomformity	
			Chocolay group	Randville dolomite Sturgeon quartzite
			uncomformity	
	LOWER PRECAMBRIAN	Gneiss granites and other crystalline rocks		
		Intrusive or replacement		
		Dickinson group	Six-Mile Lake amphibolite Solberg schist with Skunk Creek member East Branch arkose	Hardwood gneiss
		uncomformity		? — ?
		Granite gneiss		

TABLE I

Lithologic sequence of Precambrian rocks in the Felch Mountain district, Dickinson County, Michigan. (after James 1957, open file report)

rock units make up part of the Huronian series of the Precambrian. The basement complex is made up of granites, granite gneisses, and schists. The strata of these Huronian and older crystalline rocks are intruded by post-Huronian granites that are later than one set of diabase dikes and earlier than another. No strata younger than the iron-formation have been recognized. (Table I)

Structure

Although the structure in the vicinity of Felch has not been fully

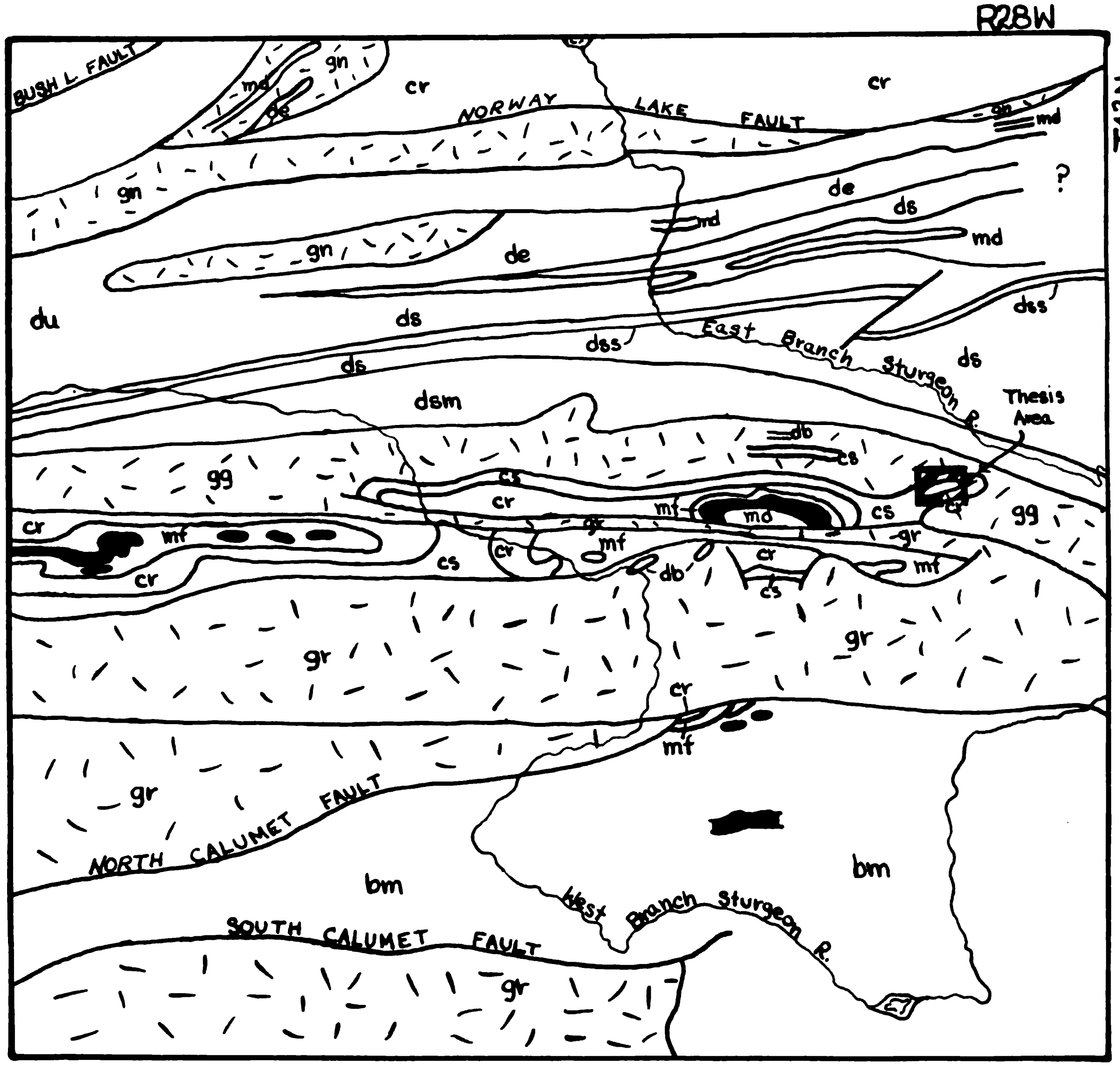

Fig. 1. Geologic Map of the Felch Mountain district and adjacent areas showing location of thesis area and its relation to the regional geology. (USGS open file report 1958)

dsm	Six Mile Lake amphibolite	db	Diabase
ds	Solberg schist	md	Metadiorite
dss	Skunk Creek member		Vulcan iron formation
de	East Branch arkose	mf	Felch schist
gr	Gneissic granite	cr	Randville dolomite
gg	Granite gneiss	cs	Sturgeon Quartzite
gn	Gneiss	bm	Michigamme slate

deciphered the general structure appears to be a tightly folded and faulted syncline in which the iron-formation is the youngest bed in the sequence. North and south, the Huronian series is bordered by the older granites and granite gneisses. The lowest member of the Huronian occupies parallel zones next to the older granite complex both on the north and south, and is succeeded toward the interior of the area by the younger members, thus indicating a synclinal structure. The trend is approximately northeast to east.

The area studied is located at the terminal end of this syncline within the Randville dolomite of the Huronian series. This brief outline of the geologic setting is at the present the most satisfactory that can be obtained; the local geologic setting can easily be correlated with the regional setting.

PETROGRAPHY AND PETROLOGY

Locally, two rock units are present. The major unit is a dolomitic marble of the lower Huronian which has been given the formational name, "Randville dolomite." The second rock unit is a post-Huronian granite which has been injected into the dolomitic marble. Each rock unit possesses certain distinctive characteristics relative to age, mode of origin, mineral assemblage, and texture. These two rock types are here called simply "Dolomitic Marble" and "Granitic Dike."

"Dolomitic Marble"

Dolomitic marble comprises the major rock unit in the area studied and is the country rock adjacent to the intruding granitic dikes. The quarry in this marble is one-hundred feet deep and extends east-west approximately three-hundred feet, and north-south one-hundred fifty feet. Detailed study of the marble was limited to samples taken along an east-west strike at varying distances up to one-hundred feet east and west of the easternmost dike. Thin section study was supplemented by field observations in other localities within the quarry. The rock is coarse grained and exhibits a bluish white color. No visable megascopic foliation is present.

Field studies of the dike-marble contact indicate that the dike has altered the surrounding host rock, injecting numerous granitic veinlets.

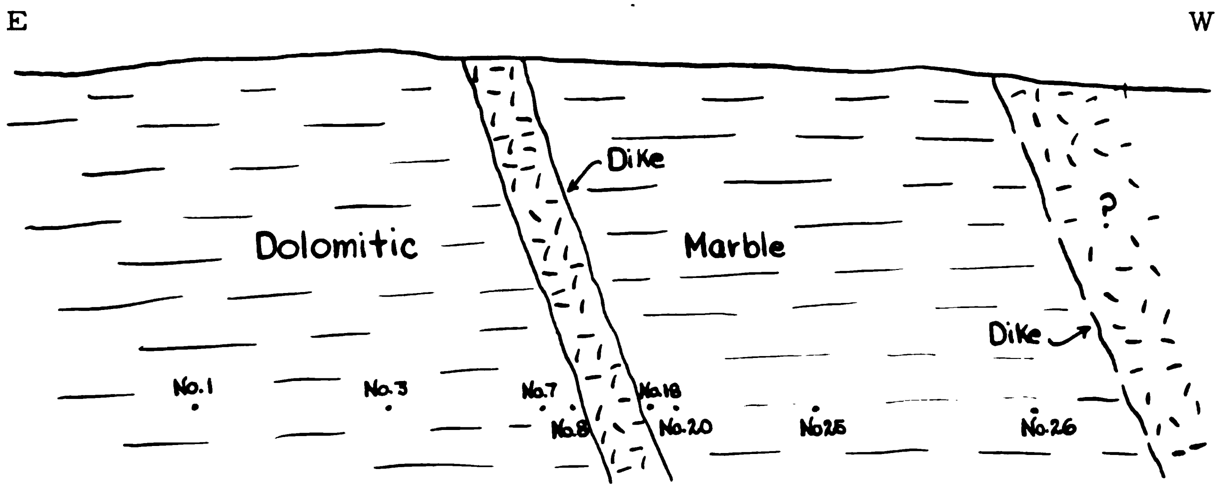

Fig. 2. Hypothetical sketch to show location of samples as related to local structure of dike and marble.

This phenomenon is especially noticeable on recently quarried faces where dike-marble contacts can be studied.

Megascopically, dolomite is the main constituent of the marble and always encloses, more or less abundantly, blades and aggregates of tremolite, which is particularly noticeable on weathered surfaces. Diopside is present in minor amounts throughout, and at the contact becomes one of the chief constituents. (Table II) Sample numbers 1, 3, 7, and 8 were taken east of the dike, numbers 18, 20, 25, and 26 west of the dike. (Fig. 2.)

Dolomite. Texturally, the mineral is granoblastic. Grain size ranges from 0.1 mm to 0.38 mm near the contact; the average is 0.31 mm. Study of thin sections revealed that the dolomite makes up approximately ninety percent of the rock in all samples with the exception of numbers 8 and 26. The grains in a few of the sections exhibit oval structures with the long axes lying in the same direction. Thus, a crude, but weak foliation appears to be present.

A distinctive characteristic of the dolomite in all sections is its prominent twinning. Over fifty percent of the grains revealed twinning, and the greater percentage of these, multiple twinning. In some instances one set of twins actually offset another. (Fig. 3.)

In sample 8, which was taken at the dike-marble contact, and where silicates are abundant, dolomite crystals are enclosed within large subhedral crystals of diopside, as the pyroxene has grown in and around the carbonate. In other situations the carbonate displays a "dirty" or "cloudy" appearance when in close association with the pyroxene.

The usual common characteristics of dolomite such as high interference colors and marked change in relief upon rotation of the microscope stage are also evident. In recording orientation of optic c-axes it was noted that a good isotropic section was characterized by moderate (brighter) interference colors which contrast with the exceedingly high order white or gray, and very high relief.

Tremolite. Tremolite occurs as an accessory mineral. It is not abundant in any of the sections but present in all. It occurs as typical long bladed individuals and aggregates. In most sections, individual blades are uncommon, but subhedral parts of grains occur together as aggregates. The longest individual measured 2.33 mm, but the average is much less. Included within the tremolite are parts of the carbonate groundmass. The mineral is colorless to light green.

In sample numbers 8 and 26, tremolite occurs enclosed within the

TABLE II

MODAL ANALYSIS OF DOLOMITIC MARBLE

Analysis	Sample			
	No. 1	No. 3	No. 7	No. 8
Dolomite	84.95	89.44	95.92	54.81
Tremolite	14.23	07.89	03.57	03.99
Diopside	00.81	02.42	00.51	41.21
Phlogopite	-	-	-	x
Pyrite	x	-	x	x
Total	99.99	100.00	101.00	100.01

	No. 18	No. 20	No. 25	No. 26
Dolomite	87.47	86.06	86.97	62.73
Tremolite	09.26	09.38	09.15	02.68
Diopside	02.30	04.57	03.89	34.58
Phlogopite	-	-	-	x
Pyrite	-	-	-	-
Total	99.03	100.01	100.01	99.99

x - trace

pyroxene. In nearly all instances the mineral occurs as bladed aggregates within the pyroxene rather than as individuals. Sample number 18 revealed excellent long individual blades that are slightly offset. (Fig. 5.)

Further detailed examination reveals a definite arrangement of the bladed tremolite. As all samples were oriented in the field, it is possible to take rough angle measurements as related to north. Although samples are limited in number, and measurements only rough estimates at best, the arrangement is nevertheless significant.

Diopside. Diopside is a rare accessory in all sections with the exception of samples 8 and 26 where it becomes a chief constituent, making up thirty-five to forty percent of the total. In these samples its common occurrence is in large subhedral crystals which are colorless, green, and pleochroic in pale greens and yellow greens. The mineral shows good pyroxene cleavage, rather high relief, fairly strong birefringence, and extinction angles of about forty-two degrees, all of which are characteristic of diopside. The mineral grows into and around carbonate, leaving small grains scattered through the diopside crystals. Associated with the larger crystals, there occurs within a cryptocrystalline groundmass of pyroxene and probable carbonate, tiny distinct diopside crystals exhibiting excellent prismatic cleavage. (Fig. 7.) Isolated portions of grains of diopside occur throughout all sections, displaying in part, sharp crystal outlines.

