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Dimensional Orientation of Calcite Grains in a Flexure Fold

By

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with 13 Text-figures and 3 Plates

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ABSTRACT: The direction, the length of the longest dimension of elongated calcite grains, and the normal to it have been measured on each sector in nine columns on ac-profile in a folded calcareous schist layer interbedded in spotted pelitic schist. The results are shown in diagrams (Figs. 2 to 10). From the diagrams, mean directions of the longest dimension and the normal to it have been determined. The pattern of distribution of the directions of the longest dimension and its normal is quite similar to the stress pattern of a buckling beam.

CONTENTS

I. INTRODUCTION

Knowledge concerning stress and strain distribution in the geologic body during folding is interesting for structural geologists and petrologists, and have been studied by many authors in various ways for approach. One of the methods for understanding strain distribution may be an experiment with models. Model experiments with soft and plastic materials such as clay, putty, butter, soft rubber etc., are relatively easy to show state of strain ellipsoids in any position of the materials under experiments, because initial state of the bodies is known and various marks can be easily drawn on the faces of the materials before deformation, and because change in shape of marks on them can be observed during deformation. Those experiments may bring us some useful knowledge similar to deformation in geologic body. However, the methods conceive difficulty of correlation between natural deformation and model experiments. Another approach is the study of naturally deformed folds, such as folded conglomerate with deformed boulders and folded limestones with oolites (E. CLOOS; 1947). Although the original form is not certain in this case, reasonable assumption based on geological evidences may enable to construct the strain ellipsoids in folds. Dimensional orientation of constituent minerals in folded schists and gneiss is often controled by the fold forms. For example, long axes of prismatic minerals such as amphibole, and epidote are parallel to the fold axis and the longest directions of elongated quartz grains are parallel to axial surface near the hinge of the fold as shown by HILL (1953), and RAMBERG (1963). Experimental study by TURNER, et al. (1956) shows that the longest axes of deformed grains of calcite coincide with the maximum extension axis of experimental cylinder and the shortest axes of the grains are parallel to the maximum compression axis. Therefore, on the basis of the experiment of calcite, analysis of dimensional orientation of calcite in a folded limestone may be useful knowledge for strain distribution in the folds. In this paper, data of dimensional orientation of calcite crystals in a flexure fold of calcareous schist will be described.

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II. DESCRIPTION OF THE LOCALITY AND THE SPECIMEN

The specimen has a folded layer of calcareous schist interbedded in pelitic schist layers as shown in Fig. 1 of Plate 17 and was collected from 300m northwest

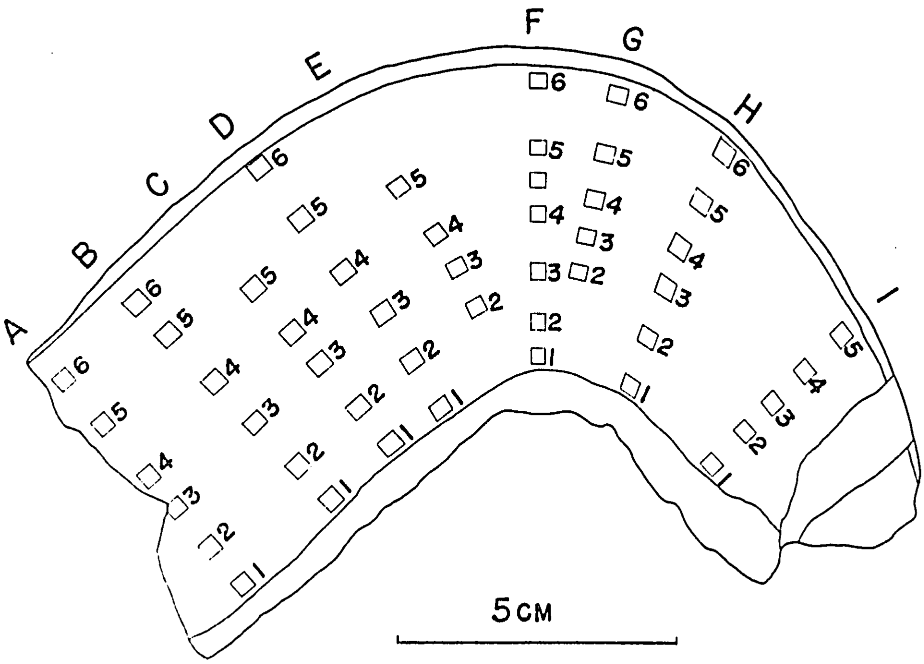


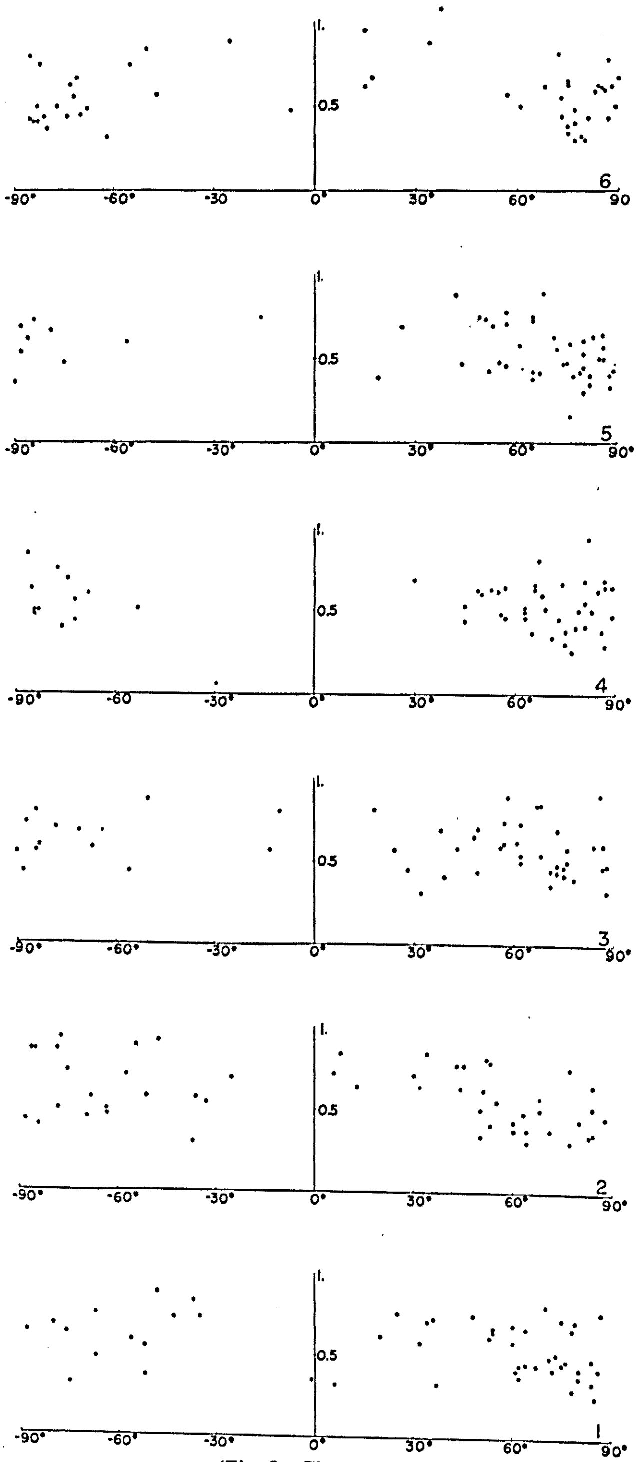
Fig. 1. Sketch showing columns (A to I) and sectors (1 to 6) in the folded calcareous schist layer, being interbedded in pelitic schist layers and cut by quartz-calcite veins.

of Fujiwara of the Sazare mining district, Central Shikoku. As the metamorphism and the structures of crystalline schists in the district have been reported in the other paper (OYAGI; 1964), only the outline of geology around the locality will be described in the following.

