Chapter IX.

MINERAL FABRIC OF THE GRANITE AND THE WALL ROCKS.

The study of mineral fabric, the spatial pattern of the lattice orientation of individual minerals, or of intergrain lattice or of other structural elements, gives a kinematic approach to the study of rock deformation, picturing the nature and symmetry of the vector fields under whose influence the rock was formed or deformed. The concept that the symmetry of the fabric records the symmetry of the movement influencing the orientation is basic to the study.

To two workers chiefly, Sander and Schmidt, we owe the development of the study. Sander, as a result of his intensive study formulated some generalised tectonic principles and some mechanisms of mineral grain orientation that could be elucidated from the fabric pattern (Gefugskunde der Gesteine: Sander 1930). The study led Sander to propose a new grouping of rocks into the tectonites and the nontectonites. The former show penetrative intergranular movement and include deformed rocks, while in the second the orientation is due to growth or deposition which include undeformed igneous rocks and sedimentary rocks.

The fabric axes $a$, $b$ and $c$, recognised within the rock body, about which the spatial distribution of the fabric elements is referred, are related to the principal axes of strain. The $ab$ or the $S$ plane is recognised as the most significant structure plane like the bedding surface, gneissosity or schistosity planes etc, the direction $b$ being marked by any puckering or lineation within the $ab$ plane, the line of intersection of more than one $S$ planes etc.*

* Full accounts of the field and laboratory technique in English appear in Knopf and Ingerson (1938), Ingerson (1936), Haff (1938) and Fairbairn (1942, 1949).
Quartz is most commonly employed in fabric studies. It is among the very few minerals which have been studied extensively for their space lattice orientation, and in the case of which attempts have been made to study the mechanism of orientation experimentally and also to correlate the deformation with the atomic structure of the mineral or with different vectoral properties incidental on the structure (Sander 1930, Schmidt 1927, Sander 1933, Griggs and Bell 1938, Hietanen 1938, Ingerson and Rainish 1942, Fairbairn 1939, 1941 1942). Several types of girdles and of point maxima, according to the spatial position of the maxima have been recognised (Sander 1930, Knopf and Ingerson 1938 etc). Sander's synoptic diagram for point maxima has been extended by Fairbairn to incorporate some new maxima positions (Fairbairn 1942, see Fig 56). Among other minerals studied in some detail are calcite and biotite (Sander 1930 etc etc).

Fabric of the Porphyritic Granite and Wall Rocks.

Carefully oriented specimens were collected in the field, and rough block diagrams were prepared showing all the important megascopic structural features. Accurately oriented sections were cut from these specimens, generally in the (00) plane of the megascopic fabric.

The scatter diagrams were counted and contoured in the usual manner. The rotation of the diagrams, when necessary, was done, generally, from the scatter diagrams, as suggested by Fairbairn (1942). In a few cases the contoured diagrams were also used for rotation. In case of two the 'chi-square' test was applied (Winchel 1937, Goulden 1939, Fisher 1936) to determine the degree of preferred orientation, though in general an inspection of the contoured diagram gives sufficiently precise estimate.

Mineral orientation in the wall rocks: (metamorphites, ultrametamorphites and granite gneiss):

To find out the influence, if any, of the porphyritic granite on the mineral fabric of rocks in vicinity to its walls, a study was made of specimens, spaced at different distances from the
wall, a few lying at considerable distances, evidently out of the zone of direct influence of any possible mechanical effect due to the granite.

Of the eight quartz fabric diagrams prepared from these rocks, three are of the granite gneiss, one of a migmatite and the rest of the sedimentary metamorphites. Only two biotite fabrics were studied, both of highly granitized rocks.

All the above rock types show very well developed planar banding, and the granite gneiss often exhibits a conspicuously formed thin layering with layers of flat quartz alternating with those of xenomorphic quartz - feldspar assemblage, thus having the typical appearance of the "granulites" of German authors (see description, page 43). The elongated or ribbon shaped quartz grain in the granite gneiss, however, show all evidences of having been introduced later, often enclosing, partially or completely, assemblages of quartz - plagioclase and accessories, besides showing some reactional structures (Chapter V). This is equally true of similar quartz grains in the metamorphites. Some quartzites, though they do not show such 'elongated' quartz, show nonetheless, some flattening of all the quartz grains, which often give undulate extinction. Close to the wall of the porphyritic granite, the granite gneiss, even when not visibly mylonized, oftentimes show strain shadows in the elongated quartz phenocrysts. Some marginal granulation may also be seen round these grains.