Other minerals in microscopic association with the dolomite are rare. A mineral believed to be phlogopite was distinguished in only two

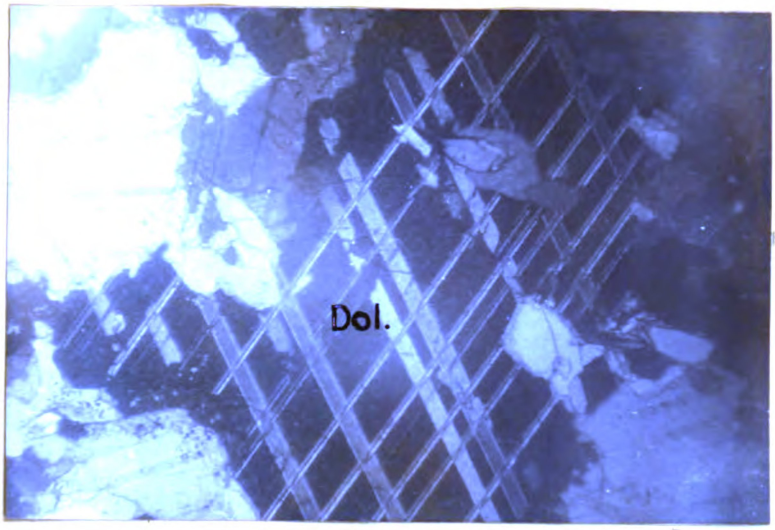

Fig. 3. Photomicrograph of dolomite in marble, showing repeated twinning. Crossed nicols.

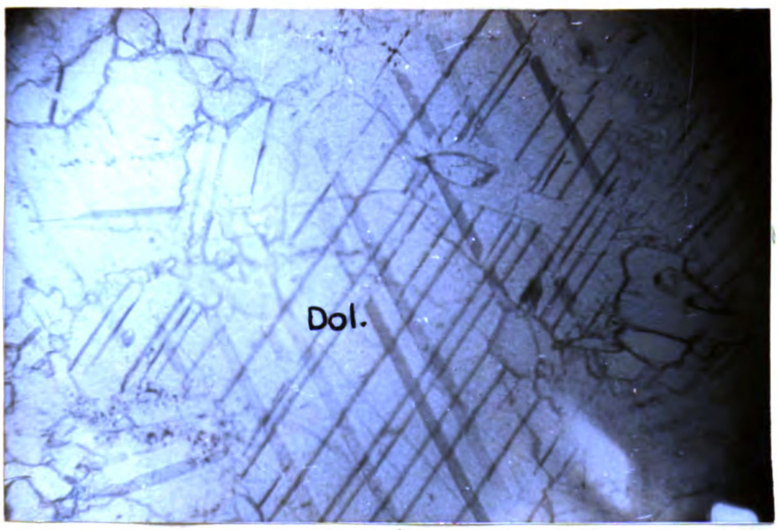

Fig. 4. Photomicrograph of dolomite in marble, showing repeated twinning. Plain light.

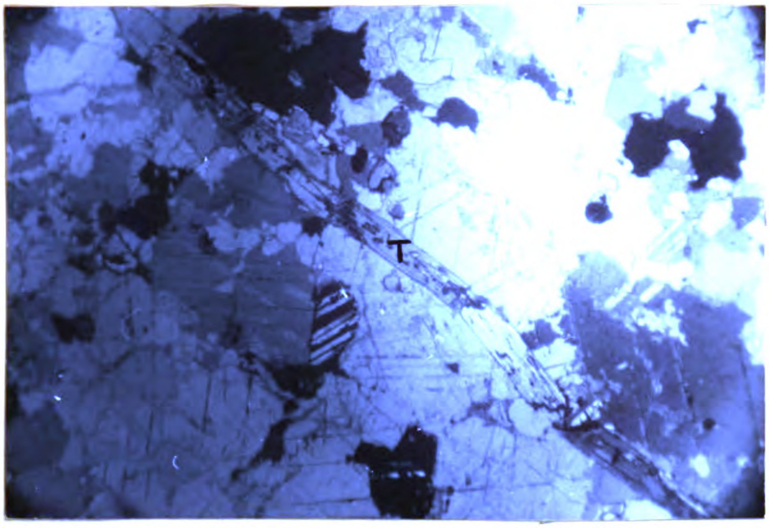

Fig. 5. Photomicrograph of tremolite in marble, showing long bladed crystal within dolomite twins. Crossed nicols.

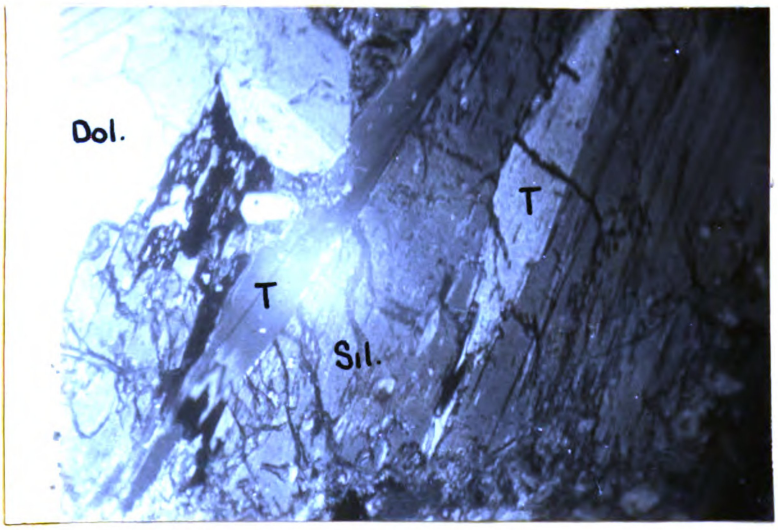

Fig. 6. Photomicrograph of tremolite fragments within silicate and carbonate. Crossed nicols.

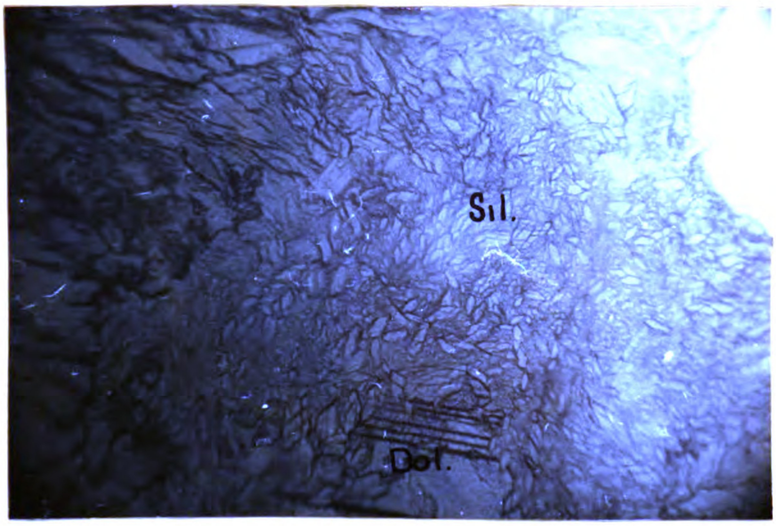

Fig. 7. Photomicrograph of silicate (diopside) showing distinct crystals in silicate-carbonate groundmass, along with twinned dolomite crystal near bottom. Plain light.

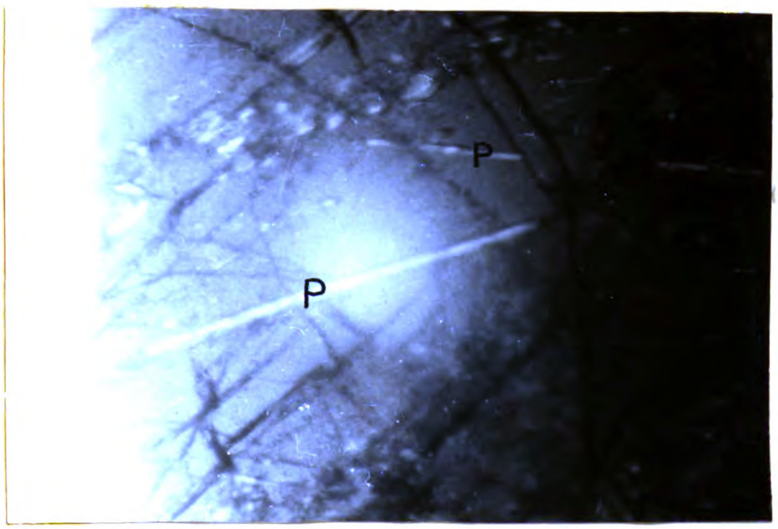

Fig. 8. Photomicrograph of what is probably phlogopite within silicate and carbonate. Crossed nicols.

sections and occurred as colorless bladed crystals, and is probably a product of secondary crystallization. (Fig. 8.)

Interpretations. Thin section study indicates that the marble has experienced complete reconstruction, for none of the constituents is present in its original form. With the exception of contact phases near the dike, it is probable that crystallization was not accompanied by the introduction of foreign materials from outside, but consisted in a mineralogical rearrangement of the elements present in the rock from the beginning. This is evidenced by the character and distribution of the accessory minerals.

The dolomite crystals show a rough foliation pattern as the dolomitic plates have their long directions striking roughly east-northeast. The deforming stress must have been a north-northwest direction for the c-axes lie perpendicular to the stress, (Fairbairn 1954); and secondly the regional strike of the northeasterly gently plunging fold is also perpendicular to the stress. Further evidences of deformation are indicated by the characteristic multiple twinning of the dolomite. Only in areas of deformation does twinning in dolomite occur. (Hawkins 1949)

Locally, the intrusion of the granite dike plays a significant role in the petrology of the dolomitic marble. In the area studied, the eastward extension of the marble from the dike is the footwall, while the hanging wall extends to the west, in that the dike has a west-northwest dip. Further study of thin sections revealed that another dike lying to the west also played a significant role.

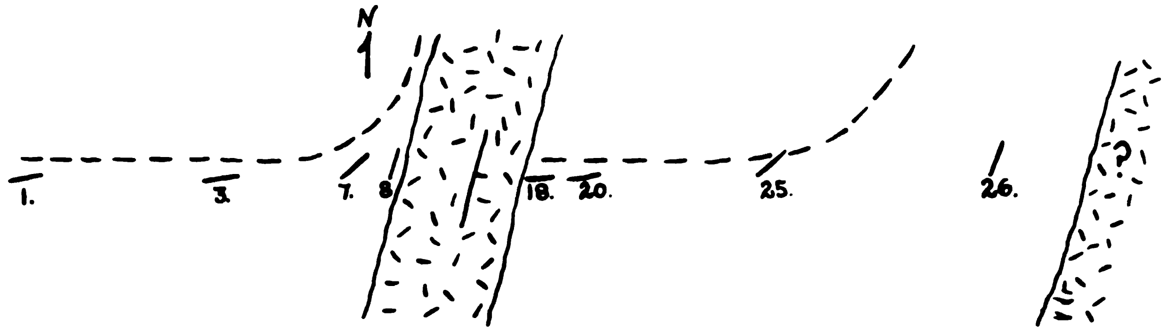

Fig. 9. Sketch map showing orientation of the bladed tremolite crystals as related to the dikes. Data obtained from sections cut from a horizontal plane. Scale is roughly fifty feet to the inch.