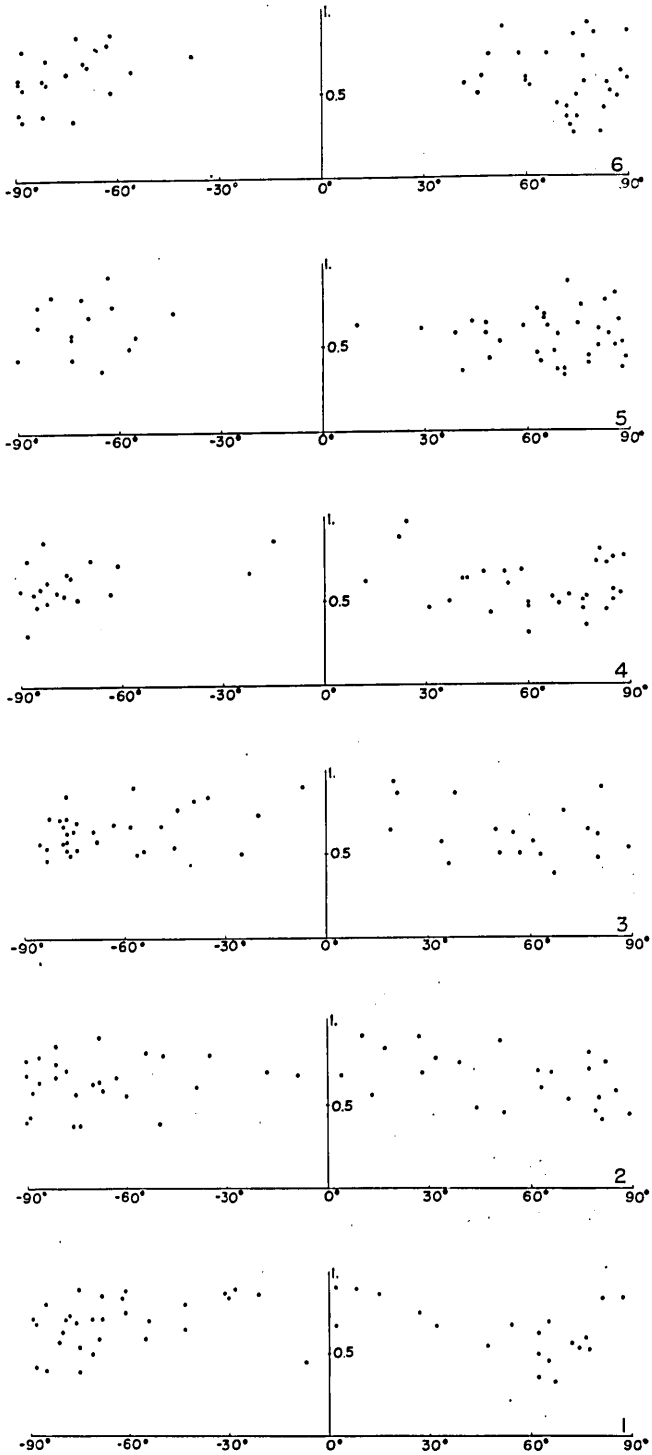
The district is occupied by the Sambagawa crystalline schists. Near the locality, component rocks are chiefly spotted pelitic schists intercalated with thin basic, psammitic, and calcareous schists. The metamorphic grade of these crystalline schists belong to the epidote amphibolite facies. The locality of the specimen is situated at the axial zone of the Tuneyama syncline where small scale folds with nearly vertical axial surfaces are observed well on the outcrop of roadside and the riverside of the Dozan River near the locality. These small scale folds show style of concentric folds (TURNER and WEISS; 1963) in layers of psammitic and calcareous schists, being accompanied with fracture or strain-slip cleavage in less competent layers of pelitic schist.

In the present specimen, a calcareous schist layer shows a style of a concentric fold. Cleavages are developed in pelitic schist layers which have been deformed passively around the calcareous layer. The fold can be identified with the type III folds after the present author which represent the combination of concentric folds in competent layers and development of fracture or strain-slep cleavage in less competent layers (OYAGI; 1964). In the neighborhood of the specimen, layers of calcareous or psammitic schists can not be observed within the distance of one wave length from the folded calcareous layer concerned, except on the upper left side, where a small scale isoclinal fold is observed as shown in Fig. 1 of Plate 17. In this respect, the influence of surrounding competent layers as suggested by CURRIE, PATNODE and TRUMP (1962) may be insignificant for the present specimen. The folded calcareous layer lacks cleavage-surfaces and the style of the fold is not similar to that of a flow fold. Therefore, the fold can be regarded as one of flexure folds (FAIRBAIRN; 1949) or one of Ramberg's buckling folds (RAMBERG; 1963). The fold axis plunges 5° toward N80°W and the axial surface of the fold is nearly vertical. The lineation (L_{2-3}) which is the intersection of the schistosity-surface and the cleavage-surface is parallel to the fold axis. The fracture or strain-slip cleavage developed in pelitic schists is practically parallel to the axial surface of the fold. In Fig. 1, the left and the right limb make an angle of 78° in the upper part and 90° in the lower part of the layer. The thickness of the folded layer is 5.9cm on the left limb, 5.5cm at the crest and 4cm on the right limb of the fold (Fig. 1). In this specimen, no increase of thickness towards the crest in the calcareous layer can be recognized.

