Title	Quartz Fabrics in a Kink Band
Author(s)	HARA, Ikuo
Citation	Journal of science of the Hiroshima University. Series C, Geology and mineralogy , 5 (1) : 1 - 12
Issue Date	1965-09-15
DOI	
Self DOI	10.15027/53018
URL	https://ir.lib.hiroshima-u.ac.jp/00053018
Right	
Relation	

Quartz Fabrics in a Kink Band

By

Ikuo Hara

with 12 Text-figures and 3 Plates

(Received April 30, 1965)

Abstract: Quartz fabrics in a kink band in the Sambagawa crystalline schist of the Kune district, Shizuoka Pref., Central Japan, has been described and discussed with reference to the stress and strain pictures developed in the system during the phase of the deformation related to the formation of the kink band.

Contents

I. Introduction

In the Sambagawa crystalline schists such as thinly foliated pelitic schist and basic schist of the Kune district, Shizuoka Pref., Central Japan, are commonly found small-scale kink folds, at whose hinges foliation surfaces are bent in markedly angular fashion, in many cases showing ruptural fractures along their axial surfaces, and on whose limbs foliation surfaces are commonly planar. In most cases form of the structure resembles the kink band developed in deformed crystals, as shown in Plate 1–1. The band structure consisting of small-scale kink folds is clearly analogous to structures described so far in such terms as Zerknitterung, Knitterung, Knickbänder, Knickzone (Hoeppener 1955 and 1956), joint-drag (Flinn, 1952 and Knill, 1961), and kink band (Paterson and Weiss, 1962——experimentally produced). In this paper, it will be designated kink band. Generally, kink bands observed in the Kune district are in one set oriented at high angles to the foliation surface, showing a monoclinic symmetry. They occur in some cases as conjugate sets approximately symmetrically oriented with respect to the foliation surface, having near orthorhombic symmetry and a form of conjugate fold (Johnson, 1956). The axis of intersection of conjugate sets of kink bands generally lies on the foliation surface, but in three examples the axis is inclined to the foliation surface, as described by TURNER and WEISS (1963) for conjugate folds. The kink bands in question are one of the structures formed during the final phase of the Sambagawa metamorphic deformation in the Kune district.

PATERSON *et al.* (1962) deformed axially cylindrical specimens of phyllite and mica schist with planar foliation at room temperature and at confining pressure of 5.000 kgm cm^{-2} while constrained in thick brass or copper jakets, and produced kink bands crossing the foliation. They found, "at small strain, narrow bands of kink folding appear at approximately 50° to the direction of shortening. In the specimens compressed parallel to the foliation, the kink bands are in symmetrically oriented conjugate sets, and where the foliation crosses successively two conjugate kink bands it shows the form of a conjugate fold. In the other specimens, the kink bands are asymmetrically developed and in specimens compressed at 25° and 45° to the foliation only one set of kink bands generally appears. For all orientations, the kink bands grow in number and width the strain increases, almost filling the whole specimen when 30–40 per cent shortening is reached" (PATERSON *et al.*, 1962, pp. 1046–1047). It is believed that experimental results of PATERSON *et al.* are of considerable value in understanding the orientation of kink bands relative to the mean strain (represented by a strain ellipsoid) of the system for naturally formed kink bands. Fortunately, the orientation of kink bands relative to the mean strain ellipsoid represented experimentally by PATERSON *et al.* (TURNER *et al.*, 1963, Fig. 13–4–d) is quite identical with that so far assumed for natural kink bands by many authors. The mechanism of kink folding of thinly foliated rocks is generally believed to involve flexural slip on the foliation surface, a process analogous to the bend gliding in crystals.

In this paper, quartz fabrics (c-axis fabric and lamella fabric) of a kink band in pelitic schist (multilayered system consisting of alternating quartz-rich layers and mica-rich layers) will be described and discussed. Described data shows that the deformation of quartz crystals in the quartz-rich layers in the deformation related to the formation of the kink band caused the formation of the Böhm lamellae but not the formation of the preferred lattice orientation, which had been already produced prior to the deformation in question. The author (1961a and 1965a) previously introduced a rule for establishing the stress system (directions of the principal stresses) relating to the formation of quartz lamellae. In this paper, local stress and strain pictures developed in the quartz-rich layers in the deformation related to the kink band is also discussed by applying the author's rule (1961a and 1965a) and HANSEN *et al*'s relationship (1962) to the quartz lamellae.

Acknowledgements: The author is specially indebted to Prof. G. Kojima for his critical reviw of the manuscript. Thanks are due to Mr. N. CHUMA of the Kanto Regional office of the Ministry of Agriculture and Forestry and to the staffs of the Kune mine, Furukawa Mining Co. Ltd., Messers H. FUKUMOTO, T. AOKI and S.

KANDA, for their kind helps in various ways. The field work for this study has been supported in part by the Grant in Aid for Scientific Researches from the Ministry of Education.

II. MACROSCOPIC FEATURES OF THE KINK BAND

The rock involved in the kink band examined in this paper is a multilayered system consisting of alternating quartz-rich layers and mica-rich layers (pelitic schist), showing distinct foliation. Both quartz-rich layers and mica-rich layers contain quartz, calcite, albite, muscovite, chlorite and carbonaceous matter as constituent minerals, but, in the former, quartz is the most abundant, while, in the latter, muscovite is predominant. The boundary between the quartz-rich and mica-rich layers is generally represented by a distinct line on the thin section (Plate 1–1). Width of individual layers is less than 5 mm.

The kink band examined and the surrounding kink bands observed in the field (the Shimo (lower) 5th level of the Kune mine) appear in one set preferably oriented at an angle ca. 50° to the foliation surface. Width of those kink bands is less than 2 cm, and spacing between them is larger than 5 cm. On the foliation surfaces of the pelitic schists containing those kink bands are found two types of linear structure. One of them is shown by the line of intersection of kink bands and foliation surfaces. This type of linear structure is named L_k. The other type of the linear structure is parallel striations perpendicular to the L_k-lineation on the foliation surface. This type of linear structure is named L_m. The L_m-lineation is older than the L_k-lineation.

Microscopic observation of the kink band in question on the thin section normal to the L_k-lineation represents that one set of slip surface, which traverses at an angle ca. 30° the quartz-rich layers and at an angle ca. 50° the mica-rich layers and which appears to be parallel to the L_k-lineation, develops in such fashion as shown in Plates 1, 2 and 3. The transversal slip surface is named S_k. As shown clearly in Plates 2 and 3, the S_k-surfaces in the mica-rich layer are associated with micro kink fold, which is not found in the quartz-rich layers, style of the structure being analogous to micro kink band. The sense of displacement on the S_k-surfaces is commonly opposed to the sense of rotation of the foliation surface within the kink band, as if the S_k-surface and the kink band correspond to the conjugate sets of slip zone produced during the same phase of the deformation. The angle between the kink band and foliation surface is about 50°.

In the mica-rich layers are found another slip cleavages which traverse at high angles the foliation surface and which appear to be parallel to the L_k-lineation. The transversal slip cleavages (here termed S_2) do not cut across the quartz-rich layers, unlike the S_k-surface, (Plate 1–2).

Broadly speaking, many of quartz grains in the quartz-rich layers show tabular habit and are preferably oriented with their longest dimension parallel to the foliation surface.