Tremolite is everywhere present within the marble and its presence is definitely not the result of the granitic intrusives. Its common occurrence throughout the Randville formation confirms this. However, the dikes have affected the orientation pattern of the tremolite. Orientation of the long bladed tremolite crystals reveal a distinct pattern what can probably be attributed to the intrusives. The data obtained can best be explained by a roughly sketched diagram. (Fig. 9)

From the diagram it can be noted in samples 8 and 26 which lie on the footwall side of the dikes (Fig. 2), tremolite crystals are aligned in a parallel position with the dikes, in samples 7 and 25 they occupy intermediate positions, while in samples 1, 3, and 20 they are oriented with their long directions parallel to the regional strike of east-northeast, and were probably not influenced by the intrusions. Tremolite from sample 18, which was taken at the contact, but on the hanging wall side, also lies parallel to the regional strike. Although observations were not precise, it is clearly indicated that the tremolite orientation was influenced

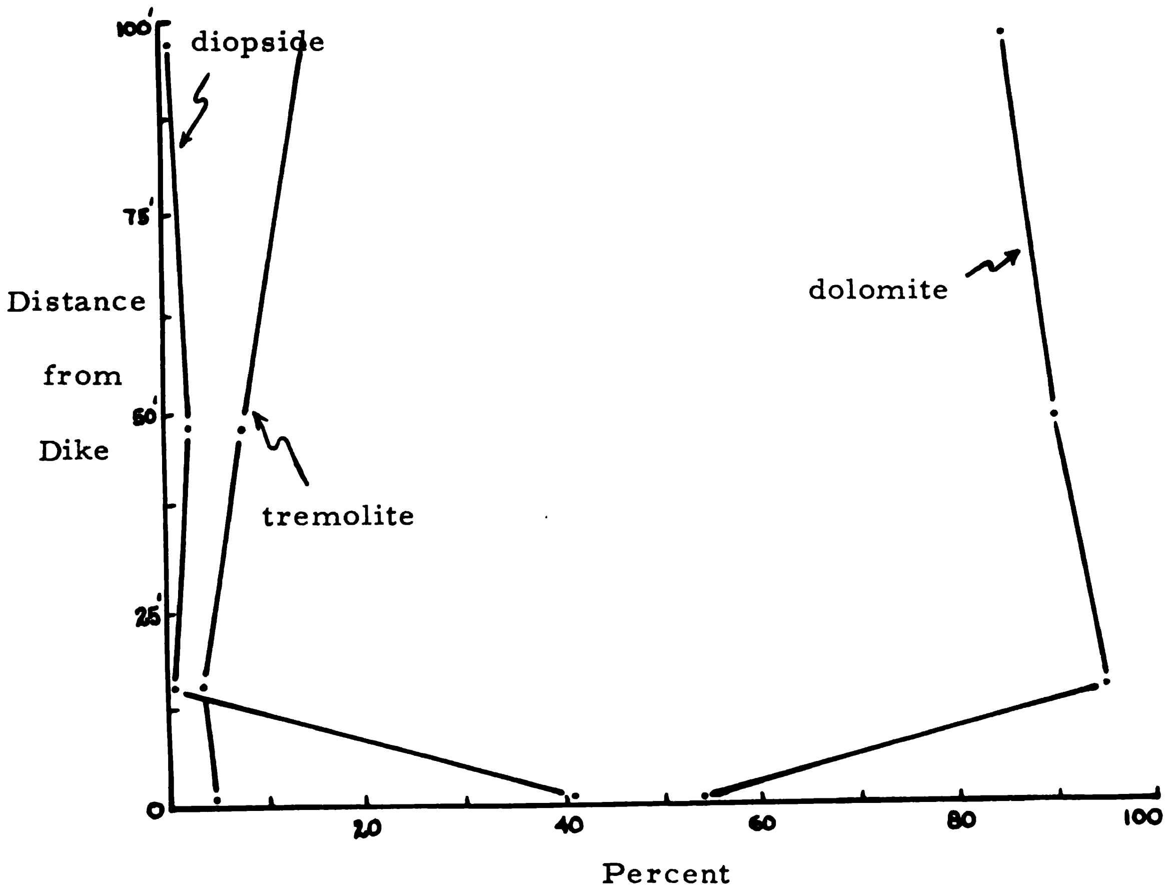

Fig. 10. Percentages of dolomite, tremolite and diopside at perpendicular distances from the dike eastward. Note definite increase of diopside near dolomite-dike contact. Data from samples 1, 3, 7, and 8.

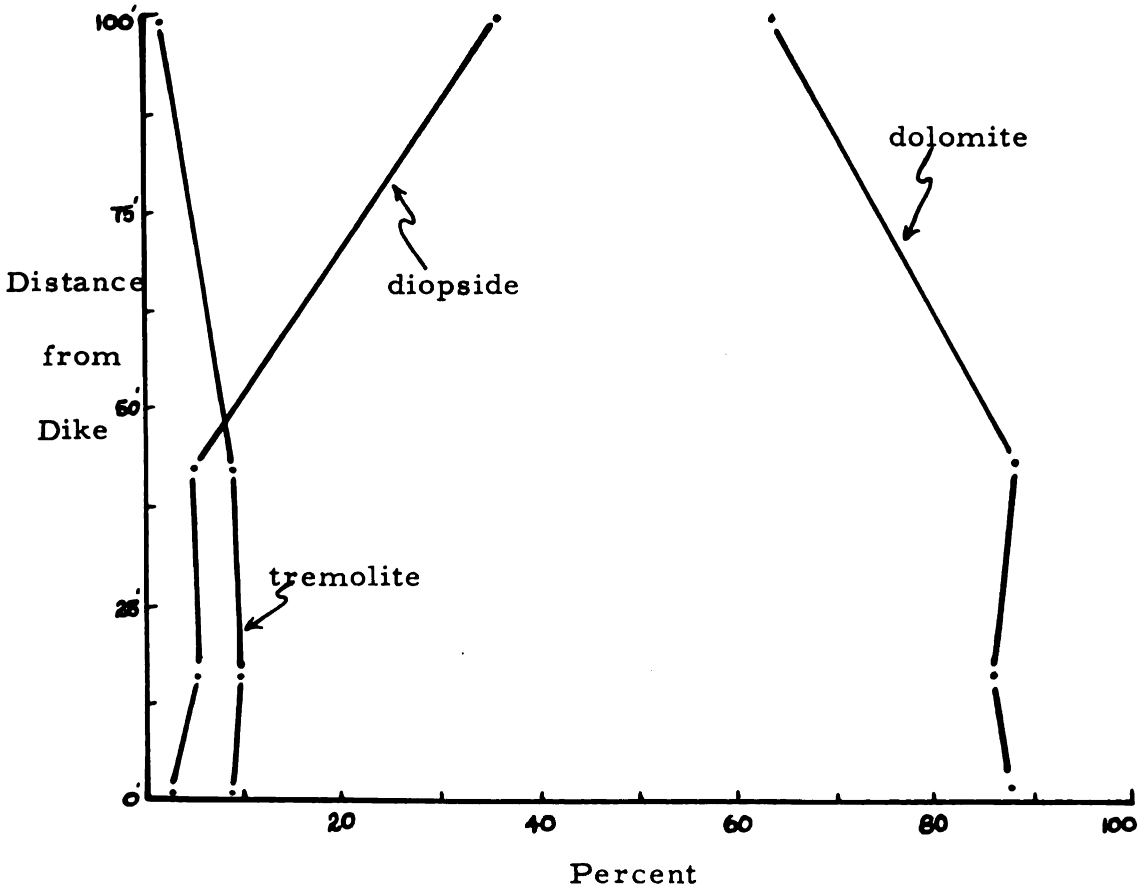

Fig. 11. Percentages of dolomite, tremolite, and diopside at perpendicular distances from the dike westward. Note definite increase of diopside near dolomite-dike contact. Data from samples 18, 20, 25, and 26. Sample number 26 is located near the westernmost dike.

in the footwall, but not in the hanging wall. It is probable that as the granite intrusion moved upward, descending solutions into the footwall caused reorientations of the tremolite, while there was apparently no movement of the solutions into the hanging wall. Another explanation is that slight movement along the footwall side of the dike might have taken place, although none is evident, causing displacement, and thus the possibility of ascending solutions along the dike-marble contact in the footwall.

This result can be further supplemented by the crystal shape of the tremolite. The best formed crystals lie in the hanging wall, or at greater distances from the intrusives. (Fig. 5)

Diopside, although rare within the rock unit, becomes a chief constituent in the footwall of the dike-marble contact, (Figs. 6 and 7). The increase in silicate must be the result of contact metamorphism. Phologopite (?), whose common occurrence is found in contact deposits in dolomitic rocks, occurred in samples 8 and 26, both of which are located at the dike-marble contacts in the footwall.

In summarizing the local rock unit, it is evident that it underwent post-Huronian, pre-granite intrusive deformation at which time its original character was changed, producing the development of metamorphic minerals related to stress; and later post-Huronian contact metamorphism by the granite dike produced the usual minerals developed by contact metamorphism and metasomatism.

"Granitic Dike"

A granitic dike about two and one-half feet wide is found intruding the dolomitic marble and is well exposed in the northerly and southerly quarry walls. The dike strikes roughly north-northeast and dips steeply to the northwest. This medium to coarse grained rock has a reddish color and contains, in places, large orthoclase and microcline phenocrysts. Field study revealed a second granitic dike occurring to the west. This much larger dike is somewhat more rhyolitic in character, and follows a similar north-northeast strike, but appears to dip more steeply. These dikes do not have welded contacts, but the contact line is marked by a non-resistant schistose material. There is little gradation in grain size from either edge.

Megascopic examination reveals the dominance of orthoclase microcline, and quartz with minor amounts of biotite that imparts to the rock a weak banded structure. Pyrite can also be identified megascopically. Samples 9, 10, and 17 were taken from the dike, 9 and 17 at either edge, number 10 from the center.

Samples 9 and 17. Texturally the samples are hypautomorphic porphyritic, with phenocrysts of orthoclase and microcline in a finer but still megascopic granular groundmass. The grain size ranges from 0.05 mm to 3.5 mm, averaging 0.52 mm. In thin section the rock consists chiefly of quartz, orthoclase, and microcline, with minor amounts of biotite and a trace of muscovite and pyrite. (Table III)

Quartz. Quartz makes up the greatest part of the rock and has the typical characteristics of the quartz in granite. Undulatory extinction is common.

Feldspar. The chief feldspar is orthoclase which constitutes greater than thirty percent of each sample. The orthoclase shows simple Carlsbad twinning, and is altering to sericite. (Fig. 12). It occurs as subhedral crystals showing no distinct crystal boundaries, probably due to overlapping crystalization or simultaneously crystallization. The other prominent feldspar is microcline exhibiting excellent grid twinning. (Fig. 13.). The sodic feldspar is oligoclase and is a rare constituent in the rock. Only in sample 17 was it easily recognized. Conspicuous polysynthetic twinning is present. (Fig. 14). The occurrence of intergrowths between the potash-feldspar and the sodic feldspar was not recognized as the greater part of the acid plagioclase forms separate crystals.

Mica. The mica present is brownish biotite, exhibiting strong pleochroism. A distinguishing feature of the biotite is its oriented nature. It occurs interstitially among the prominent constituents and has a definite parallel pattern lying normal to the strike and dip of the dike. (Figs. 15 and 16).

Pyrite is rare and is probably of secondary nature.

Sample 10. There is little difference between samples 10, 17, and 9. Mineral types and relationships are similar. A minor difference is the percentage of microcline; whereas in sample numbers 9 and 17 it constituted not quite fifteen percent of the total, in number 10 it constitutes as much

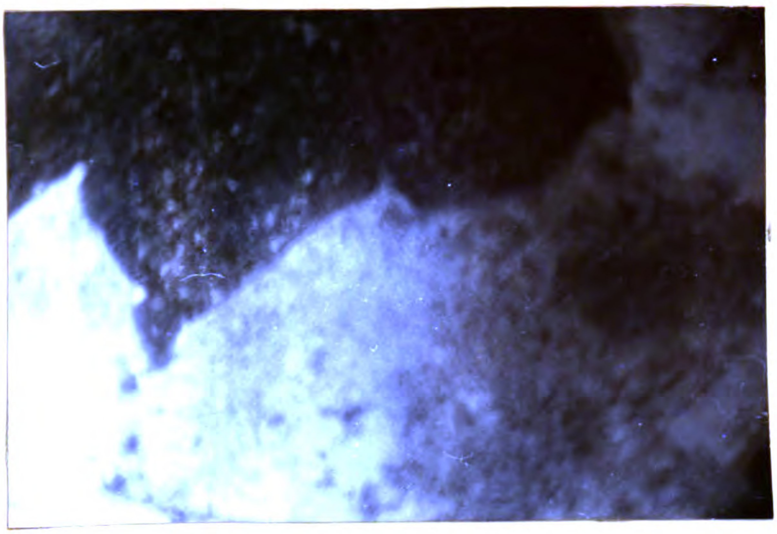

Fig. 12. Photomicrograph of orthoclase (sericitic) in granite dike showing Carlsbad twinning. Crossed nicols.

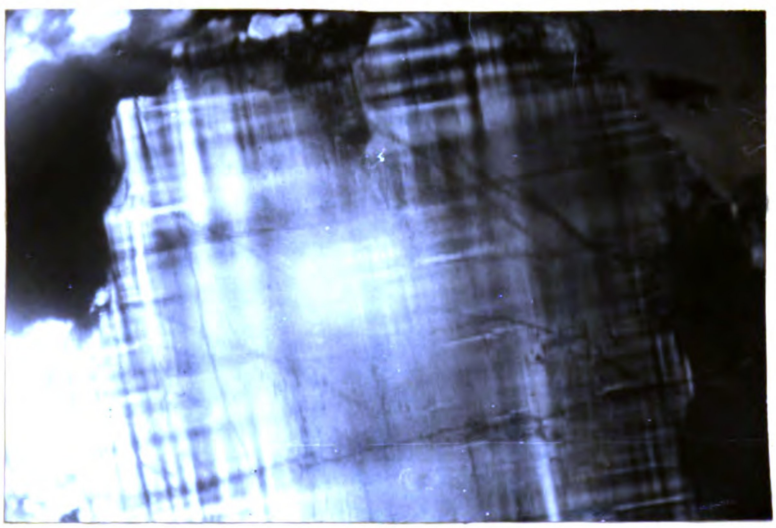

Fig. 13. Photomicrograph of microcline in granite dike, showing prominant grid twinning. Crossed nicols.