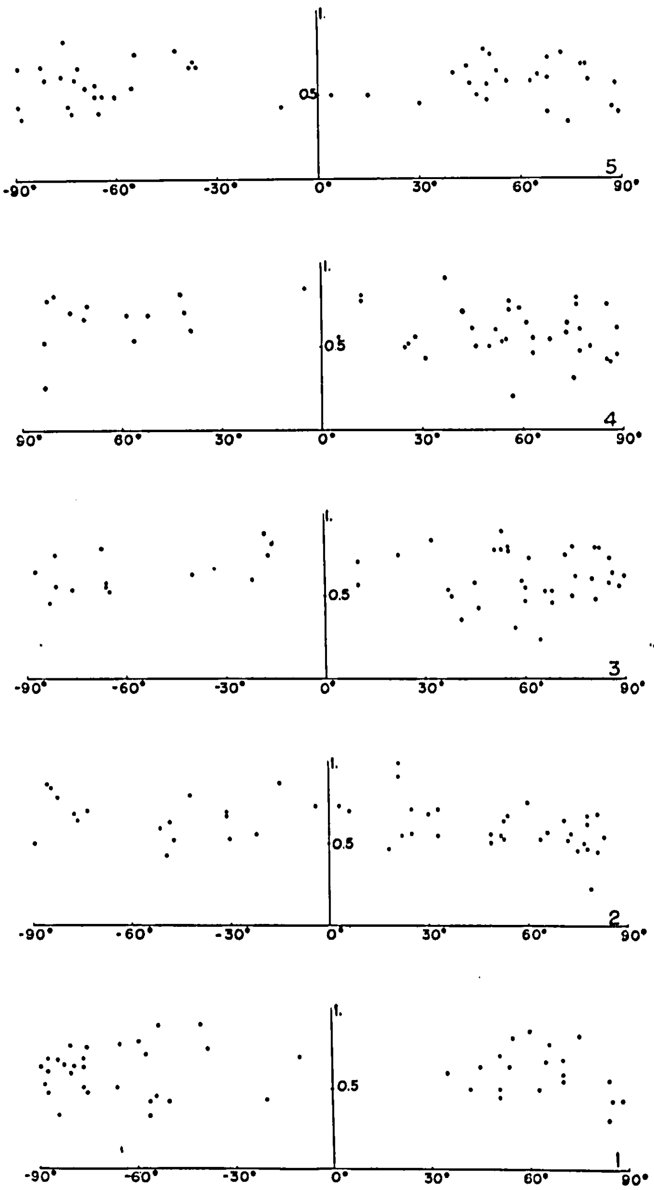
Both limbs are cut perpendicularly by quartz-calcite veins with width of approximately 1cm as shown in Fig. 1. However, the pelitic schist layers intercalating the folded calcareous schist layer are not cut by these veins as read from Fig.1 of Plate 17. Careful observation can make clear that the folded calcareous layer is thinner near the veins than at other positions of the layer. From these



(Fig. 2 Cloumn A)

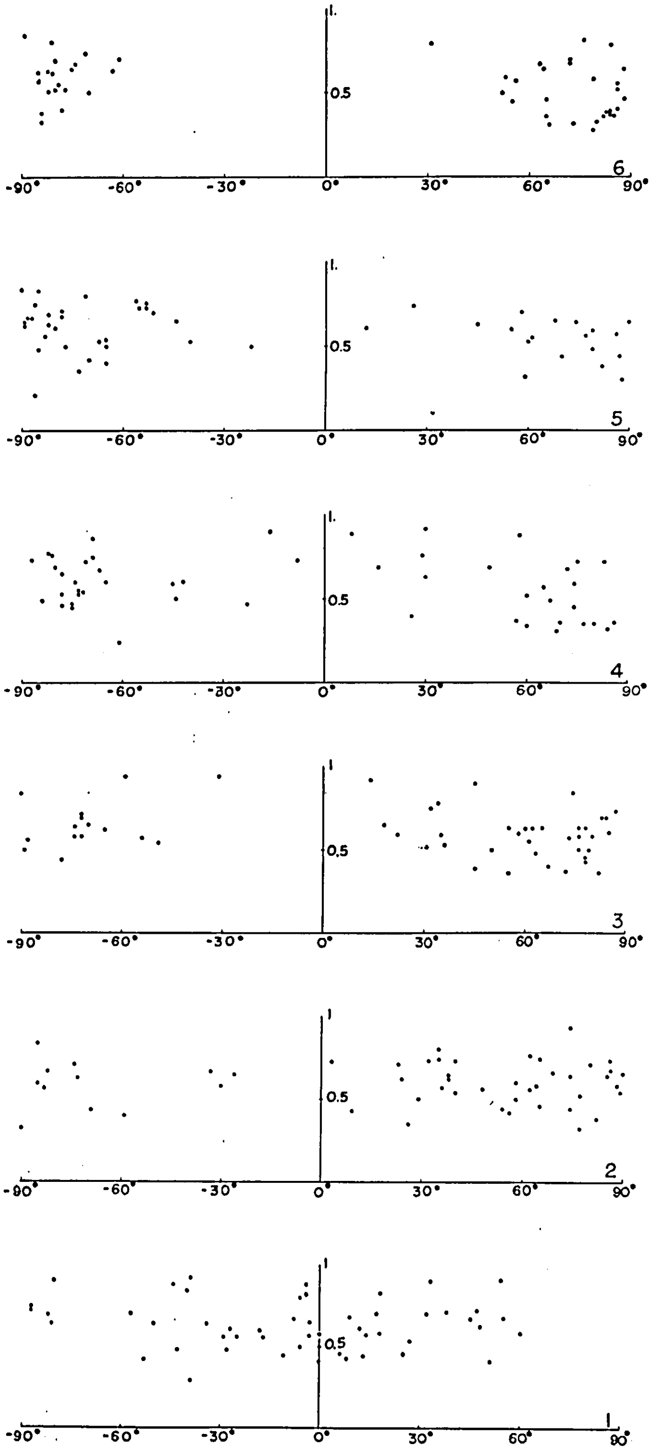


(Fig. 3 Column B)

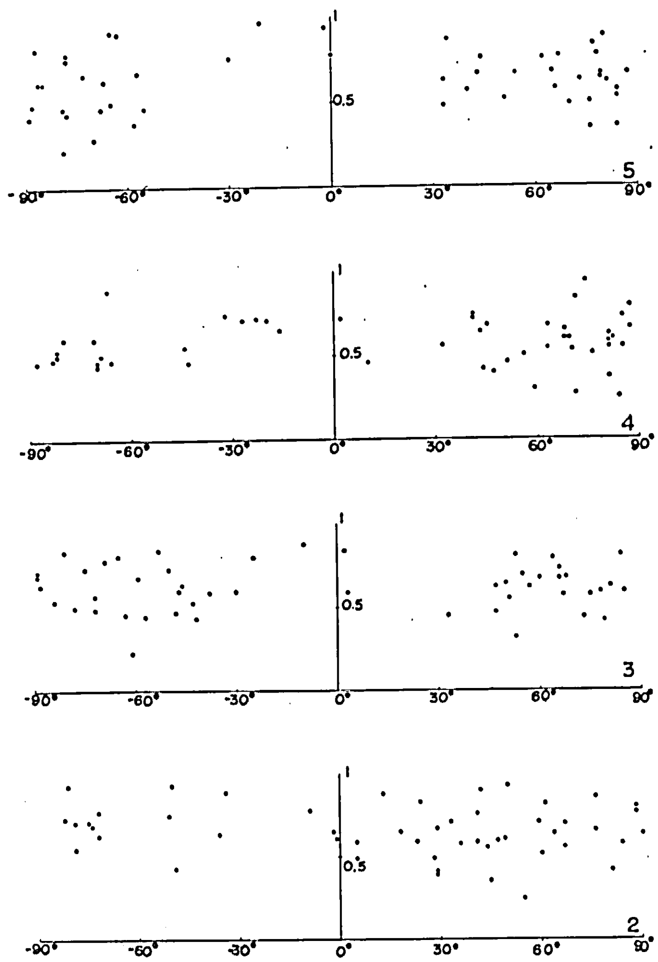


(Fig. 4 Column C)

observations, the structure can be identified with one of boudinage structures. The vein in the right limb is parallel to the fold axis and that in the left limb is nearly parallel to slightly oblique to it. This suggests that the structure formed during folding of this fold. It can be considered that the structure is another evidence that the folded calcareous schist layer is more competent than the pelitic schist layers during the formation of the flexure fold concerned and