Not quite rarely the planar structure is associated with an equally well developed lineation. The lineation has more commonly been produced by microfolds due to parallel disposition of the axes. Orientation of elongated quartz grains may also give rise to lineation, which is parallel to the direction of microfolds axes where both are seen to have been developed. Because of the flattened nature of the granulitic quartz, the mineral in sections in any direction at right angles to the foliation, would show a streaky elongated habit. Whether a lineation has been developed or not is better appreciated on the ab plane of the megascopic fabric, that
is to say, the foliation plane. Close spaced joints, with nearly vertical planes, roughly 0.2" to 0.3" apart (e.g. in specimen 11211), may impart a look that simulates lineation, which may be present or absent.

More generally the lineation is approximately parallel to the strike of the foliation, keeping close to it and pitching at low angles. Sometimes, though locally, it may be approximately parallel to the direction of the dip (Structure map Plate VII), where it is always determined by the orientation of the elongated quartz grains and sillimanite needles. It may be worthwhile in this connection to compare it with the lineation seen in the porphyritic granite. The two do not seem to have anything in common, except for a broad apparent conformity, in as much as these structures are related only to the respective planar structures, the foliation in the country rocks in one case and the flow layers in the granite in the other, changing with the changes in their trends, the changes in the two rocks being always unrelated. That the lineation in the country rocks was not impressed subsequent to the major deformation has a positive support in the fact that it never shows, as it normally should under such circumstances, any persistent direction in spatial orientation irrespective of the changes in the trend of the foliation. The lineation has obviously been developed concomitantly with the planar banding, both results of major tectonic disturbances, just as the lineation in the granite has been developed simultaneously with the flow layers, both results of fluxion in the process of emplacement of a solid-liquid system (Chapter VII).

With reference to the regional fold axes the lineation which is roughly parallel to the strike of the foliation has been taken to indicate the direction of the δ fabric axis. This is further corroborated by both the quartz and the biotite fabrics. The second type of lineation locally developed is found to be parallel to a.
In rocks close to the porphyritic granite, the effect of its intrusion has caused secondary folding. The axes of these folds, towards the east of the granite massif, are at right angles to the regional strike of the foliation, obviously a result of direct compression due to the intrusion. But the effect is local, the folds dying out at a distance. The deformation, not of any considerable extent with little folds remaining open, has caused thus a rotation of the strain axes so that they now belong to what may be described as B - B testonites. Where the wall of the granite is parallel to the schistose trends of the country rocks the result has been an intensification of the structures with some mylonisation in immediate contact (see preceding chapters).

Biotite Fabric: The biotites, generally arranged in almost rigidly parallel layers with the flattest surface parallel to the ab plane of the megascopic fabric, show even in hand specimens undulations round both b and a axes of the fabric. This is well seen specially in coarse grained biotite schists that show passage in the field from pyroxene granulites and amphibolites from which they have been derived by granitisation. Because of a general coarse grain size of these biotites, and the undulations being different in different portions of the same specimen, collective diagrams were prepared from a number of sections from the same specimen.

Fig. 52 is a collective diagram of 200 poles of the (001) plane of biotite flakes in a biotite schist (sp No 216). The specimen shows a gradation, within a small thickness, from a slightly biotitised pyroxene granulite, changing into a biotite schist in contact with a pegmatoid granite vein that cuts across the schistosity. The diagram shows a decided concentration of the poles round c, the flakes being, thus, more or less parallel to ab. The fabric is symmetrical about ab with a girdling round b, giving an almost complete peripheral ac girdle. There is also a very incomplete bc girdle. The fabric is indisputably due to neocrystallisation controlled by the existing ab plane, all the biotites having crystallised out of hornblendes and pyroxenes, such
that they had, in the words of Fairbairn "no petrofabric past" (Fairbairn 1942). This applies also to the second biotite fabric (Fig 53) of an ultrametamorphite (sp 285), near granite in composition, showing passage in the field to rocks that have undergone different degrees of granitisation. The diagram, very similar to the former, shows a very nearly complete peripheral ac girdle, but there is comparatively little tendency to form a second bc girdle in this diagram. Both the diagrams exhibit symmetry of the triaxial ellipsoid.