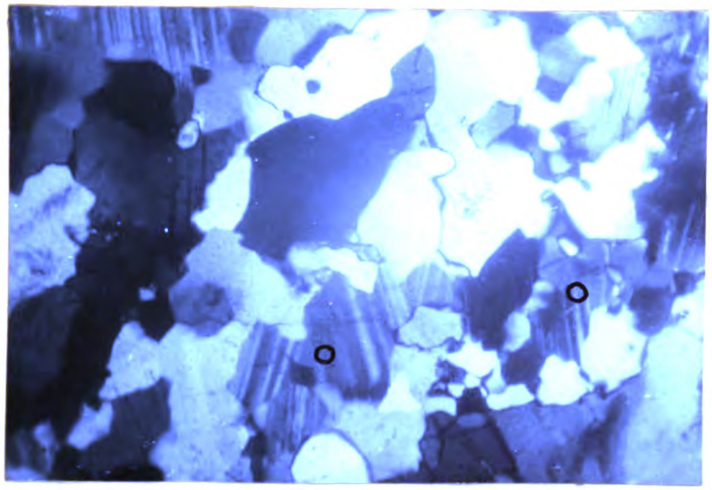

Fig. 14. Photomicrograph of oligoclase in granite dike showing polysynthetic twinning. Crossed nicols.

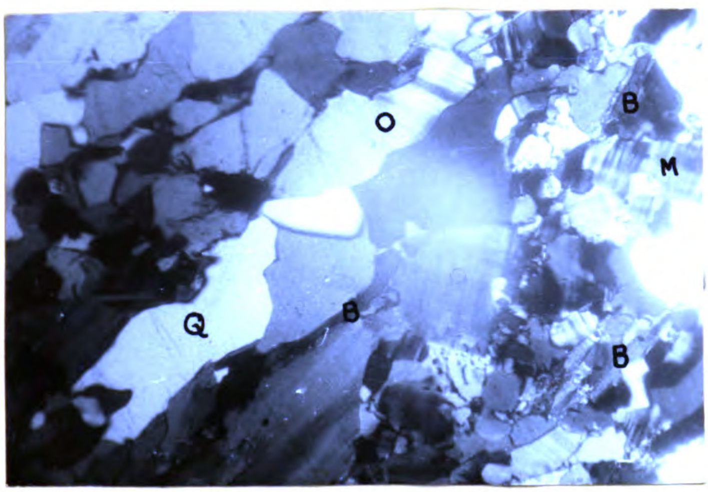

Fig. 15. Photomicrograph of quartz, orthoclase, microcline, and interstitial biotite in granite dike. Crossed nicols.

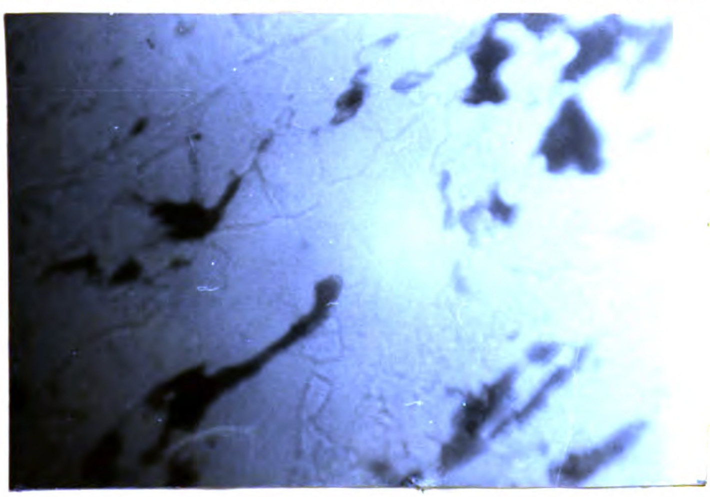

Fig. 16. Photomicrograph of interstitial biotite in granite dike. Plain light.

TABLE III

MODAL ANALYSIS OF DIKE

Analysis	Sample		
	No. 9	No. 10	No. 17
Quartz	50.49	40.83	46.98
Orthoclase[1]	32.67	23.33	32.89
Microcline	13.86	35.00	13.42
Oligoclase	x	0.83	4.02
Biotite	2.97	x	2.68
Muscovite	x	x	x
Pyrite	x	x	x
Total	99.99	99.99	99.99

[1] Highly sericitic

x - trace

as thirty-five percent. This increase might be related to the increase in grain size, where the average is here 0.67 mm. However, due to the relatively large feldspar crystals within the dike, variations like this might well be expected when few samples are taken, and as a consequence bears little significance, if any at all. Another difference noted is the absence of mica as only a trace is present.

Interpretations. On the basis of superficial field examination and extensive study of thin sections, these dikes can be classified as "granitic" intrusions. Modal analysis of the rock clearly presents the large percentage of feldspar and quartz and the rare occurrence of the dark mineral.

That this dike is post-Huronian in age is unquestionable. Locally it cuts the lower Huronian dolomite. Further west in the vicinity of Felch similar granite intrusions are found cutting the youngest member of the Huronian in the area, the Vulcan iron-formation. Thus, the post-Huronian age of the dikes is clearly evident. The granite intrusives also indicate that they are post-metamorphic as they intrude a rock unit that has already been metamorphosed to dolomitic marble, and there is no evidence that the dike has ever undergone metamorphism.

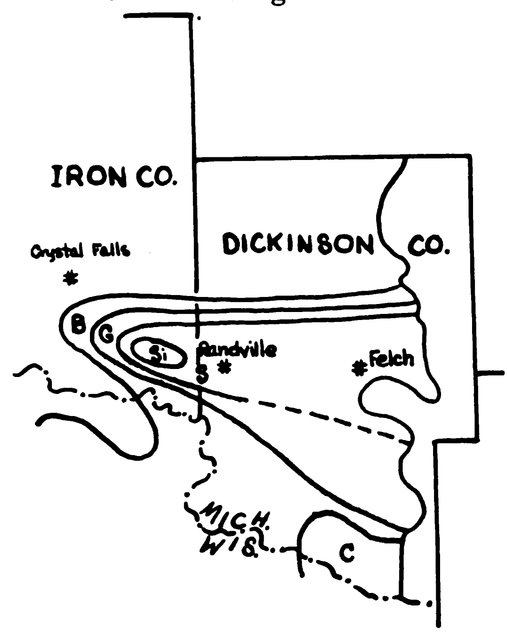

Fig. 17. Zones of regional metamorphism in Dickinson County, Michigan. Shown is the Peavy node. Si-sillimanite, S-staurolite, G-garnet, B-biotite, C-chlorite. (After James 1955)

Measurements:

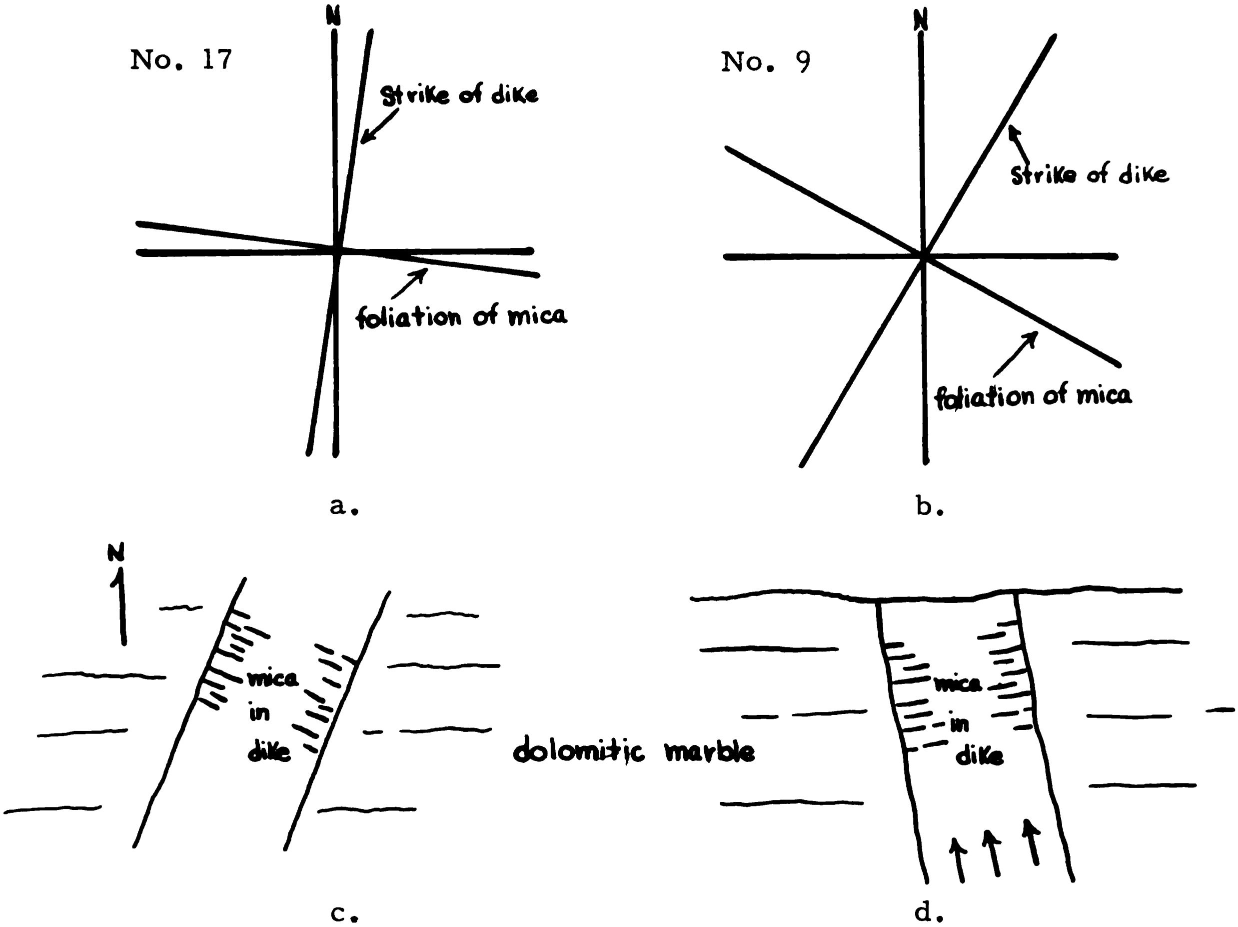

Fig. 18. Orientation of mica as related to local structures within the dike. (a) data from sample 17; (b) data from sample 9; (c) plan-view; (d) cross-section.

It can generally be assumed that the granitic dikes originated from a magma of similar composition, which emanated from depth during post-Huronian time and constituted the original aureol for earlier metamorphism of the region. James (1955) in his study of the metamorphic zones of northern Michigan showed that scattered intrusive bodies extended from Crystal Falls on the west, through the nodal area, into the Felch district, and were in direct relation to the metamorphic high. (Fig. 17). Also, their abundance along the Peavy belt was greater than elsewhere, and in general are post-metamorphic.

This post-Huronian dike is also a primary igneous intrusion rather than ultrametamorphic in origin. Thin section study reveals the uniform composition within the rock even though it has cut a rock unit of a highly different type, thus indicating its igneous nature. Further evidence is indicated by sharp contacts featuring a schistose zone. The weak but significant banding of the mica provides further data that the dike is of primary origin for the biotite is not parallel to the regional slaty cleavage. The mica lies normal to the strike of the dike. (Fig. 18). All samples displayed the same phenonmenon. This being the case, it can be deduced that the intrusion was injected en' mass. Of further significance is the fact that there has been no deformation in the area since the time of intrusion. If further deformation has occurred post dating the granite intrusion, the mica would tend to lie parallel to any foliation caused by the youngest deforming stress, but it does not.

In summary, although samples are limited, petrological study reveals the post-Huronian, post-metamorphic age, and the probable origin of the granite dikes.

PETROFABRICS

In order to determine any possible fabric orientations of the dolomite a petrofabric study was undertaken. Eleven samples were collected from the quarry wall. A Brunton compass was used to determine directions. All samples were oriented with respect to magnetic north, since the magnetic declination in the area is less than one degree off true north.

When selecting the samples it was necessary to collect them at varying distances from the dike so that representative results might be obtained in either direction. Three samples were taken from the dike, one at either edge and the other from the center. Eight samples were collected from the dolomitic marble at distances of one foot, fourteen feet, forty-five feet, and one-hundred feet east and west of the intrusive. (Locations of all samples studied are shown on Fig. 2 and accompanying map). The attitudes of each specimen were etched on it with a nail and later re-marked with a good tape label. All locations and attitudes were noted in a field notebook.

Twenty-two oriented thin sections were prepared from eleven samples. As no conspicuous megascopic fabric element could be observed, two sections were cut: (a) north-south vertical; and (b) east-west horizontal. The sections were cut in the manner diagrammed in figure 19.