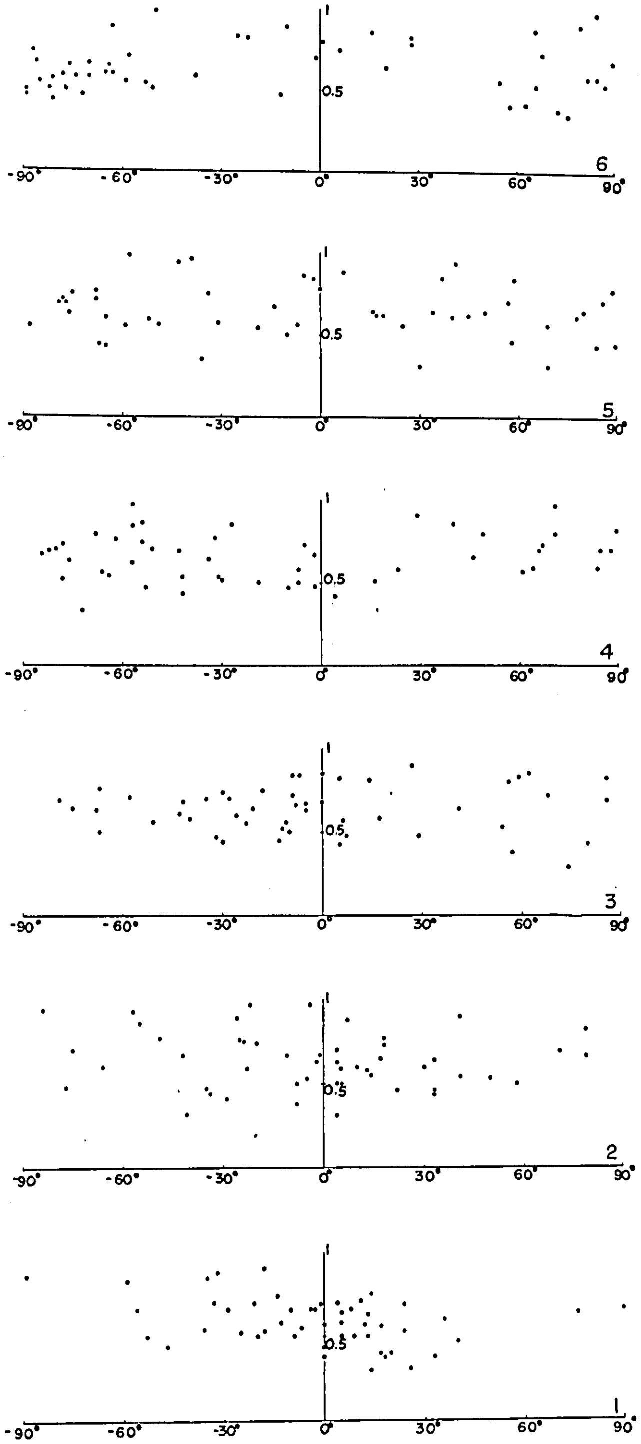
(Fig. 5 Column D)



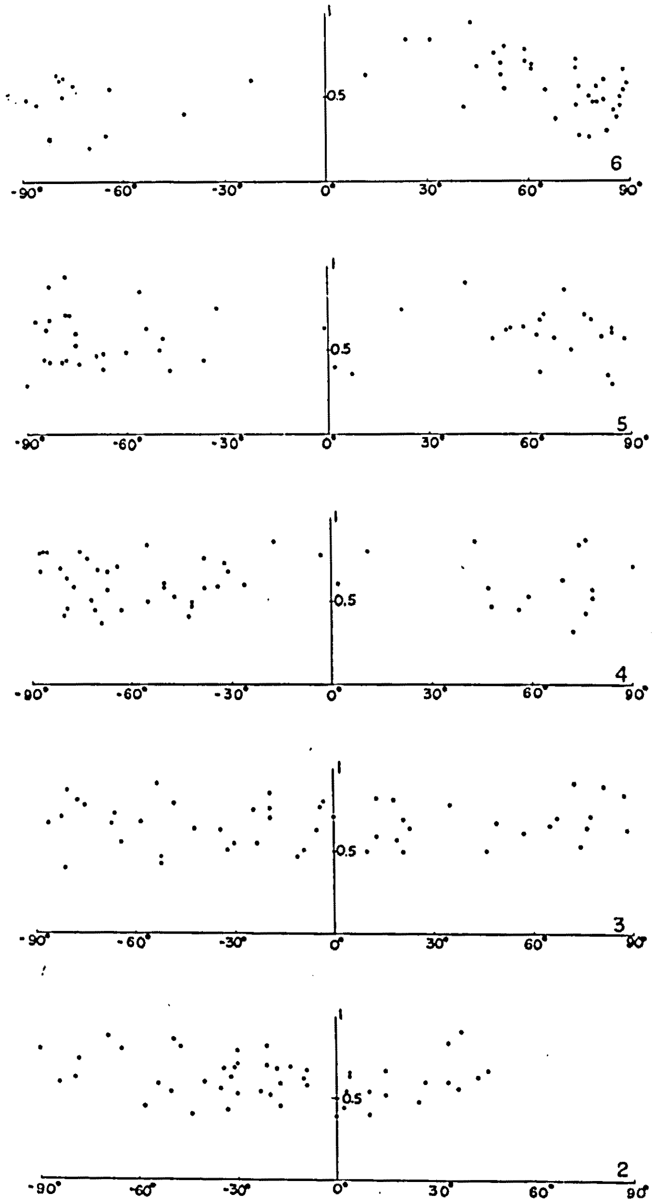
(Fig. 6 Column E)

the "boudinage" like structure.