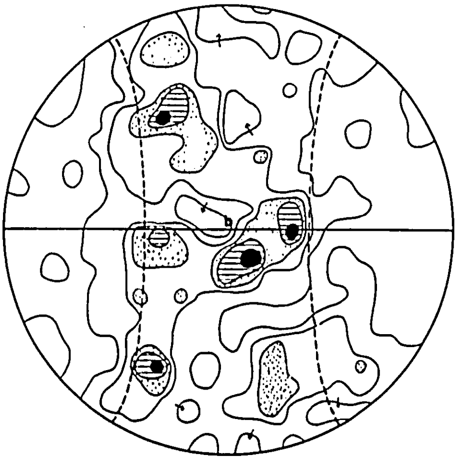

Fig. 1 c-axes of 200 quartz grains in subarea A.
Contours: 5-4-3-2-1 %

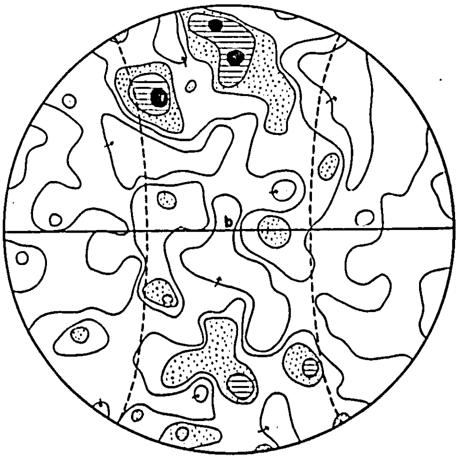

Fig. 2 c-axes of 200 quartz grains in subarea B.
Contours: 5-4-3-2-1 %

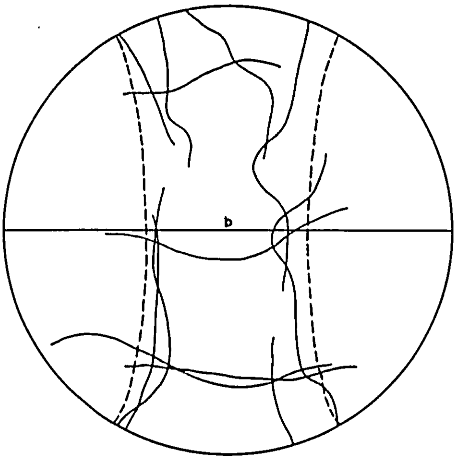

Fig. 3 Diagram showing the trends of the girdles containing maxima and submaxima (from Figs. 1 and 2)

III. QUARTZ FABRICS

A. c-AXIS FABRIC

The c-axis fabric of quartz in the quartz-rich layer has been examined in two subareas (A and B) indicated in Plate 1–1. It is illustrated in Figs. 1 and 2. As shown in Fig. 1 for subarea A and in Fig. 2 for subarea B, many of quartz c-axes are concentrated in a zone making angles of between 90° and 60° (small circles in those figures) to the direction of the L_m-lineation, showing a broad great circle girdle with some maxima and submaxima (here termed main girdle, for convenience' sake).

Degree of preferred orientation of quartz c-axes is rather stronger in subarea A than in subarea B adjacent to the hinge of kink fold. When examined in detail, nature of orientation patterns in FIGS. 1 and 2 appears to approach to that of "cleft circle girdle", characterized by less concentration in a zone making angles of between 90° and 85° to the direction of L_m-lineation, and it is also characterized by subordinate incomplete girdles (here termed subordinate transversal girdle, for convenience' sake) approximately perpendicular to the main girdle (FIG. 3). The symmetry of the pattern of quartz fabric of FIG. 1 as well as of FIG. 2 is characteristically nearly orthorhombic. The main girdle for subarea A as well as for subarea B is oriented perpendicular to the L_m-lineation and parallel to the L_k-lineation. Therefore, it can be pointed out that, with reference to the quartz c-axis fabric, the kink band is completely unfolded around the L_k-lineation.

"...significant is the fact that the symmetry of quartz orientation patterns so commonly is approximately though seldom perfectly, orthorhombic. It is tentatively suggested——and this admittedly is speculation——that syntectonic recrystallization of quartz yields patterns whose symmetry approximates that of the stress system——orthorhombic in the most general case. Herein lie the orthorhombic affinities of most quartz patterns. Departures from perfect symmetry is attributed to the relatively feeble influence of some factor other than stress, in all probability the preexisting anisotropy of the parent rock. On the above interpretation the three mutually perpendicular directions of intersection of the planes of near-symmetry could be equated with the axes of principal stress σ_1, σ_2, and σ_3." (TURNER *et al.*, 1963, p. 432). On the basis of correlation between the calcite fabrics and quartz fabrics in a calcite-quartz vein deformed naturally by axial compression, the author (1961a and 1963b) pointed out that in the metamorphic deformation of quartz aggregate, generally, c-axes of quartz may stably be oriented at an angle ca. 30° to the greatest contraction axis in the system concerned and at an angle ca. 60° to the greatest extension axis, this relation causing the concentration of c-axes in a plane containing the former and the latter axis, although the nature of the preferred orientation may be characteristic of the nature of the strain as is the case of the cold-worked metal fabric (*cf.*, BARRETT, 1952). The c-axis diagrams shown in FIGS. 1 and 2 may be interpreted as follows, according to the author's rule and TURNER and WEISS' assumption cited above: Radial compression perpendicular to the L_m-lineation and concomitant extension in the direction of the L_m-lineation may have caused the broad (weakly cleft) great circle girdle perpendicular to the L_m-lineation. However, the presence of maxima within the girdle, weakly cleft nature of the girdle and subordinate transversal girdles seem to show a number of different episodes of compression or/and extension in different orientations on the plane perpendicular to the L_m-lineation at the earlier phase of the deformation concerned——formation of a great circle girdle perpendicular to the L_m-lineation——(as NICKELSEN *et al.* (1959) interpreted the calcite c-axis fabric, a great circle girdle with some maxima), and, during the later phase of the deformation, weak axial extension parallel to the L_m-

lineation——formation of the cleft nature of the girdle and the subordinate incomplete transversal girdles——*cf.*, HARA, 1962). In view of the nature of the quartz c-axis fabric described and discussed above, there can be no doubt as to the conclusion that the quartz lattice orientation in the quartz-rich layers involved in the kink band was induced during the phase of the deformation related to the formation of the L_m-lineation but not to the formation of the kink band.

B. LAMELLA FABRIC

Böhm lamellae have been recognized in quartz grains of the quartz-rich layers. The crystallographic location of the Böhm lamellae has been examined by the measurement of angles between their pole ($L\perp$) and c-axis of the host crystal (Ch). $Ch \wedge L\perp$ is between 2° and 85°, showing large variation of the crystallographic location of the lamellae (FIG. 4). For most grains (85 per cent of the grains containing the lamellae), however, $Ch \wedge L\perp$ is between 12° and 29°. This result is similar to that noticed by SANDER (1930), FAIRBAIRN (1941), INGERSON and TUTTLE (1945), CHRISTIE and RALEIGH (1959), HANSEN and BORG (1962) and HARA (1961a and b, 1963a and 1964).

FIG. 5 shows the distribution of quartz grains containing the lamellae through the examined quartz-rich layers and the trend of the lamellae in each grain, analysed on the thin section perpendicular to the L_k-lineation. They are distributed in a sharply restricted part in the quartz-rich layers, that is, in kinked zone of the layers.

FIG. 6 illustrates the preferred orientation of poles of the Böhm lamellae through the kink band, analysed on the thin section perpendicular to the L_k-lineation. It is characterized by a sharply defined great circle girdle perpendicular to the L_k-lineation and so parallel to the L_m-lineation. Therefore, it can be pointed out that the lamellae are roughly tautozonally oriented with respect to the L_k-lineation. Also in FIGS. 8 to 10 are understood the trends of the lamellae in subareas A, B and C shown in FIG. 7, respectively.