A study was made of the orientation of the c-axes of one-hundred fifty quartz grains in each thin section of the dike and one-hundred twenty-five to one-hundred fifty dolomite grains in each marble thin section. For this study a 4-axis Universal Stage was used. Standard orientation procedures were applied in quartz orientation, referring to the method outlined by Fairbairn (1954). In the case of the carbonate, which is highly birefringent, a correction factor obtained from Plate 8 in Emmons was used, (G.S.A. Memoir 8), using the index for the hemisphere and the high index for the carbonate. For N-S readings of less than fifty degrees there is no appreciable error for n_o, for n_e the

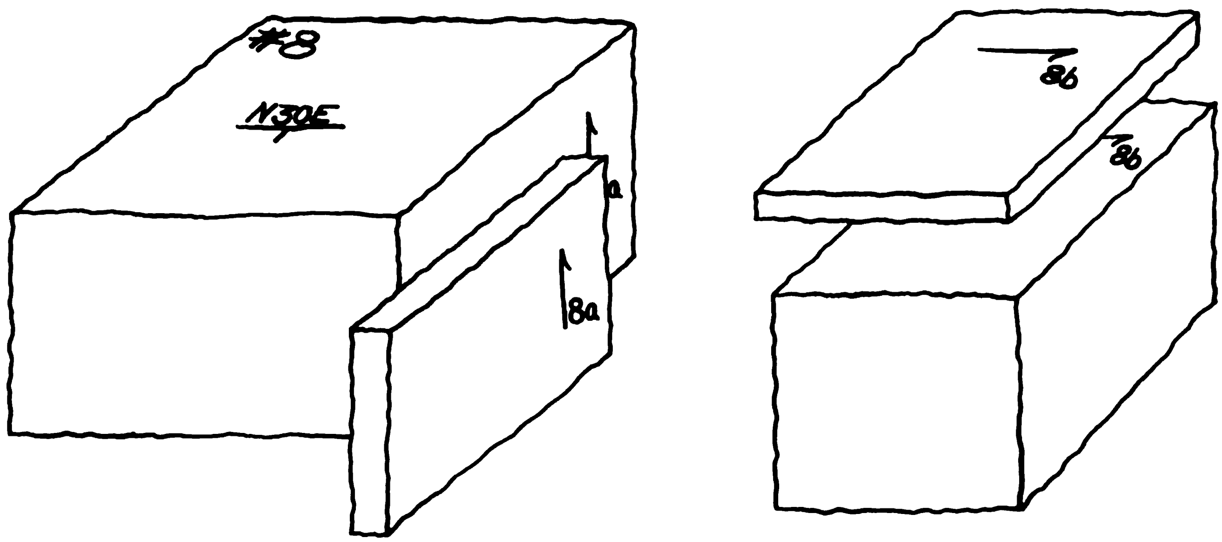

Fig. 19. Chip a - north-south vertical and normal to the crude foliation. Chip b - east-west horizontal and parallel to the crude foliation.

correction increases with the size of N-S. As nearly all N-S readings obtained were low, required corrections were of little significance. All points were plotted on the lower hemisphere of a Schmidt equal-area net and rotated to a horizontal plane. Concentrations of the c-axes were determined by standard center and peripheral counters of 1.0 cm radius.

Composite diagrams were compiled and contoured for each sample. Individual diagrams were compiled and contoured separately for samples exhibiting multiple twins.

Petrofabric Analysis of Dike

Quartz Orientation

The strike of the dike is approximately north-northeast and dips steeply to the west-northwest. The rock exhibits a weak foliation of the mica which lies normal to the strike of the dike.

Figure 20 shows 317 quartz axes plotted from two thin sections from sample 9 which was taken at the eastern contact where the attitude is approximately N30°E, 70°NW. The diagram appears almost isotropic although a five percent maximum occurs. The weak orientation has a bearing of roughly N73°E and plunges fifteen degrees to the southwest and appears independent of any structure.

Figure 21 shows 317 quartz axes plotted from two thin sections from sample 17 which was taken at the western contact where the attitude is approximately N10°E, 65°NW. The quartz axes diagram displays a partial girdle with a five percent maximum orientation lying in the plane of the dip. The orientation has a bearing of about N86°E and plunges 65 degrees to the west. The rake is roughly 82 degrees to the southwest. It is apparent that this quartz orientation is related to structural conditions.

Sample 10 was taken from the center of the dike and represents 300 quartz axes from two sections, (Fig. 22). The attitude is again N30°E,

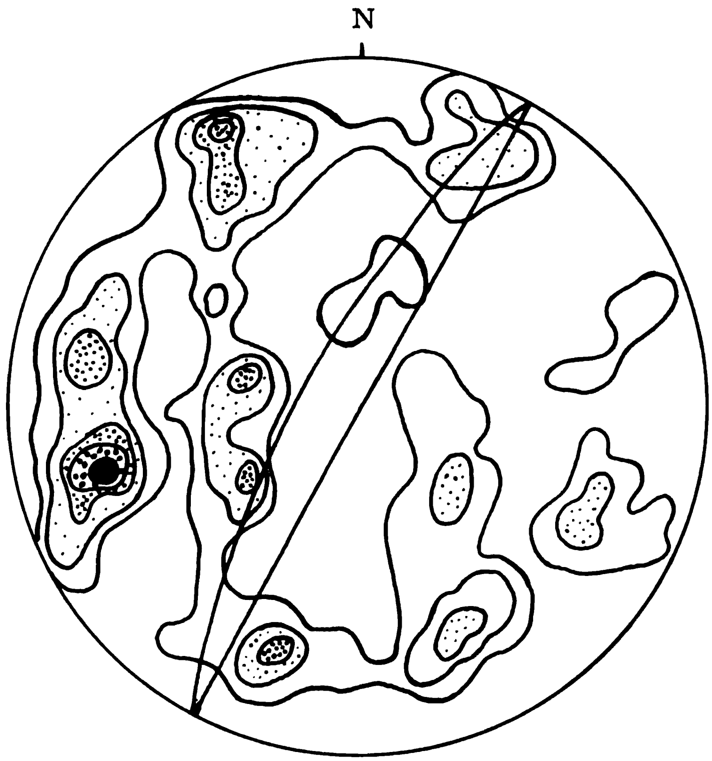

Fig. 20. 317 quartz axes from sample 9. Contours 5-4-3-2-1 percent. The local attitude of the dike is shown by a great circle.

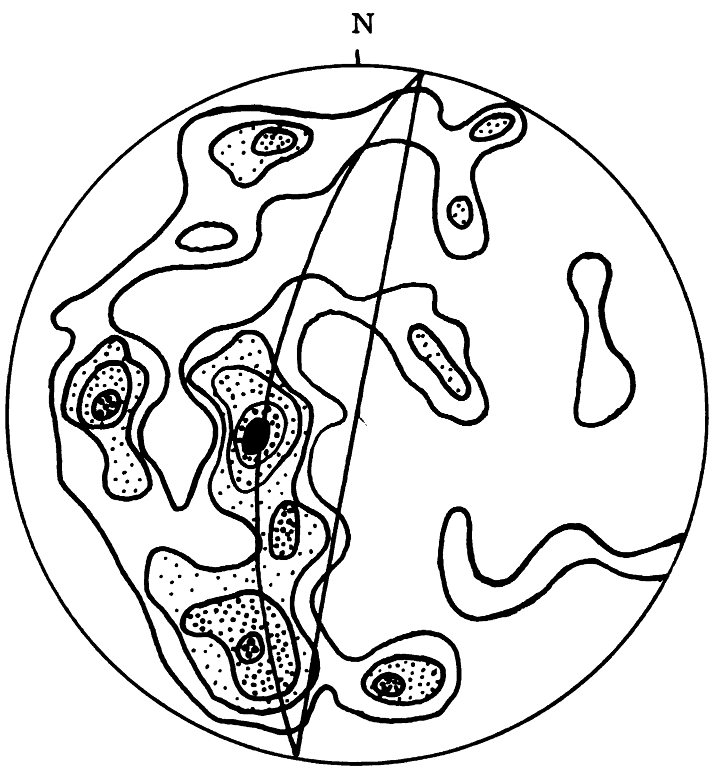

Fig. 21. 317 quartz axes from sample 17. Contours 5-4-3-2-1 percent. The local attitude of the dike is shown by a great circle.

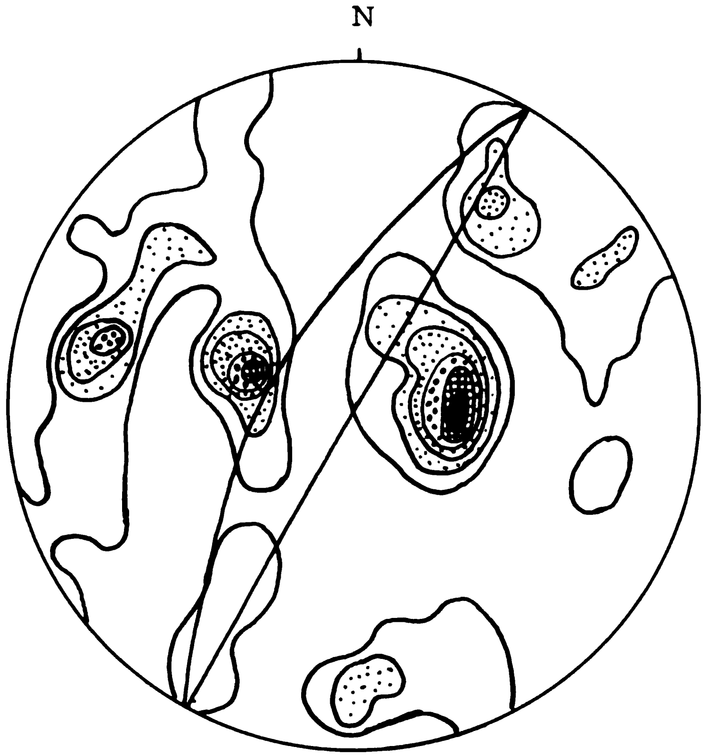

Fig. 22. 300 quartz axes from sample 10. Contours 6-5-4-3-2-1 percent. The local attitude of the dike is shown by a great circle.

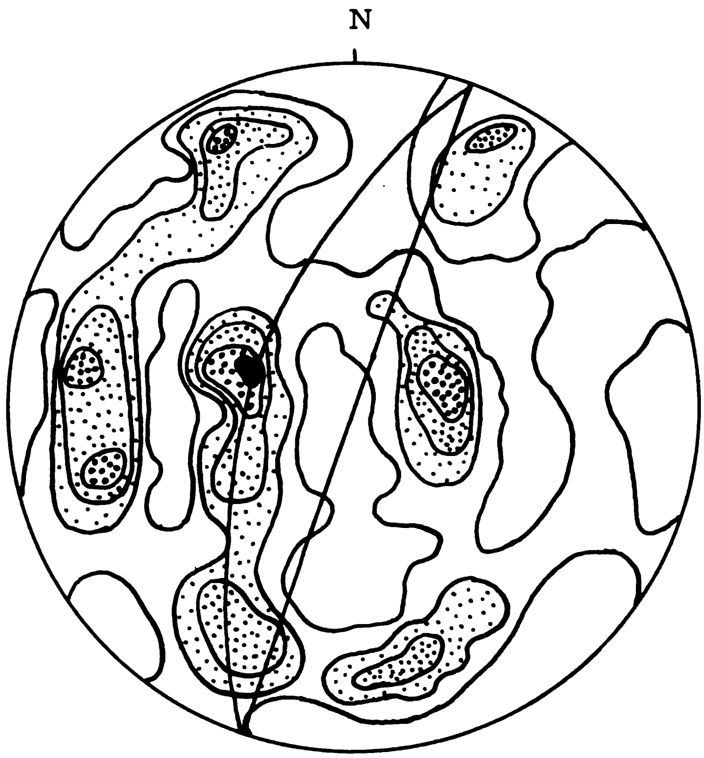

Fig. 23. 930 quartz axes from samples 9, 17, and 10. Contours 3.3-2.7-2.0-1.3-0.7 percent. The composite attitude of the dike is shown by a great circle.

70°NW. Two maxima of six and five percent with a bearing of N75°W occur, the former plunging 64 degrees southeast, the latter 64 degrees northwest. Although the maximum orientation appears to be independent of any structure, the secondary maximum of five percent is dependent on local structural conditions as shown by the meridian falling on the great circle for the dike.

The composite diagram of samples 9, 17, and 10 represent 930 quartz axes plotted from six sections, (Fig. 23). The diagram presents a 3.3 percent maximum with a bearing of roughly N74°W and plunging 64 degrees northwest. Assumming an average strike of N25°E with a dip of roughly 65 degrees to the northwest for the dike, it becomes apparent that maximum orientation of the quartz axes lies in the plane of the northwest dipping dike.

Petrofabric Analysis of Dolomitic Marble

Dolomite Orientation

Locally the rock exhibits no conspicous foliation. Regional studies have indicated a general east-northeast strike for the synclinal structure. Detailed microscopic studies revealed a weak foliation of the dolomite as exhibited by the ellipsoidal dolomite grains. This was taken as the ab plane with the assumption that b was in a horizontal position as indicated by the regional fold axis.