The folded calcareous layer is almost composed of calcite with very small amounts of quartz, albite, muscovite, chlorite, epidote, titanite, and rutile. Calcite shows ellipsoidal shape with more or less mosaic texture. Grain size of calcite is large (0.3~0.8mm) in most positions but is small (0.1~0.2mm) at the lower part of the calcareous schist layer near the hinge of the fold (Fig. 2 of Plate 19) and narrow parts which contact with pelitic schist layer (Figs. 1, 2, and 3 of Plate 19). In the veins, calcite shows very large grain size (0.6~2mm). Undulatory extinction of calcite is strong near the crest of the fold in the lower part of the layer as shown in Fig. 2 of Plate 17, but weak near the upper part of the layer as shown in Fig. 4 of Plate 17. Grain boundary granulation is recognized at the former but less observed at the latter part of the fold. Twins are

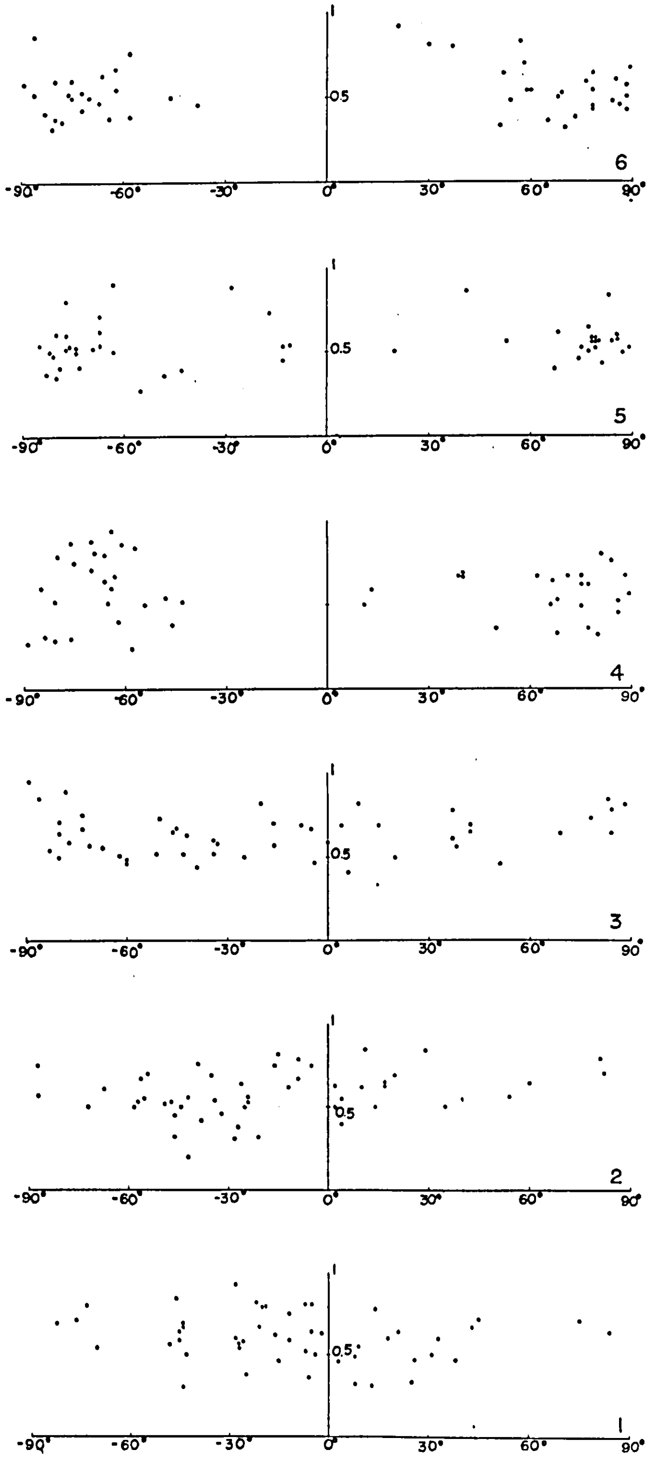


(Fig. 7 Column F)

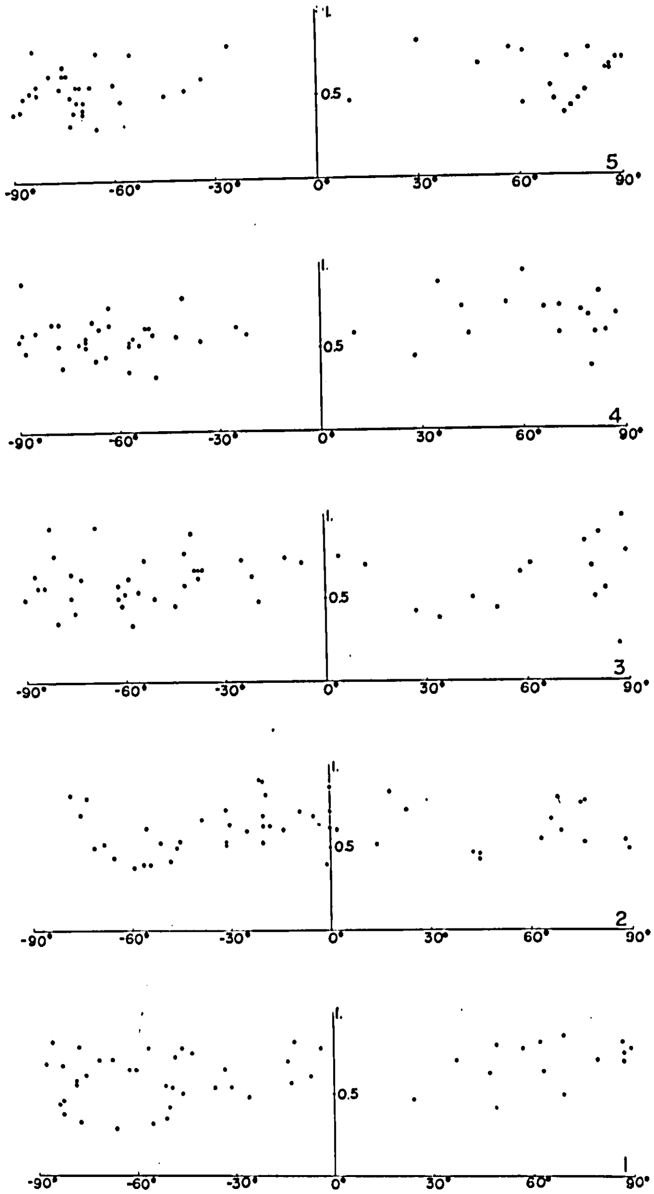


(Fig. 8 Column G)

observed in almost all grains in the folded layer, and are strongly developed near the crest of the fold in the lower part. These characteristics of calcite grains are shown in figures of Plate 17.



(Fig. 9 Column H)



(Fig. 10 Column I)

Fig. 2～10. Diagrams showing the directions of the longest dimensions and the s/l-ratio in elongated calcite grains.