Poles of the lamellae in subarea A tend to be distributed in two restricted parts in the diagram (FIG. 8), centers of which lie with an angular distance ca. 90° in the plane perpendicular to the L_k-lineation. In FIG. 8, many of the great circles containing Ch and $L\perp$ tend to be inclined at high angles to the L_k-lineation, and, moreover, a familiar regularity with respect to the positional relationship between Ch in any grain and $L\perp$ in the same grain is found, as are the cases noticed by INGERSON *et al.*

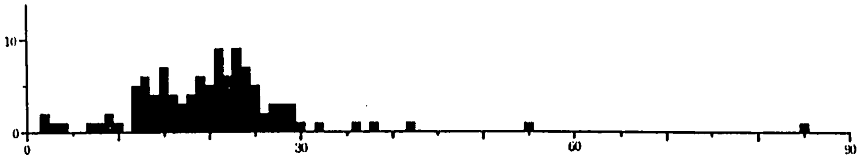

FIG. 4 Histogram showing the variation in the angle between the pole of Böhm lamellae and the c-axis of host crystal The ordinate: frequency given by number of grains

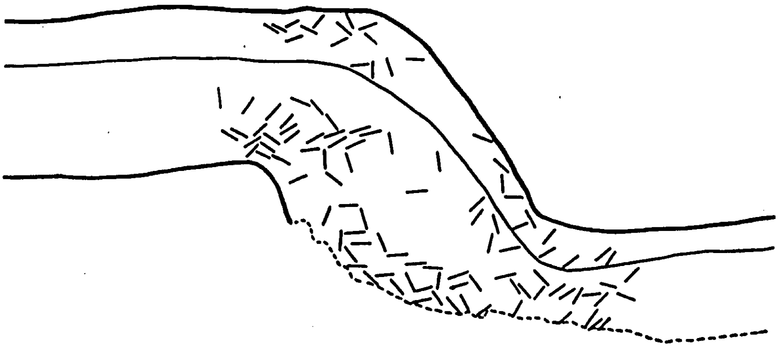

Fig. 5 Diagram showing the distribution of quartz grains containing the Böhm lamellae through the kink band and the trend of the lamellae in each grain

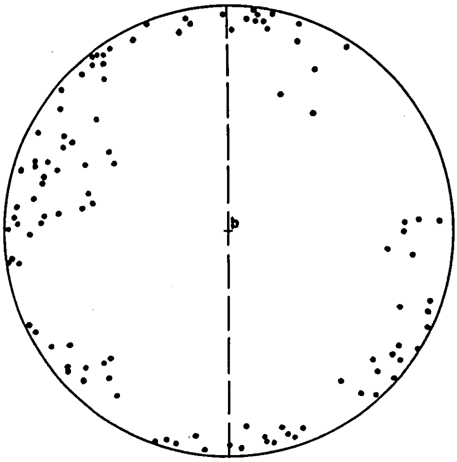

Fig. 6 Poles of Böhm lamellae in 107 grains b: the fabric axis b for the lamella fabric (parallel to the L_k-lineation) Brocken line: the axial surface of kink fold

(1945), Christie *et al.* (1959) and Hara (1961a and b, 1963a, 1964 and 1965a). Namely, in Fig. 8, $L\perp$ in any grain tends to be closer to point C than Ch in the same grain. Points C and T lie together on the plane containing two groups of poles of the lamellae distributed separately with an angular distance ca. 90° and they lie midway between those two groups. Analogous relationships between Ch, $L\perp$, and points C and T are equally obvious for subareas B and C, as shown in Figs. 9 and 10, respectively. Figs. 8 to 10 together shows a monoclinic or near orthorhombic symmetry, indicating that the direction parallel to the L_k-lineation corresponds to the symmetry axis. In view of the nature of the lamellae described and discussed above, there can be no doubt as to the conclusion that the lamellae in the quartz-rich layers involved in the kink band was induced during the phase of the deformation related to the formation of the kink band but not to the formation of the L_m-lineation. As mentioned in the preceding page, it is clear that quartz lattice orienta-

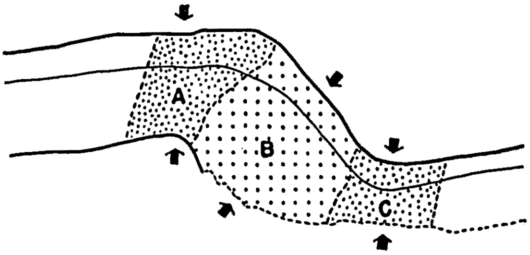

FIG. 7 Diagram showing the positions of subareas A, B and C and the mean direction of the principal compressive stress for the Böhm lamellae (arrows) in those subareas

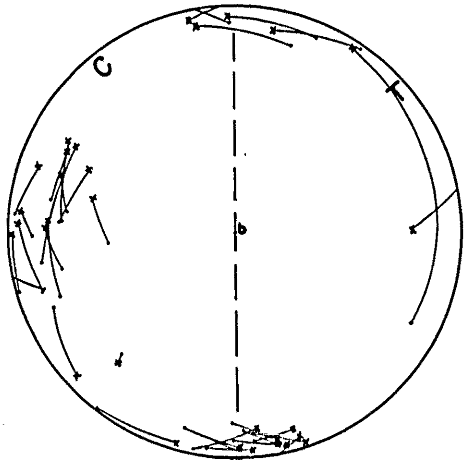

FIG. 8 Poles of Böhm lamellae (crosses) and c-axes of host crystal (dots) in 30 grains in subarea A

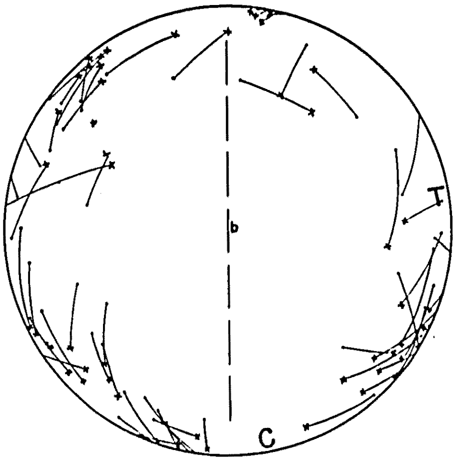

FIG. 9 Poles of Böhm lamellae (crosses) and c-axes of host crystal (dots) in 51 grains in subarea B

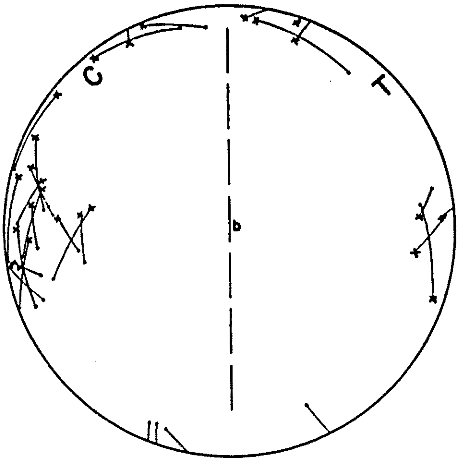

Fig. 10 Poles of Böhm lamellae (crosses) and c-axes of host crystal (dots) in 26 grains in subarea C