Figure 24 shows 270 dolomite axes plotted from two sections from sample 1. The dolomite axes diagram appears anisotropic with a 5.5

percent maximum. The orientation has a bearing of approximately N31°W and plunges 49 degrees northwest. It appears that the strike of the maximum orientation lies roughly normal to the regional structure.

Figure 25 shows 302 dolomite axes plotted from two sections from sample 3. A weak girdle bearing northwest with a maximum orientation of 5 percent occurs. The bearing is N20°W, plunging 15 degrees northwest, while a secondary maximum of 4 percent bears in the same direction but plunges 28 degrees southeast. The maximum orientation normal to the regional structure is again evident.

A diagram of 304 dolomite axes from sample 7, (Fig. 26), shows a 4 percent maximum and displays little or no orientation. Two weak maxima are present, one bearing N28°W and plunging 35 degrees northwest, the other bearing N28°E and plunging 16 degrees northeast. While the first is in conjunction with the regional structure, the latter with a northeast bearing appears independent of any structural trend, but might be attributed to the closeness of the granite dike whose northeasterly strike roughly parallels the northeast orientation. Another possible explanation is that the dike might have destroyed any orientation that was previously present.

The diagram of figure 27, which represents 250 dolomite axes from two sections from sample 8, shows what appears to be random orientation. A maximum orientation of 4.8 percent is shown bearing N22°E and plunging 10 degrees southwest. This orientation might again be the result of the dike as this sample was taken at the contact. Two lesser highs with maxima of 4 percent bears N12°W and N17°W, while their plunges are 22 degrees northwest, and 28 degrees southeast respectively. The diagram indicates that the granite dike must have effected the orientation of the dolomite, as an isotropic fabric is clearly evident.

Figure 28 shows 312 dolomite axes plotted from two sections from sample 18. Preferred orientation is apparent with a 6 percent maximum, the maximum orientation bears roughly N-S and plunges 10 degrees to the south, and clearly complies with the regional structure.

Figure 29 represents 307 dolomite axes plotted from two sections of sample 20. Orientation is weakly defined but two maxima of 4 percent are found bearing N31°W and N-S with plunges of 42 degrees northwest and 57 degrees north. The orientation pattern is again in accordance with regional structures.

A dolomite axis diagram of sample 25 represents 275 dolomite axes, (Fig. 30), and appears almost isotropic with a 4.4 percent maximum. Two weak orientation patterns bear roughly N46°W with a plunge of 64 degrees to the northwest, and N61°E with a plunge of 70 degrees northeast. The first may be dependent upon regional structures, but the latter with a northeast bearing and plunge is probably independent on any regional structures.

Figure 31 shows 232 dolomite axes plotted from sample 26. Preferred orientation is apparent with a maximum of 6.5 percent bearing N22°W and plunging 14 degrees northeast. Assuming the

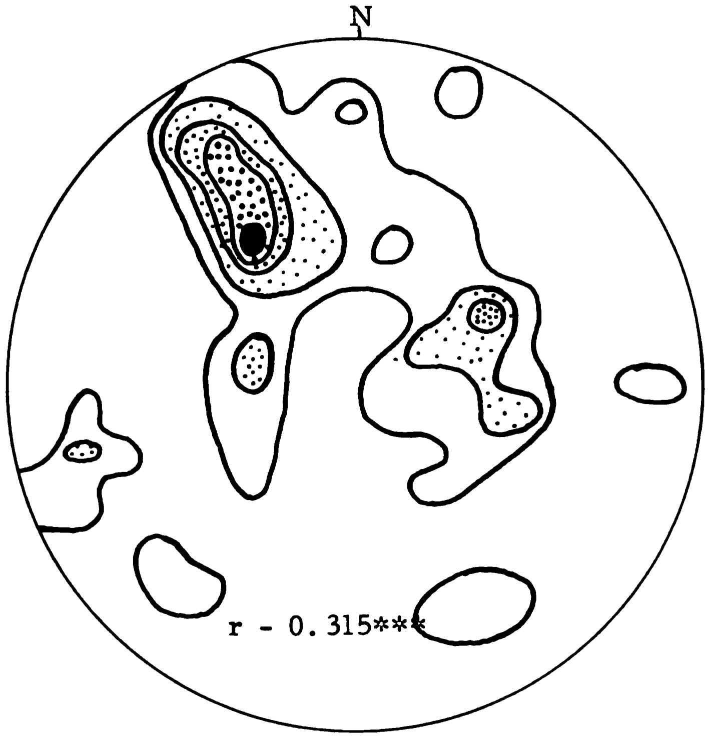

Fig. 24. 270 dolomite axes from sample 1, twinned and untwinned grains. Contours 5.5-4.4-3.3-2.2-1.1 percent.

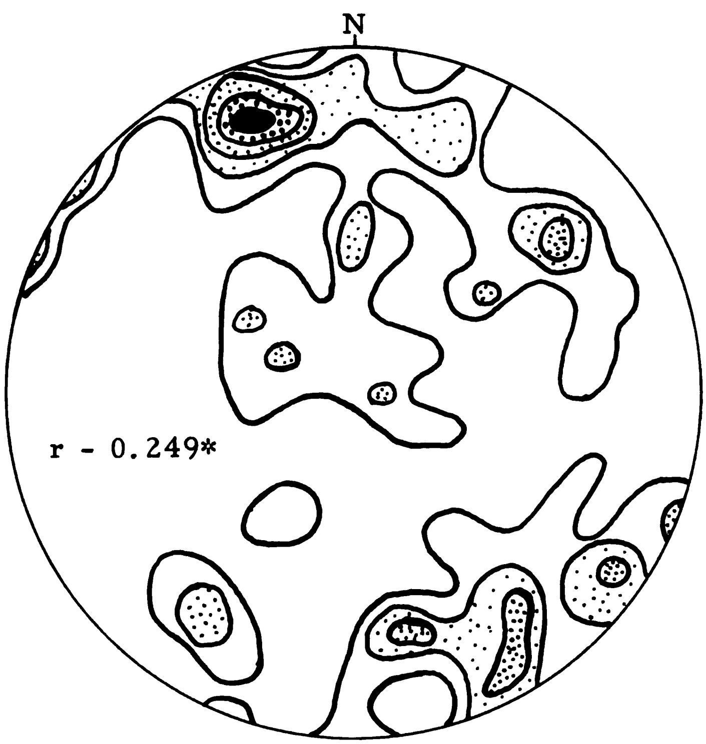

Fig. 25. 302 dolomite axes from sample 3, twinned and untwinned grains. Contours 5-4-3-2-1 percent.

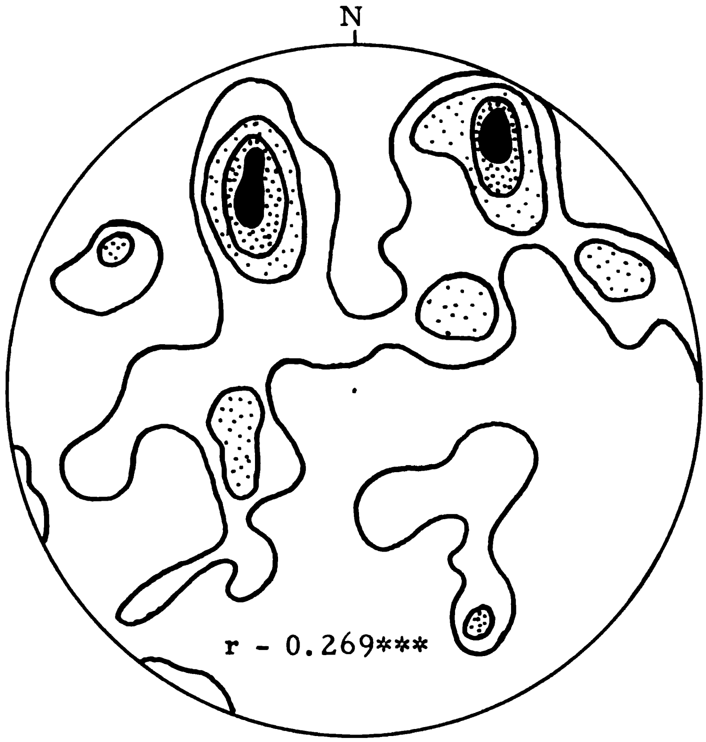

Fig. 26. 304 dolomite axes from sample 7, twinned and untwinned grains. Contours 4-3-2-1 percent.

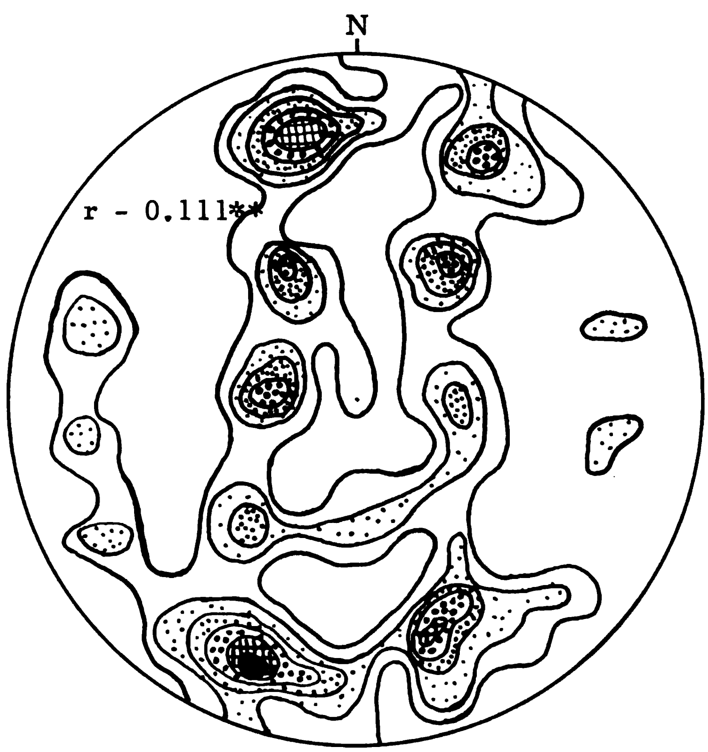

Fig. 27. 250 dolomite axes from sample 8, twinned and untwinned grains. Contours 4.8-4.0-3.2-2.4 -1.6 -1 percent.

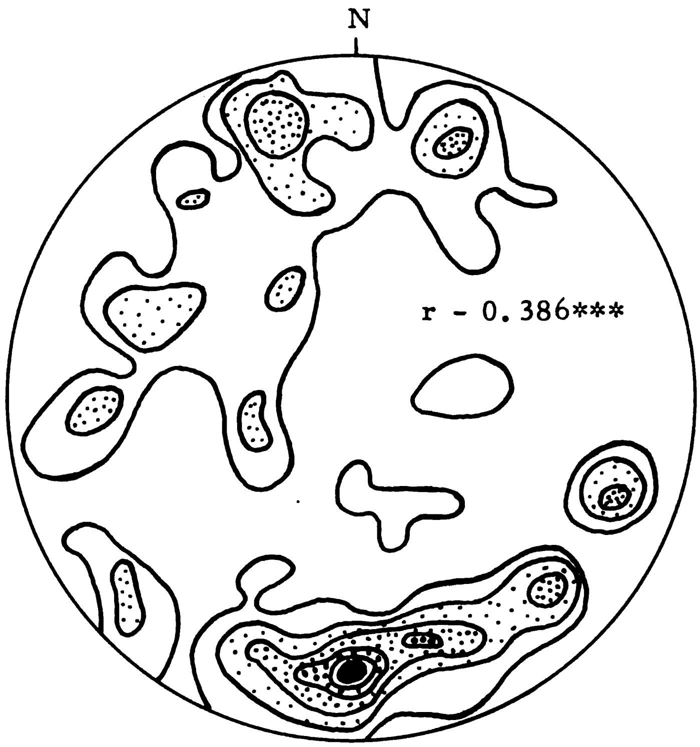

Fig. 28. 312 dolomite axes from sample 18, twinned and untwinned grains. Contours 6-5-4-3-2-1 percent.

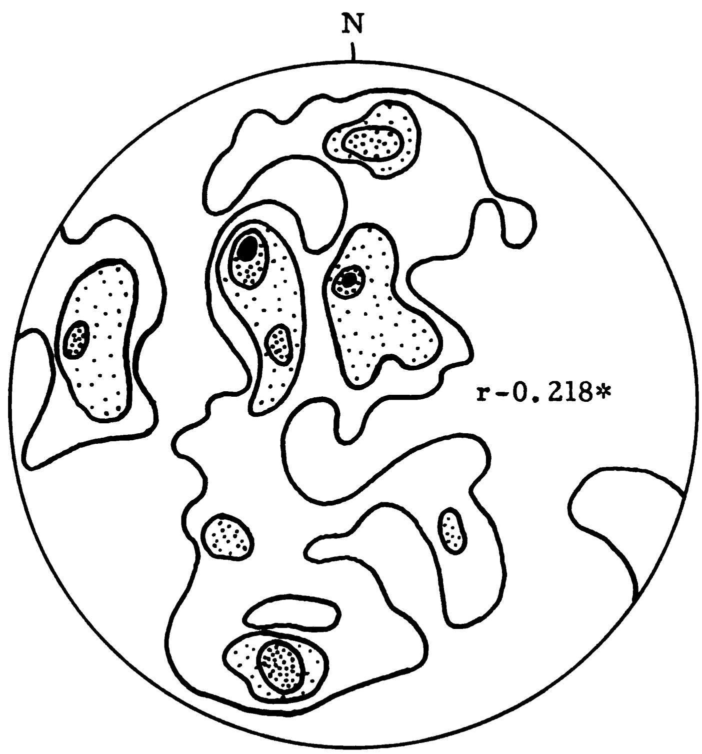

Fig. 29. 307 dolomite axes from sample 20, twinned and untwinned grains. Contours 4-3-2-1 percent.