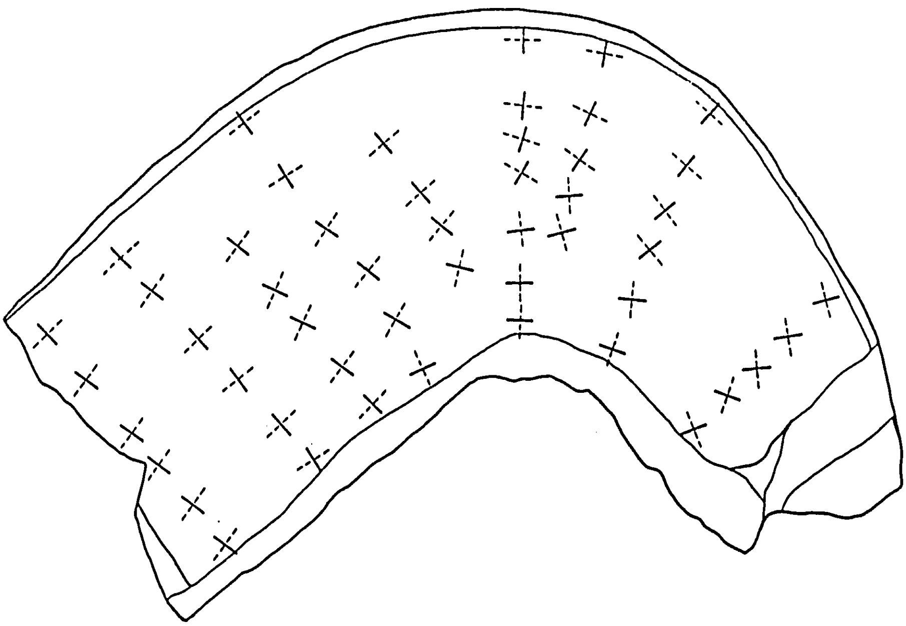
Abscissa shows angles between the normal to the form surface of the fold and the directions of the longest dimensions in calcite grains. The angles measured clockwise are represented as plus. Ordinate shows *s*/*l*-ratio: *s* represents the length normal to the longest dimension and *l* shows the length of the longest dimension.

III. Dimensional Orientation in Calcite Crystals

Nine columns have been set up on the *ac*-profile of the folded layer and four to six sectors in each column. The columns are called from the left to the right A to I and the sectors are called from the lower to the upper 1 to 6 as shown in Fig. 1. In each sector, the direction, the length of the longest dimension and the length normal to it have been measured respectively in fifty grains of calcite. Results of these measurements have been plotted on diagrams as treated by Hara (1963). However, in this paper, the abscissa represents the angle from the normal to the form surface of the fold which is almost parallel to the schistosity-surfaces to the direction of the longest dimension in calcite grains. They are expressed as plus when the angle is measured clockwise from the normal to the form surface to the direction. In Figs. 2 to 10, the ordinate represents the s/l-ratio. In this case, s represents the length normal to the longest dimension and l means the length of the longest dimension.

In the sectors 1 to 6 of the column A, central parts are vacant and many points are clustered near the margins of the diagrams, especially near the right margins. The s/l-ratio ranges between 0.3 and 0.8. This ratio in the sectors of the column varies in small range. Diagrams of most sectors in the columns B and C are characterized by the tendency of concentration of points at the margins of the diagrams as shown in Figs. 3 and 4. Dimensional orientation in ac-profile is rela tively homogeneous with respect to the tendency of concentration. The direction of the longest dimension of calcite grains is generally parallel to the schistosity-surface (S_1) in the columns A, B, and C. In the sector 1 of the column D (Fig. 5), the central part is occupied by many points and the margins of the diagram are vacant. In the sectors 2 and 3 of the column D, the points concentrate to the right half in each diagram and, in the sectors 4 to 6, they occupies the margins of the diagrams. This means that the direction of the longest dimension of calcite grains is nearly normal to the schistosity-surface at the lower part of the layer and that it rotates gradually clockwise as one goes upwards from the sector 1 to the sector 6 in the column D. In the column E (Fig. 6), the tendency of the diagram is similar to that of the column D. In the column F(Fig. 7), points concentrate near the center of the diagrams in the sector 1 and gradually disperse towards both mar gins from the sector 2 to the sector 3. In the sectors 4 to 6 of the same column, points concentrate at both margins of the diagrams. As shown in s/l-ratio which is 0.5 to 0.9, in the sector 3 and 4, calcite grains are less elogated than in other sectors. In this column F, the direction of the longest dimension of many calcite grains are normal to the form surface (schistosity-surface) but gradually disperse with change in shape to less elongated form as one goes upwards from the sector 1 to the sector 3. However, from the sectors 4 to 6, the grain dimension becomes ellipsoidal in form again and the directions of the longest dimension are parallel to the form surface. In the sectors 2 and 3 of the column G(Fig. 8), concentrated positions of points occupy the center of the diagrams, and gradually shifts to the left side of the diagrams in the sectors 4 and 5 of the column. These patterns of the diagrams in the column G are opposite to those in the column E. In the column H (Fig. 9), patterns of the diagrams are similar to those in the column G. Further, the column H is the mirror of the column D. The longest directions of calcite grains are nearly vertical to the form surface and gradually rotated counter clockwise to the orientation nearly parallel to the form surface. However, in the column I (Fig. 10) ,the directions of the longest dimension are oblique to the form surface, making angles of 20°~40° with it.

From these diagrams, Fig. 11 shows the direction of the longest dimension and



Fig, 11. Mean directions of the longest dimensions (broken lines) and the normal to them (solid lines) in calcite grains in sectors.

the normal to it. In Fig. 11, thin dashed lines show the orientation which are determined by maximum concentration of the direction of the longest dimesion of calcite grains in each sector, and thick solid lines represent the normal to that orientation.

In the columns A, B, and C, thin dashed lines are nearly parcllel to or slighlty oblique to the form surface. Thick solid lines are vertical or oblique to the form surface with high angles. In the columns D and E, thin dashed lines are nearly parallel to the form surface in the sectors 3 to 6 with some fluctuations and rotate counterclocwise until they are nearly vertical to the form surface in the sectors 1 and 2. In the column F, change in roientation of lines occurs more suddenly.

Thin broken lines are nearly parallel to the form surface in the columns 4 to 6 and nearly normal to it in the columns 1 to 3. Orientation of thin broken lines in the column H can be regarded as a mirror projection of that in the column D with respect to the axial surface of the fold. The orientation of the lines in the column I differs slightly from a mirror projection with respect to the axial surface of the fold and the lines are oblique to the form surface in all sectors.