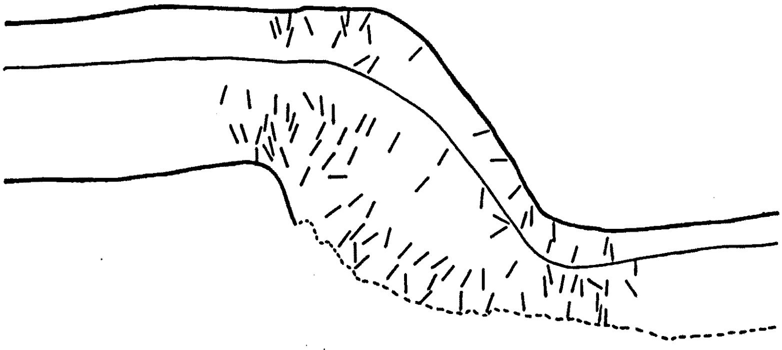

Fig. 11 The compression axis for the Böhm lamellae in individual grains in Fig. 5

tion in the quartz-rich layers was induced during the phase of the deformation related to the L_m-lineation. Therefore, it may be said that, in the deformation related to the kink band, the deformation of quartz grains in the quartz-rich layers occurred essentially by weak deformation of the grains characterized by the formation of the Böhm lamellae and undulatory extinction.

The author (1961a and 1965a) proposed a rule for establishing the stress system (directions of the principal stresses) developed in the system concerned during the phase of the deformation which produced the quartz lamellae, on the basis of correlation between the calcite fabrics and quartz fabrics in naturally deformed calcite-quartz veins. According to the rule, points C and T in FIGS. 8 to 10 correspond to the mean direction of the principal compressive stress and that of the principal tensile stress, respectively, developed in the quartz-rich layers involved in subareas A, B and C, that is, in kinked zone of the layers, (FIG. 7). The compression axis responsible for the formation of the lamellae in each grain has also been determined according to the author's rule and plotted on the plane normal to the L_k-lineation (FIG. 11). As obviously shown in FIGS. 7 to 11, the distribution of the stress axis is uniform through the kinked zone of the quartz-rich layers, and the stress system suggests that the compression axis is approximately normal to the average trend of the foliation surface within each of subareas A, B and C and the tension axis is approximately parallel to it and normal to the L_k-lineation. Therefore, it may be concluded that mechanism of kink folding of the quartz-rich layer can not be strictly referred to the type of the neutral surface folding (ICKES, 1923 and HILLS, 1963), because stress picture corresponding to the compression side developed in the neutral surface folding is not found in any quartz-rich layer (see FIG. 11), unlike in the case of the concentric folds in multilayered system consisting of alternating quartz-rich layers and mica-rich layers previously described by the author (HARA, 1963a and 1965b). Generally speaking, width of kink band tends to depend upon the thickness of the layer involved in such fashion as the kink band becomes wider, as the layer becomes thicker (HOEPPENER, 1955 and 1956), as in the case of the natural concentric fold well known as the competence law (FAIRBAIRN, 1949). It is not explained why and how in the present case kink folding does not involve neutral surface folding in the quartz-rich layer and kink folding causes such a stress picture as shown in FIG. 11. Generally, in natural kink bands, especially in their hinge zones, are found tension fractures developed approximately perpendicular to the surface of the layers involved, the stress picture for the kink folding, which may be inferred from those tension fractures, being in accordance with that for the present kink band. However, the deformation which produced those tension fractures may not be responsible for the formation of the kink band.

HANSEN and BORG (1962) discussed the dynamic significance of deformation lamellae in quartz of a calcite-cemented sandstone. In one diagram given by them (HANSEN *et al.*, 1962, FIG. 5–D), the c-axis in any quartz grain tends to lie nearer than pole of lamellae in the same grain to the principal compressive stress, which

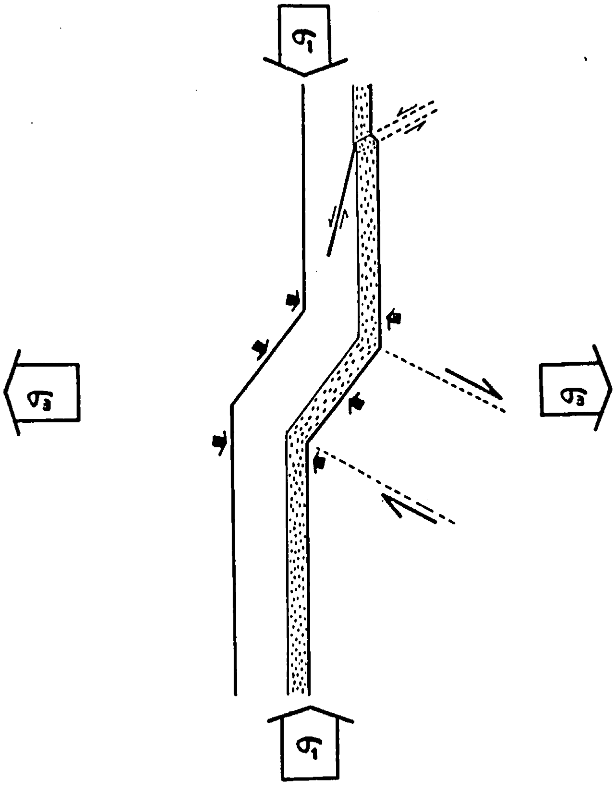

FIG. 12 For explanation see the text. Arrows (solid): local princpal stress in kinked zone (related to the formation of the Böhm lamellae) Arrows (σ_1 and σ_3): the direction of external compressive stress (σ_1) and that of external tensile stress (σ_3) in the deformation which produced the kind band and S_k-surfaces.

was deduced on the basis of twinning in calcite, unlike the cases found by the present author (1961a and 1965a). If the stress picture for the lamella fabric in the kink band is interpreted on the basis of HANSEN *et al*'s data cited above, points C and T in FIGS. 8 to 10 correspond to the mean direction of the principal tensile stress and that of the principal compressive stress, respectively, developed in the quartz-rich layers involved in subareas A, B and C. Therefore, it can be said that the principal compressive stress is approximately parallel to the foliation surface and normal to the L_k-lineation through those subareas, and that the principal tensile stress is approximately normal to the foliation surface. Now, there occur two quite different opinions on the stress picture for the lamella fabric in the kink band. In order to select either one of dynamic interpretation for the lamella fabric given in the preceding paragraph and that in this paragraph, however, further work on the experimental and natural quartz lamellae is required.

Although the time-relation between the formation of the kink band and that of the S_k-surface can not be determined, it is probable that, broadly speaking, both structures are of the same phase. If so, the external force exerted to the system and the strain developed in the system during the phase of the deformation related to the formation of the kink band and S_k-surface can be schematically drawn in such fashion as shown in FIG. 12, with reference to the information on shear failure of anisotropic rocks given theoretically by JEAGER (1960) and the result given experimentally by PATERSON *et al.* (1962). As mentioned in the preceding page, the kink band is inclined at an angle ca. 50° to the foliation surface. The S_k-surfaces are inclined at an angle ca. 30° to the quartz-rich layer, while in the mica-rich layer they, associated with micro kink fold, (micro kink band) are inclined at an angle ca. 50° to the layer (Plates 1, 2 and 3). It is very interesting that the angle between the kink band in question and foliation surface is approximately equal to that between the micro kink band (S_k-surface in the mica-rich layer) and foliation surface while the former and the latter angle are quite different from the angle between the S_k-surface in the quartz-rich layer and foliation surface. In FIG. 12 are represented such relations that in the quartz-rich layer the angle between σ_1 and S_k-surface is smaller than 45° while the angle between σ_1 and kink band is larger than 45°, and that in the mica-rich layer the angle between σ_1 and S_k-surface (micro kink band) is larger than 45°. RAMSAY (1962, p. 525) said, "conjugate folds and related structures (kink bands, knick bands, joint drags)……appear to be produced by movements on one or more shear surfaces which usually (but not invariably) make an angle of less than 45 degrees to the principal stress axis." Above-described data for the present specimen seems to be unfavourable against RAMSAY's kinematic interpretation of the structure in question.