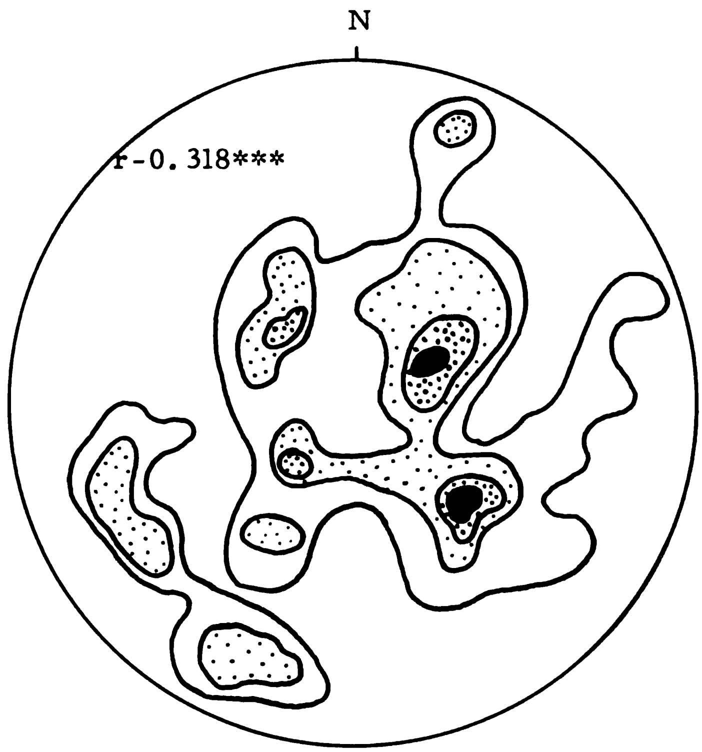

Fig. 30. 275 dolomite axes from sample 25, twinned and untwinned grains. Contours 4.4-3.3-2.2-1.1 percent.

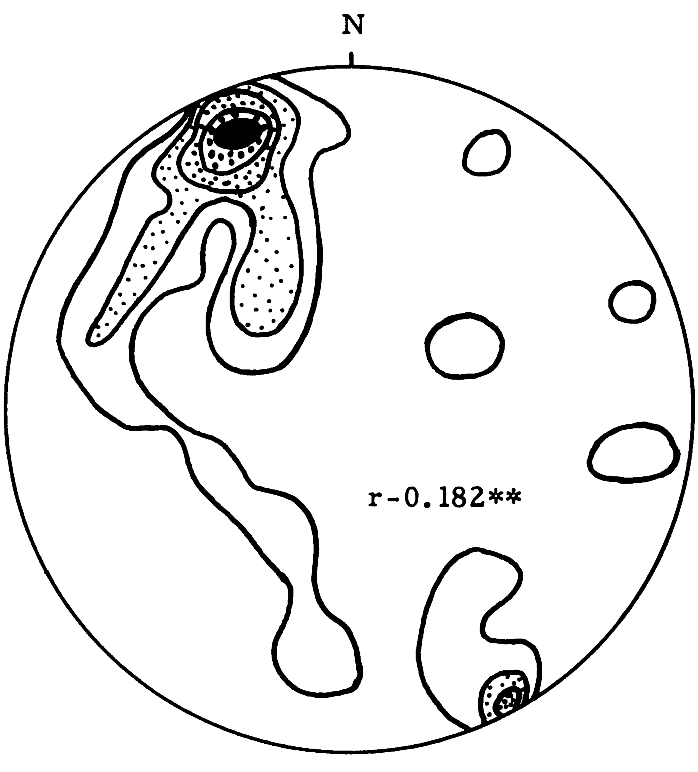

Fig. 31. 232 dolomite axes from sample 26, twinned and untwinned grains. Contours 6.5-5.2-3.9-2.6-1.3 percent.

regional east-northeast strike, the orientation is once more dependent upon regional structures.

Dolomite orientation as presented by petrofabric diagrams indicates a weak orientation pattern in nearly all samples. Maximum orientations have bearings of roughly north-northwest with variable plunges ranging from 49 degrees to 14 degrees, averaging 35 degrees in the same direction. The conclusion reached is that any preferred orientation lies parallel to the deforming stress or approximately normal to the east-northeast regional strike. The deforming force must have been from the northwest or southeast. Turner (1952), states: "It is conceivable that recrystallization of marble under simple compression may yield a fabric with strong preferred orientation of c-axes (the direction of maximum compressibility) parallel to the direction of maximum compressive stress".

It is also indicated that the granite dike influenced the orientation of the dolomite; only in the footwall has dolomite orientation been destroyed or reoriented, (Figs. 22 and 23). Best orientation occurred next to the contact on the hanging wall and will be further supplemented by statistical data.

In most samples twins occurred in greater than fifty percent of the grains. These twins, termed "doublets", were plotted individually. Only four diagrams showing the most valid results are included.

Figure 32 is a diagram of the crystal axes of those grains containing twins only. The dolomite doublets are plotted from two sections

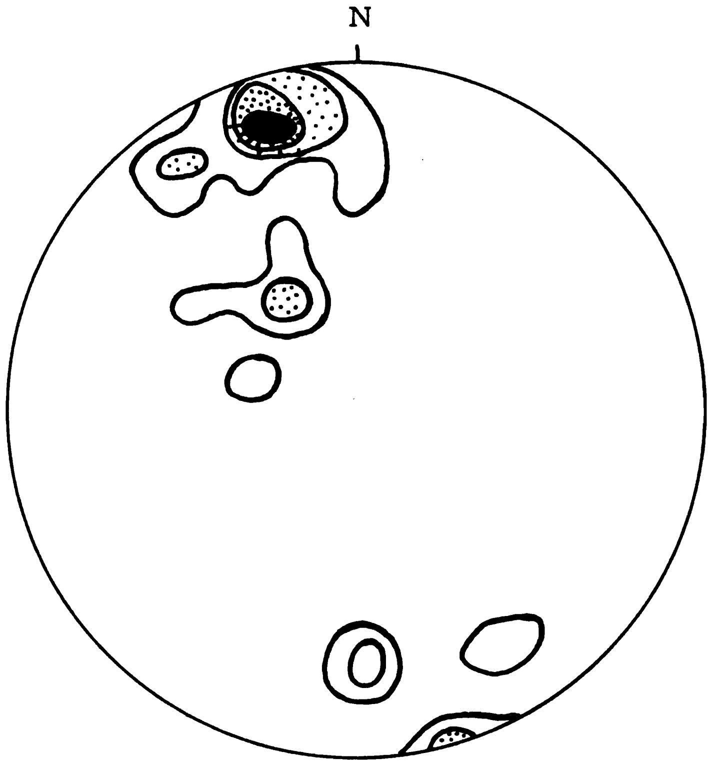

Fig. 32. 64 dolomite axes from sample 18, twinned grains only. Contours 12-9-6-3 percent.

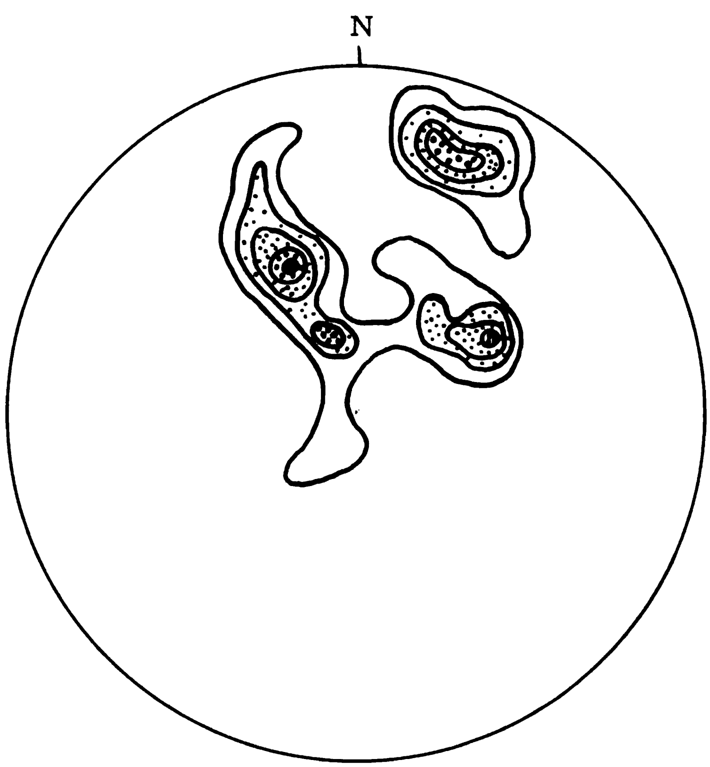

Fig. 33. 68 dolomite axes from sample 7, twinned grains only. Contours 7.1-5.7-4.3-2.9 percent.

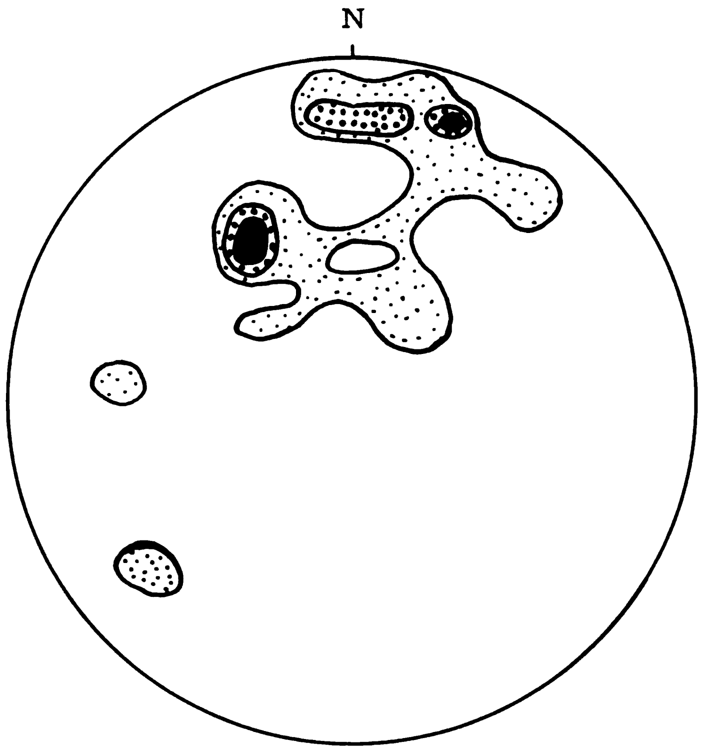

Fig. 34. 76 dolomite axes from sample 20, twinned grains only. Contours 8-5.3-2.6 percent.

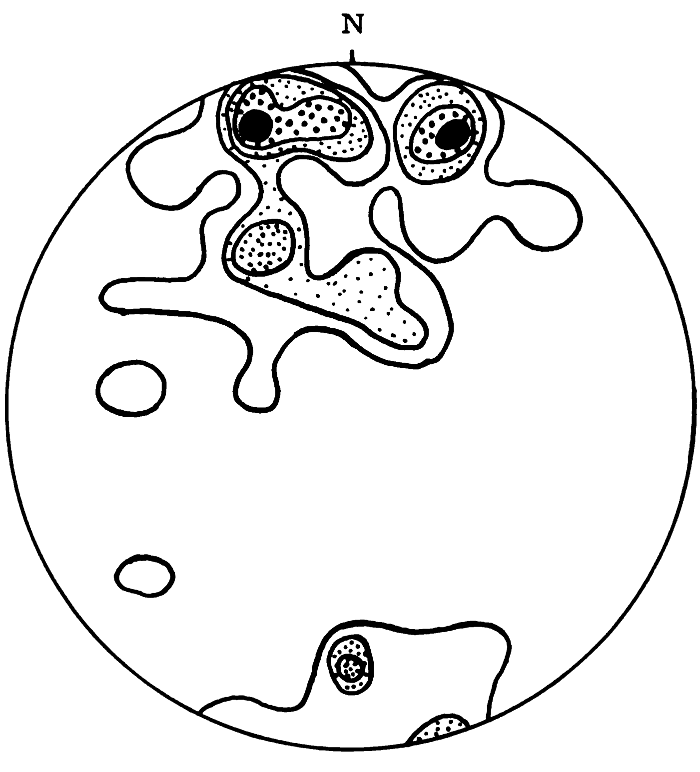

Fig. 35. 160 collective dolomite axes from samples 25, 20, and 18, twinned grains only. Contours 6.25-5.0-3.75-2.5 1.25 percent.

of sample 18. The maximum is approximately perpendicular to the regional strike. Figure 28 shows the orientation of all axes without selection of those containing twins. The major maximum, which is roughly normal to the regional strike, is dispersed over a much wider area than in figure 32. Figures 33 and 26 indicate similar results.