Generalized orientations of the directions of the longest dimension and the normal to it are shown by thin dashed lines and thick solid lines in Fig. 12, re-

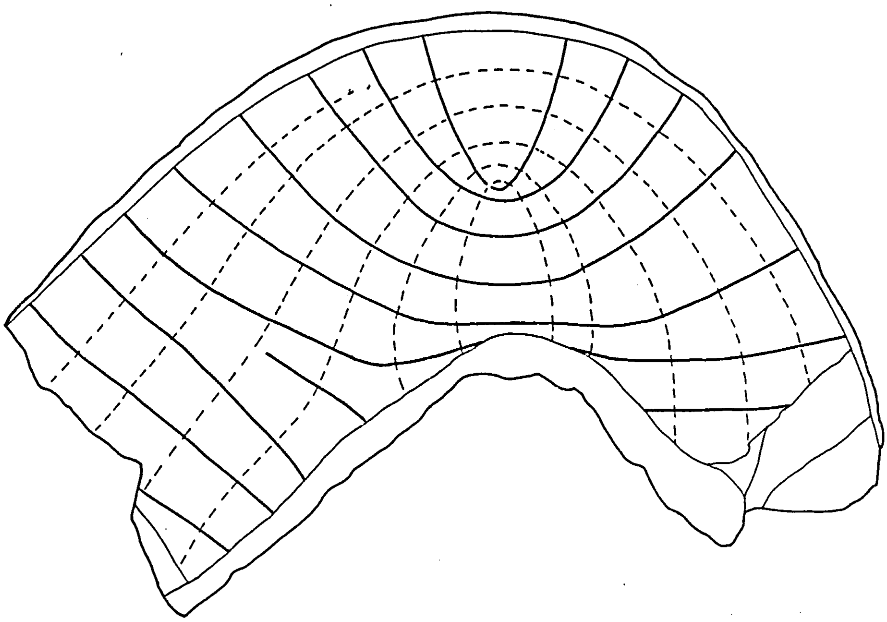


Fig. 12. Schematic sketch for the mean directions of the longest dimensions (broken lines) and normal to them (solid lines).

spectively. The pattern of the figure is slightly different between the left and right limbs. However, the pattern can be regarded practically as a symmetric pattern with respect to the axial surface and a similar one to stress distribution figures in buckling beams. In Fig. 13, the hatched part in the folded layers shows the area in which the angle between the direction of the longest dimensions and the form surface ranges from 45° to 90°, and the blank part represents the area in which the angle ranges from 0° to 45°. Therefore, the directions of the longest dimension in elongated calcite grains is nearly vertical to the form surface of the fold in the hatched part but nearly parallel to it in the other part.

In the experimental deformation of Yule marble by TURNER, et al. (1956), the longest axes of deformed grains of calcite coincide with the maximum extension

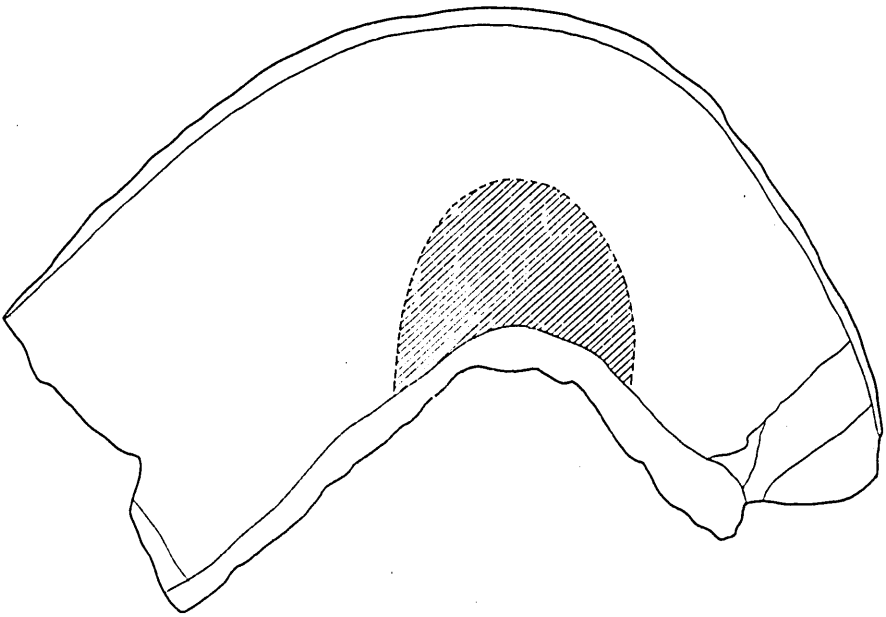


Fig. 13. Sketch showing the part (lined) that the angle between the mean directions of the longest dimensions and the form surface of the fold are 45°~90°.

axes and the shortest axes of the grains are parellel to the maximum compression axis. Assuming that disturbance of dimensional orientation of calcite due to various behaviors such as grain rotation, fracturing, recrystallization etc. during deformation is negligibly small in the present specimen of the fold, it may be concluded that the hatched part in Fig. 13 is compressed roughly parallel to the form surface and the blank part is extended nearly parallel to it during the folding.

REFERENCES

CLOOS, E. (1947): On the deformation in the South Mountain fold, *Maryland. Bull. Geol. Soc. Amer.* **58**, 834-918.

CURRIE, J. B., PATNODE, H. W., and TRUMP, R. P. (1962): Development of folds in sedimentary strata. *Bull. Geol. Soc. Amer.* **73**, 655-674.

FAIRBAIRN, H. W. (1949): *Structural petrology of deformed rocks.* Cambridge, Mass.

HARA, I. (1963): Petrofabric analysis of a drag fold. *Geol. Rep. Hiroshima Univ.* (12), 463-492.

HILLS, E. S. (1953): *Outlines of structural geology.* Methuen and Co. Ltd. London.

OYAGI, N. (1964): Structural analysis of the Sambagawa crystalline schists of the Sazare Mining District, Central Shikoku. *Jour. Sci. Hiroshima Univ., Ser. C,* **4**, (1), 271-332

RAMBERG, H. (1963): Strain distribution and geometry of folds. *Bull. Geol.* **42**, 1-20.

TURNER, F. J., GRIGGS, D. T., CLARK, R. H., and DIXON, R. H. (1956): Deformation of Yule marble. Part VII: Development of oriented fabrics at 300°C-500°C. *Bull. Geol. Soc. Amer.*, **67**, 1259-1294.

TURNER, F. J., and WEISS, L. E. (1963): *Structural analysis of metamorphic tectonites*. McGraw-Hill.

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Explanation of Plate XVII.

Fig. 1. Folded calcareous schist layer.
White bands show calcareous layers and grey or black bands are pelitic schist layers.

Fig. 2. Calcite crystals in the sector 1 of the column F.
Calcite grains are elongated nearly vertical and show extreme undulatory extinction. x10.

Fig. 3. Calcite crystals in the sector 3 of the column F.
x10.

Fig. 4. Calcite crystals in the sector 6 of the column F.
Calcite grains are elongated nearly parallel to the form surface (horizontal). x10.

Fig. 1

Fig. 2

Fig. 3

Fig. 4

Explanation of Plates XVIII and XIX.

Variation in dimensions of calcite crystals from the lower part to the upper part of the folded calcareous layer. Figures are continuous from Plate XIX to XVIII.

Fig. 1 shows the column B, Fig. 2 the column F, and Fig. 3 the column H.