Now, the following two points come into question: 1) Is it due to what cause that, when the deformation of the quartz-rich layer occurs by faulting (the formation of the S_k-surface), the deformation of the mica-rich layer occurs by kinking (the formation of the micro kink band)? 2) Is it due to what cause that the angle between σ_1 and S_k-surface (represented as fault plane in the quartz-rich layer) is considerablly different from the angle between σ_1 and kink band? Finally, it must be pointed out that, for most of the kink bands observed in the Sambagawa crystalline schists of the Kune district, generally, the direction of σ_1 established with reference to the result given experimentally by PATERSON *et al.* is approximately parallel to the foliation surface.

REFERENCES

BARRETT, C. S. (1952): *Structure of metals.* New York, McGraw-Hill Book Co.

CHRISTIE, J. M. and RALEIGH, C. B. (1959): The origin of deformation lamellae in quartz. *Am. Jour. Sci.,* **257,** 385-407.

FAIRBAIRN, H. W. (1941): Deformation lamellae in quartz from the Ajibik formation, Michigan. *Geol. Soc. America Bull.,* **52,** 1265-1278.

————, (1949): *Structural petrology of deformed rocks.* Addison-Wesley Press Inc. Cambridge.

FLINN, D. (1952): A tectonic analysis of the Muness phyllite block of Unst and Uyea, Shetland. *Geol.*

Mag., **89**, 263-272.

HANSEN, E. C. and BORG, I. Y. (1962): The dynamic significance of deformation lamellae in quartz of a calcite-cemented sandstone. *Am. Jour. Sci.*, **260**, 321-336.

HARA, I. (1961a): Dynamic interpretation of the simple type of calcite and quartz fabrics in the naturally deformed calcite-quartz vein. *Jour. Sci. Hiroshima Univ. Series* C, **4**, 35-53.

———, (1961b): Petrofabric study of the lamellar structures in quartz. *Jour. Sci. Hiroshima Univ. Series* C, **4**, 55-70.

———, (1962): Studies on the structure of the Ryoke metamorphic rocks of the Kasagi district, Southwest Japan. *Jour. Sci. Hiroshima Univ. Series* C, **4**, 163-224.

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

———, (1963): Revised interpretation of quartz c-axis fabric in metamorphic tectonites (abstract in Japanease). *Jour. Geol. Soc. Japan*, **69**, 322.

———, (1964): The lamella fabrics in a concentric fold. *Jour. Sci. Hiroshima Univ. Series* C, **4**, 365-394.

———, (1965a): Deformation bands in calcite and quartz crystals. *Geol. Report Hiroshima Univ.*, **14**,

———, (1965b): Dimensional fabric of quartz in a concentric fold. *Japan. Jour. Geol. Geogr.*, (in press).

HILLS, E. S. (1963): *Elements of structural geology.* John Wiley & Sons, Inc., New York.

HOEPPENER, R. (1955): Tektonik im Schiefergebirge, eine Eniführung. *Geol. Rdsch.*, **44**, 26-58.

———, (1956): Zum Problem der Bruchbildung, Schieferung und Faltung. *Geol. Rdsch.*, **45**, 247-283.

ICKES, E. L. (1923): Similar, parallel and neutral surface types of folding. *Econ. Geol.*, **18**, 575-591.

INGERSON, E. and TUTTLE, O. F. (1945): Relations of lamellae and crystallography of quartz and fabric directions in some deformed rocks. *Am. Geophys. Union Trans.*, **26**, 95-105.

JEAGER, J. C. (1960): Shear failure of anisotropic rocks. *Geol. Mag.*, **97**, 65-72.

JOHNSON, M. R. W. (1956): Conjugate fold system in the Moine thrust zone in the Lochcarron and Coulin Forest areas of Wester Ross. *Geol. Mag.*, **93**, 345-350.

KNILL, J. L. (1961): Joint-drags in Mid-Argyllshire. *Proceed. Geol. Assoc.*, **72**, 13-19.

NICKELSEN, R. P. and GROSS, G. W. (1959): Petrofabric study of Conestoga limestone from Hanover, Pennsylvania. *Am. Jour. Sci.*, **257**, 276-286.

PATERSON, M. S and WEISS, L. E. (1962): Experimental folding in rocks. *Nature*, **195**, 1046-1048.

RAMSAY, J. G. (1962): The geometry of conjugate fold systems. *Geol. Mag.*, **99**, 516-526.

SANDER, B. (1930): *Gefügekunde der Gesteine.* Vienna, Springer Verlag.

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

I. HARA: INSTITUTE OF GEOLOGY AND MINERALOGY,
FACULTY OF SCIENSE, HIROSHIMA UNIVERSITY.

EXPLANATION OF PLATE I

FIG. 1 Kink band and S_k-surface. Crossed nicols. ×10
FIG. 2 S_2-surface in the mica-rich layers. Lower nicol only. ×25