The conclusion reached by Fairbairn (1954) that twins develop only in grains of restricted orientation is here exemplified.

Figure 35 is a composite diagram of dolomite axes plotted from twinned grains from samples 25, 20, and 18. A good orientation pattern normal to the regional structural strike is present.

STATISTICAL ANALYSIS

Where the pattern of preferred orientation is weak, as is true in the marble, it is advisable to test its significance by statistical means.

Contouring of point diagrams distinguishes areas of different "densities" or relative frequencies of the fabric; in other words a clearer distinction is drawn between points which seem to be grouped together and those areas in which relatively few points appear. The correlation coefficient (r) is used in this report as a measure of the degree of the preferred orientation of the c-axes diagrams.

The correlation coefficient "r" measures the correlation as determined between the number of cells on a square and the number on each of the four squares nearest it; if there is a tendency of these squares of equal densities to lie closer together in some parts of the diagram than in others, this correlation may be significantly positive and the fabric has a preferred orientation.

In this study, comparisons were made between orientations of the samples taken east of the dike, from those taken west of the dike. It is believed that the dike may have reoriented or obliterated any orientation that was once present within the dolomite.

Two grids were used in the correlation tests so that each cell contained one percent and two percent of the total area of the diagram. Since the ten centimeter Schmidt net was used for plotting points, the

sides of each cell were 1.77 centimeters and 2.51 centimeters long respectively. (Fig. 36)

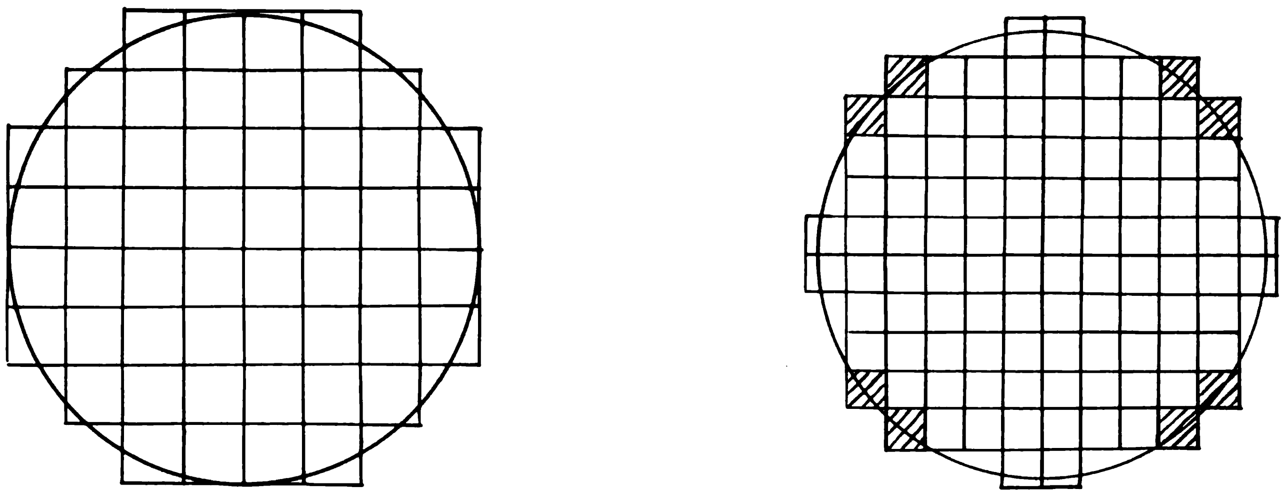

Fig. 36. Two and one percent grids used for counting points in the Statistical analysis.

The area each cell encloses directly effects the accurracy of the test. A test in which each cell of the grid contains two percent of the total area will not reveal a coefficient of correlation as accurate as one obtained by using a grid in which each cell contains one percent of the total area. This test does not determine the nature of the fabric, but is used only for comparison.

Procedures and computations necessary to determine the correlation coefficient are referred to in Fairbairn (1954, pp315-321). It should be noted that the number of points plotted does not enter into the computations as "n" is the number of comparisons and not the number of points in the point diagram. Also, regardless of the frequency distributions, it is always true that $-1<r<1$.

Fairbairn states that the degrees of freedom for the test be set at one less than the number of squares in the grid. The test involving 272 comparisons made on a grid containing 96 squares (the one used in this report), for 95 degrees of freedom the .01 level of r is 0.26 and the .05 level is 0.20. The correlation coefficient by no means indicates the location of the plotted maxima.

Sample	Coefficient of Correlation "r" One Percent	Two Percent
1	0.315	0.376
3	0.249	0.046
7	0.269	0.160
8	0.111	0.107
18	0.386	0.346
20	0.218	0.379
25	0.318	0.292
26	0.182	0.457

TABLE IV

Comparison values of coefficient of correlation for one and two percent grids.

The correlation coefficient "r" are shown in Table IV for one and two percent grids and the values obtained from a one percent grid are also plotted on the fabric diagrams. Three asterisks following the value indicates that the .01 level has been reached, two asterisks that the .05 level has not been reached, and one asterisk represents values lying between the .01 and .05 levels.

Figure 37 (using curves for the one percent grid), shows the values of "r" as related to measured distances east and west of the dike. It can be noted that the lowest value r (0.111) is from sample 8 which is located at the contact on the footwall side, while the highest value (0. 386) is from sample 18 which was also taken at the contact but on the hanging wall side. These statistical values coincide with interpretations of the fabric diagrams and also confirms earlier results indicating once again that the dike has effected the dolomitic marble on the footwall side but not on the hanging wall. The low value of r obtained from sample 26 can be attributed to the westernmost dike that has also effected the footwall contact as the smaller dike has effected the orientation in sample 8.

Locally the values of r show a weak fabric orientation within the quarry, but values at the dike-marble contact indicate reorientation or obliteration which can be attributed to the intrusive.

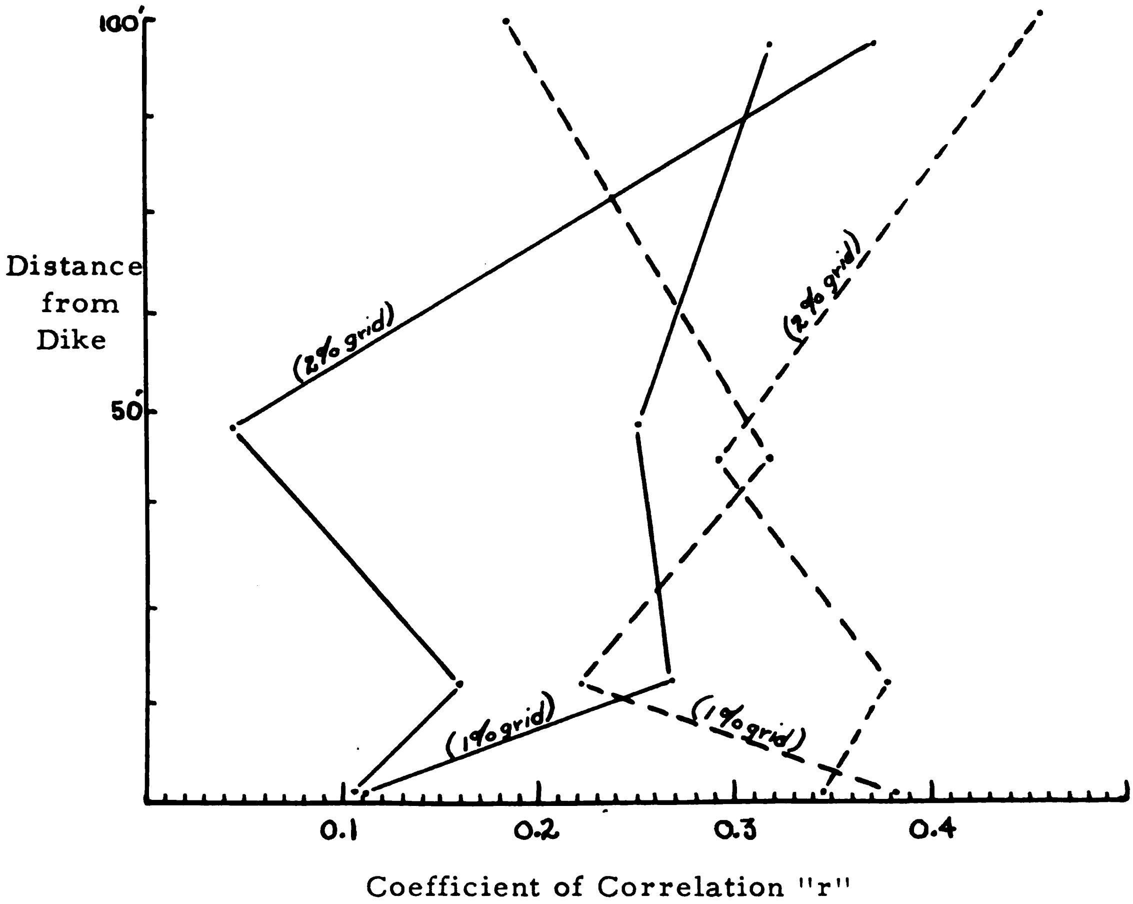

Fig. 37. Coefficient of correlation "r" as plotted at perpendicular distances from the dike. Solid line represents values east of the dike, dashed lines values west of the dike. Note maximum and minimum values of r at the dike-marble contact. A weak distribution curve is obtained from values lying east of the dike, while values west of the dike indicate a random pattern.

SUMMARY

Results obtained from field and laboratory study are conclusive with regional structures while certain conclusions concerning local structures can be drawn.

Two rock units comprise the area, dolomitic marble and granite dikes. The oldest unit, the marble, consists of textures, compositions and structures that indicate sedimentary origin with later deformation and metamorphism. Thin sections show that the rocks have experienced nearly complete reconstruction while the character of the accessory minerals in the marble indicate that crystallization was not accompanied by significant introduction of foreign materials but consists of mineralogical rearrangements of elements already present. The younger granitic dike is clearly of post-Huronian age and the time of intrusion must have occurred after metamorphism of the area. Evidence also shows that the dike is of igneous origin and probably originated from a magma at depth, which may have caused widespread regional metamorphism throughout the area at an earlier date.

It can be concluded that the granite dike directly altered the marble on the footwall side as evidenced by the presence of many silicates (diopside), re-orientation of long tremolite blades, and deformation of the fabric pattern, while on the hanging wall none of these phenomena occurred.

A weak fabric pattern is present within the dolomite which lies normal to the regional structure or parallel to the deforming stress. This relation is drawn from the fabric diagrams which indicate maxima which lie normal to a regional east-northeast strike and plunge in the same direction. At the dike-marble contact this orientation has undergone deformation, but only on the footwall side. Statistical analysis confirms the results interpreted from the petrofabric diagrams of the dolomite.

Within the dike, the quartz orientation lies within the plane of dip which is approximately N25°E, 65°NW.

In summarizing, six conclusions can be drawn:

1. The dolomite is of sedimentary origin, and has undergone later deformation and metamorphism.

2. A weak fabric pattern is present and lies normal to the regional structure and parallel to the deforming stress.

3. The granite dike is of post-Huronian age, is clearly of igneous origin and is the youngest of the deformation, metamorphism, granite intrusion orogenic sequence.

4. Quartz crystallographic c-axes in the dike lie in the plane of dip which has an attitude of approximately N25°E, 65°NW.

5. The dike altered the marble on the footwall side, but not on the hanging wall as evidenced by the presence of silicates, reorientation of the bladed tremolite, and deformation of dolomite fabric patterns.

6. Statistical data supplement the fabric diagram interpretations.

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MAP OF THE
FELCH METRONITE QUARRY
DICKINSON COUNTY, MICHIGAN
MAPPED AND DRAWN
BY
R. A. SOLBERG
MARCH 1958
SCALE
0
15
30
in feet
EXPLANATION
Outer rim of quarry
Edge of quarry floor
Underground workings
Inferred correlations
x Sample locations
00 Height above floor
Dickinson County
Dickinson County
Felch
N
44'
83'
56'
94'
97'
Pump shed
10 ft water filled depression
Ladder
Gate
Slope
ledge
Rock pile
Dike
Rock pile
dike exposure in cave
Vertical quarry wall
Quarry Floor
Western dike
dike exposure on western wall
Rock pile
Ledge
Vertical quarry wall
Sample 1
Samples 10 - 9
Sample 8
Sample 7
Sample 3
Slope
Sample 26
Sample 25
Sample 20
Samples 18 - 17
Rock pile
Pillar
Rock pile
Piller
Pillar
Pillar
dike exposure in addit
Rock pile with granite fragments
numerous granite veinlets