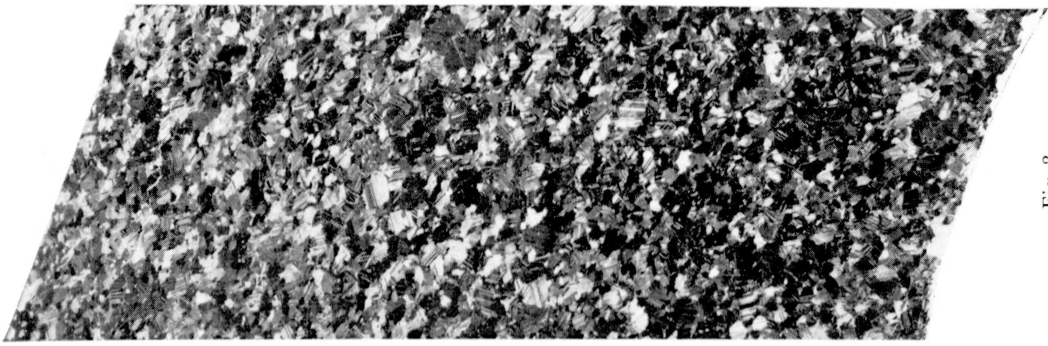
Fig. 3

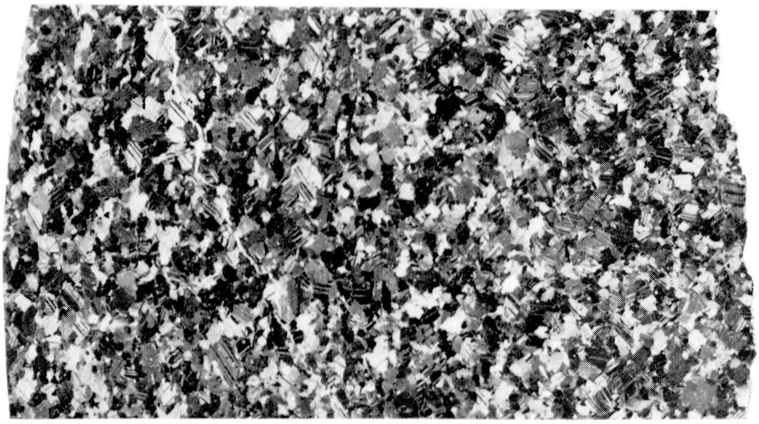
Fig. 2

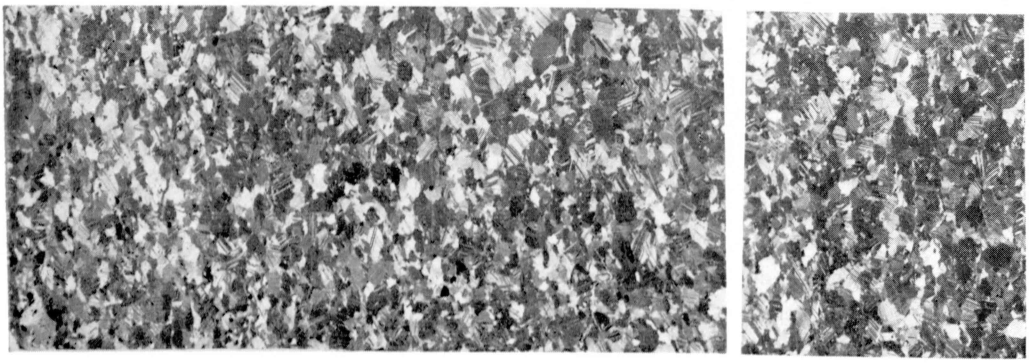
Fig. 1

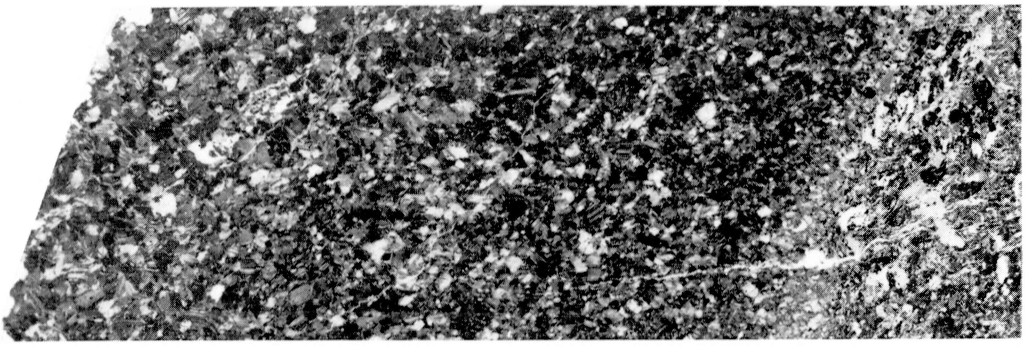

Fig. 3

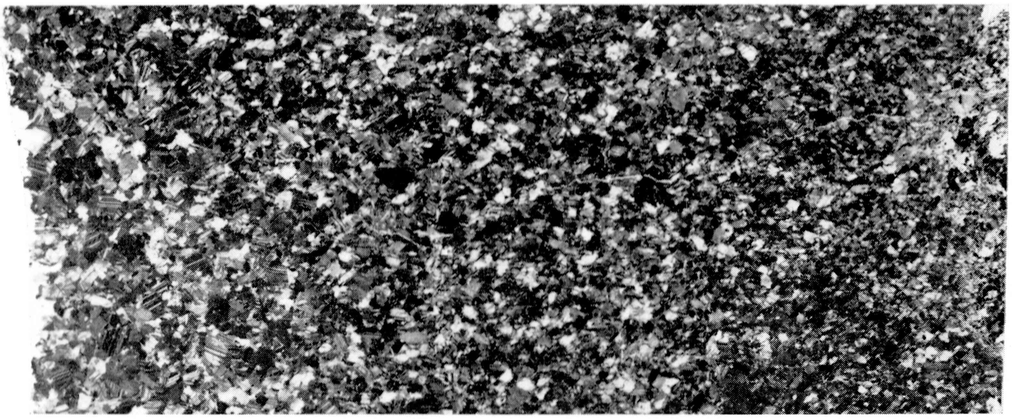

Fig. 2

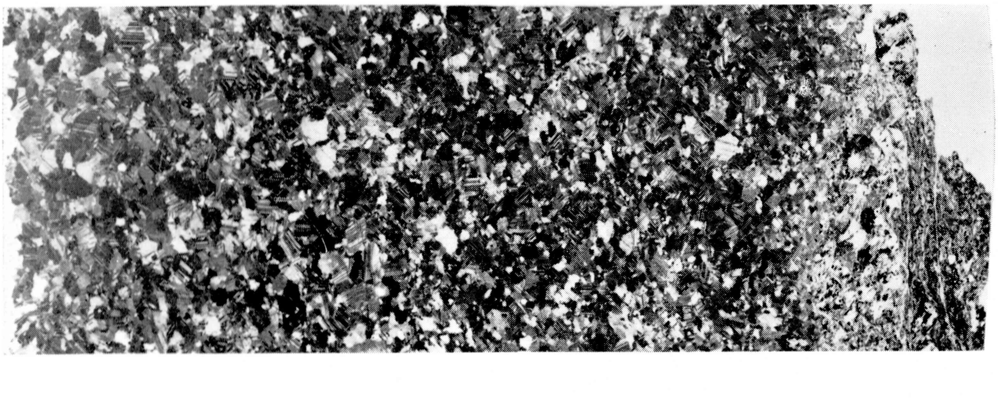

Fig. 1