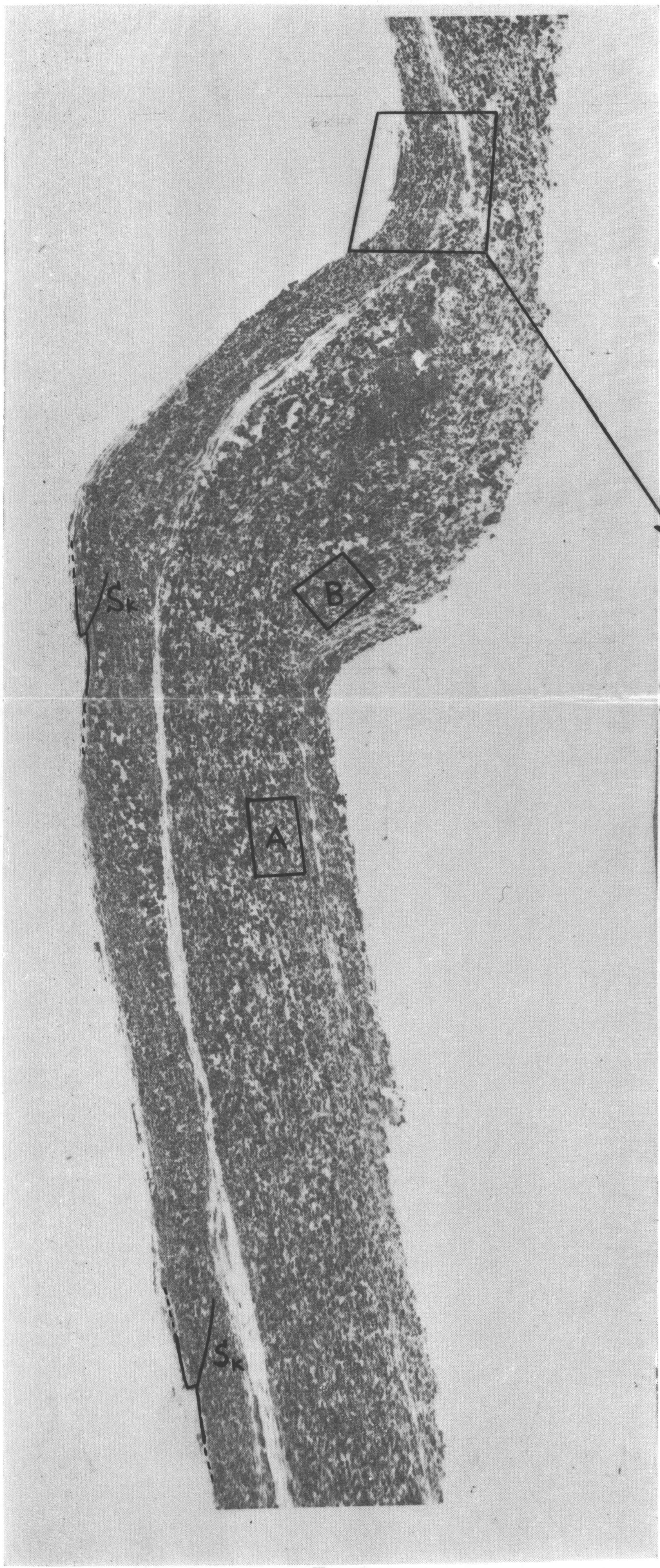

FIG. 1

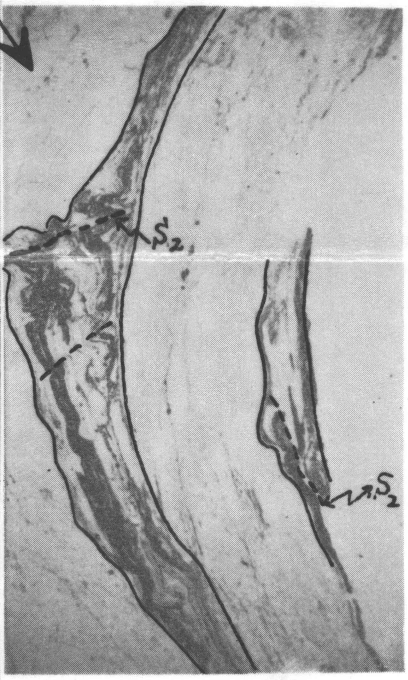

FIG. 2

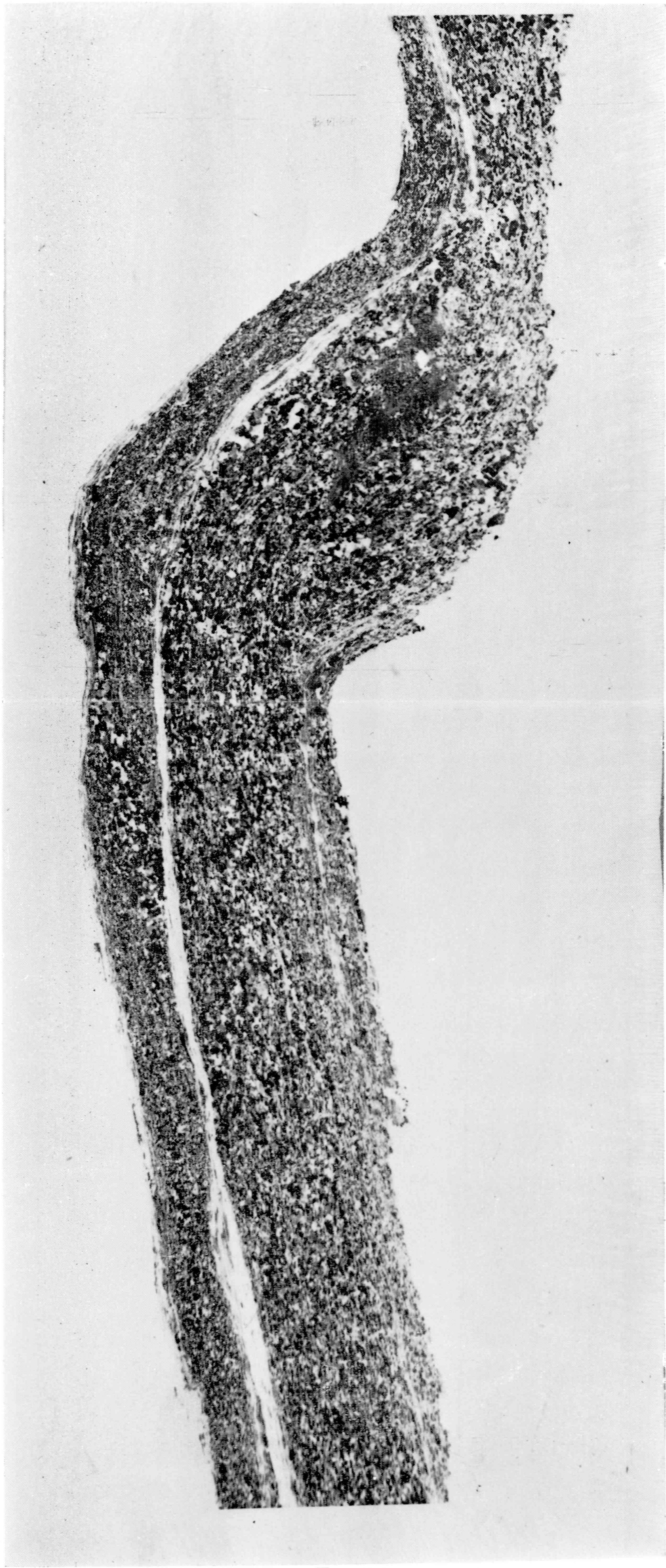

FIG. 1

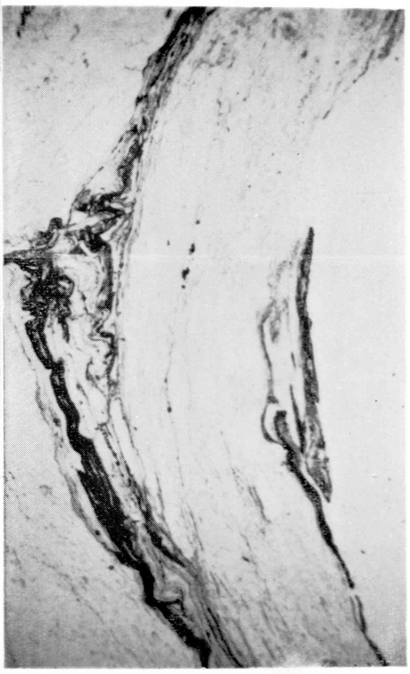

FIG. 2

EXPLANATION OF PLATE II

FIG. 1 S_k-surface in the quartz-rich layer and micro kink band in the mica-rich layer. (found in the lowest part of Plate 1). Lower nicol only. ×55

FIG. 2 ditto. Crossed nicols. ×55

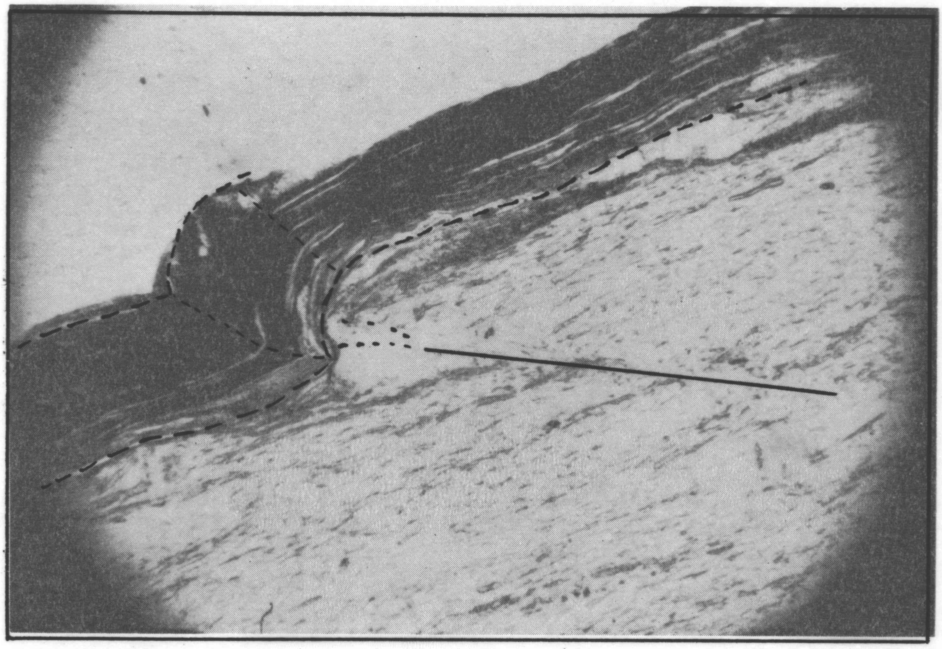

FIG. 1

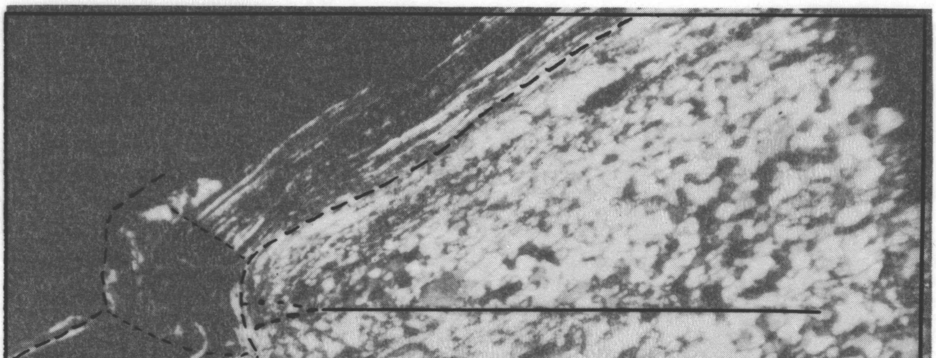

FIG. 2

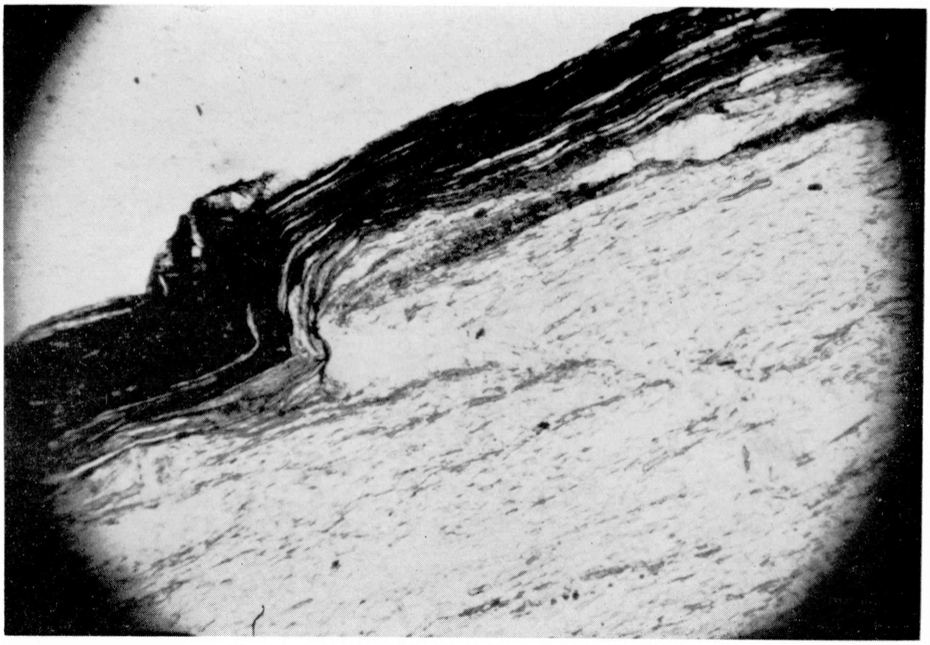

FIG. 1

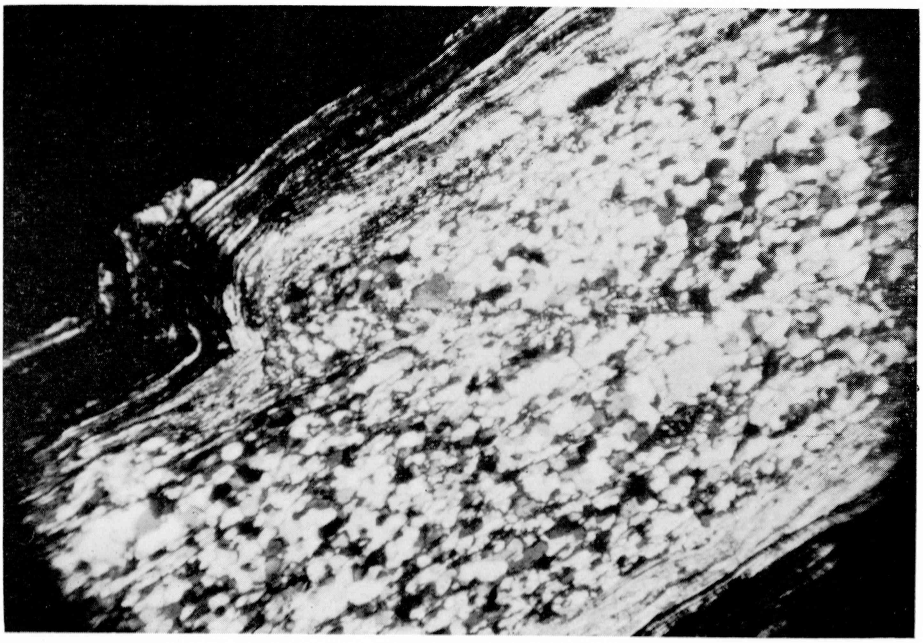

FIG. 2

EXPLANATION OF PLATE III

FIG. 1 S_k-surface in the quartz-rich layer and S_k-surface, associated with micro kink fold, in the mica-rich layer (found in the middle part of Plate 1). Lower nicol only. ×55

FIG. 2 ditto. Crossed nicols. ×55

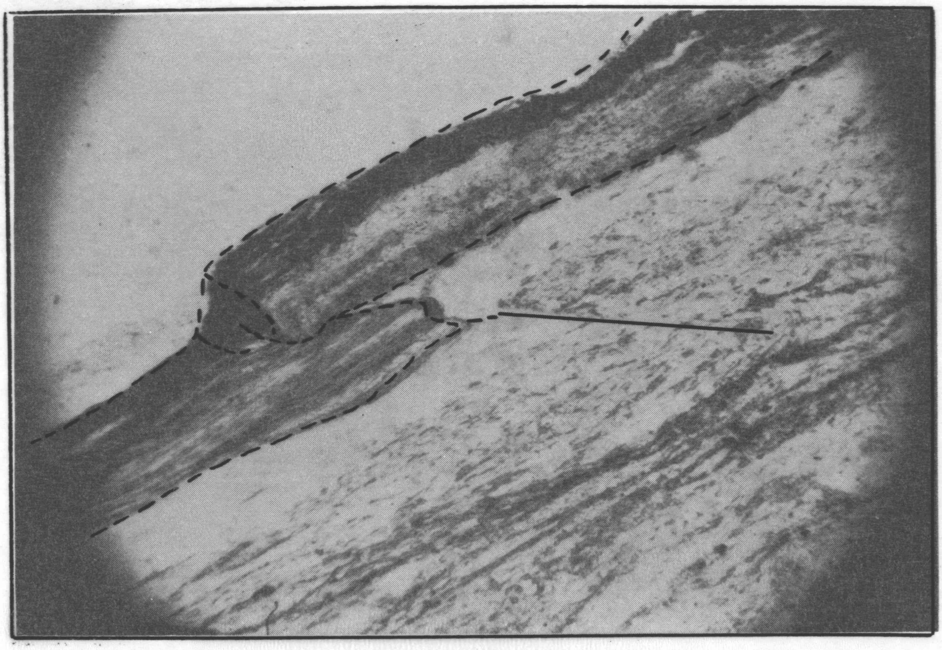

FIG. 1

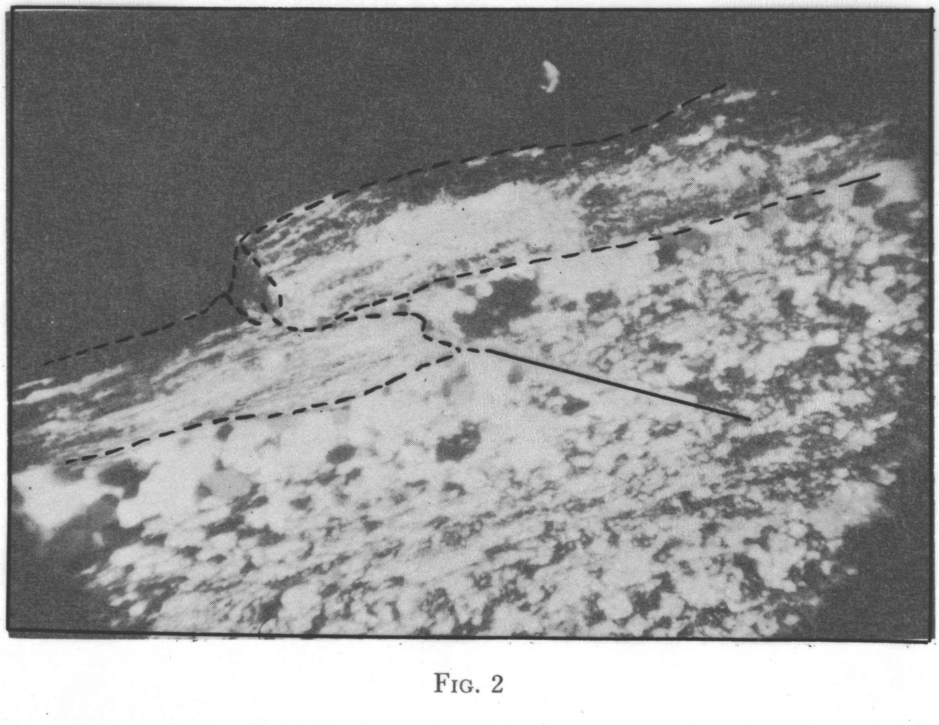

FIG. 2

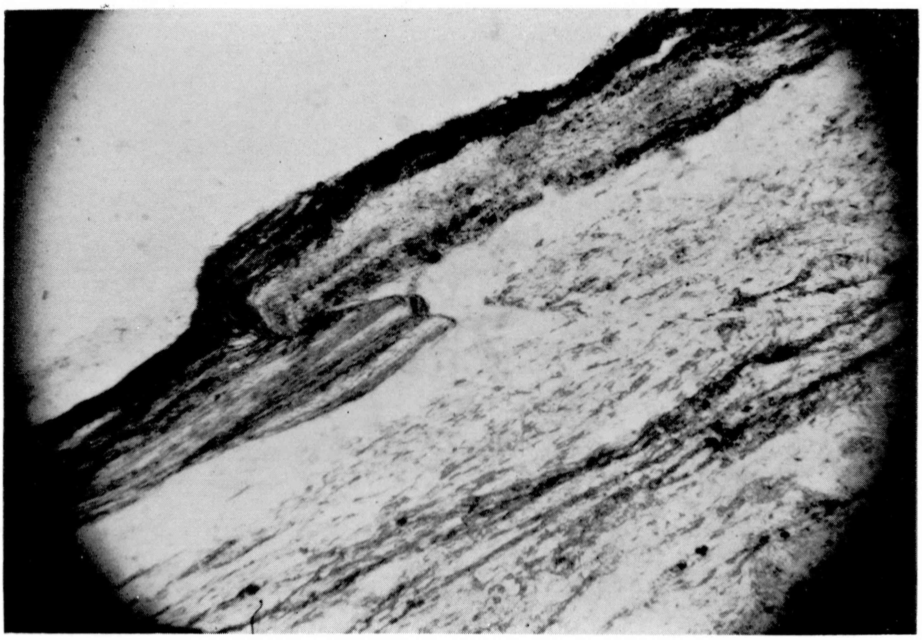

FIG. 1

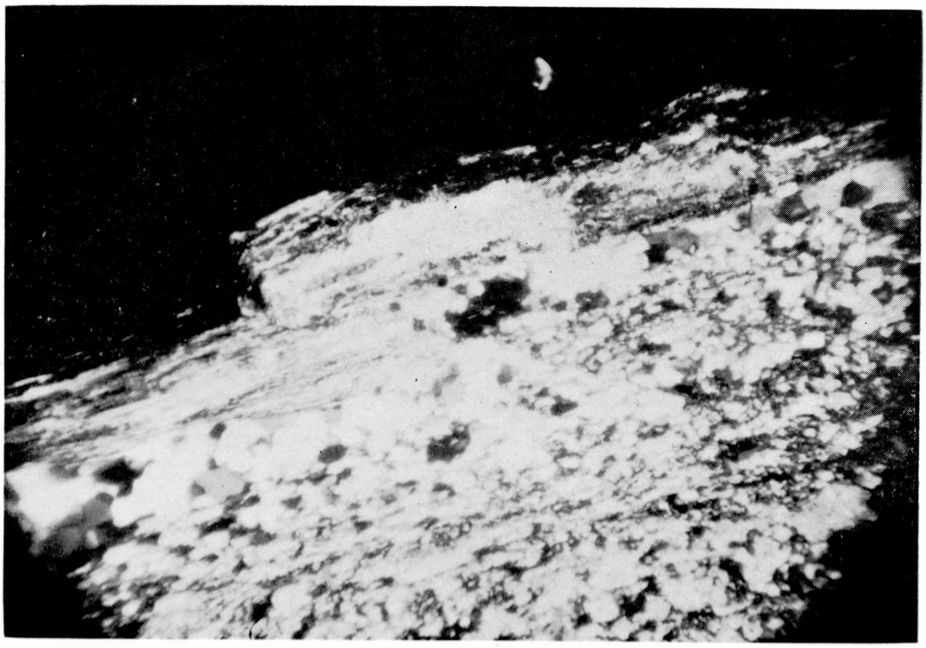

FIG. 2