The orientation of the biotites had nothing to do with the tectonic history of these rocks, the minerals having formed subsequently due to granitisation. The neocrystallisation was evidently controlled by the existing ab plane, so that the (001) cleavage planes of the biotites came to lie statistically parallel to the ab plane. The girdles thus, fortuitous in their preferential appearance in any one plane over the other, have formed, not due to rotation external or translational, but due to crystallisation along openings available, chiefly by crystallisation round the hornblende and the pyroxenes. Only in case of rocks showing minor folds associated with, and caused by, the emplacement of the porphyritic granite, having obviously formed concomitantly with the neocrystallisation, there would result a girdling round the fold axes. The girdling comes out on a collective diagram of specimens spaced systematically along different parts of such a fold. The diagram (Fig 54) is of 200 poles of (001) faces of biotite flakes from four sections spaced in relation with the axis of the fold as shown in the figure (Fig 55). The axes of these folds, near Hirbahal (86°25'30"E, 23°25'N; 73°7') for example, from where the above specimen comes (284a), are at right angles to the regional fold axes. The direction of these axes of secondary folding, taken as b' (= B of the new strain) is parallel to the a axis of the regional magmatic fabric of the country rocks. Sections were prepared on the ac (= b'ac') plane. A strong peripheral girdle is noticed round b' = a besides the original peripheral ac girdle which shows signs of breaking up.
Diagrammatic block of a folded schist showing positions of oriented slices with ref. to the secondary fold axis (B')

Fig. 5
Quartz Fabric: The most striking feature of quartz grain orientation in the country rocks is the very considerable change in the fabric seen in specimens close to the porphyritic granite in comparison with those further away. Two distinct types of fabric are thus recognisable, the regional fabric noticed in all the rock types outside the zone of mechanical influence due to the intrusion of the porphyritic granite, and the fabric of the wall rocks. The change from the former to the latter is traceable in several stages. A more detailed study of closer spaced specimens would, obviously, have given a more complete picture of the successive stages in the evolution of the structure.

Fig. 56 is the diagram of 200 quartz axes of a sillimanite gneiss (Sp 5611) from the foot of the small rise WNW of Ramchandrapur Peak (QM 445099; 73 1/4) on the cart road leading from Ramchandrapur village to Dubrajpur (Plate VI). The specimen shows a very well developed lineation in an equally well formed S plane. The trend of the lineation, very nearly parallel to the direction of dip of the foliation, was taken as parallel to a with reference to the regional fold axes. The lineation is made evident by the arrangement of sillimanite needles and elongated quartz grains. The oriented section cut from the specimen was not accurately parallel to the ac plane of the megascopic fabric. Its spatial position with respect to the ac plane is indicated in the block diagram (Fig. 57). The plane of section could be obtained by rotating the ac plane 18° on c, clockwise, looking at the direction of dip, and then 5° on c, again clockwise. The fabric has been shown diagrammatically in the figure on the negative direction of c.

The diagram shows a considerably thick ac circle, extending on the average 40° both sides of ac, without any strong tendency to form maxima. The maximum concentration is 6% per 1% area. The small maxima concentrated near c are roughly equivalent to maximum V (synoptic diagram Fig. 58) and intermediate between V and II, with a fourth on a (maximum I) which is, however, of lesser importance.
Fig. 57:
Block diagram to show the position of the plane of section with reference to the ac plane for specimen 5611 (c.f. Fig 56) See text.

Fig. 58:
Synoptic quartz axes diagram for point maxima (extended by Fairbairn).
Fig. 69:

Block diagram to show the relation of the quartz fabric of a granite gneiss (sp 22) with the joints developed in the rock. (c.f. Figs 68 and 71) see text.
The second quartz diagram is of 80 axes of another specimen of quartz - sillimanite schist which comes from the north foot of the eastern extremity of the Ramchandrapur hill (QM 459102, 73 \( \frac{1}{14} \)). The rock shows a faint lineation. The foliation dips 72° towards 30°. The lineation, very nearly parallel to the strike of the foliation, makes 20° with it on the plane, and it was chosen as the b axis. The section was prepared nearly on the bc plane, rather parallel to the strike of the foliation, so that it was slightly deviated from the plane, making an angle of 20° with the plane (clockwise). The diagram has been rotated through 70° to the right, to get the projection on the bc plane on the "positive side of b (Fig 60).

The diagram shows a very well formed peripheral ac girdle much more clearly defined than in the former (Fig 57). The choice of the axes was, thus, correct, the fabric being essentially similar to the former, the regional strike or a direction very near to the strike, determined by the lineation (either parallel to or at right angles to it) being the axis round which the girdling is seen to have occurred. The maximum concentration per unit area does not exceed 7.5%. The axes are more or less uniformly distributed along the girdle. There are four small zones in which the concentration exceeds 4%, two of these, showing the maximum concentration, close to a (maximum I), one inbetween the maxima II and I but closer to a and the fourth close to c (maximum V). The maximum concentration is thus, on the whole, more near maximum I.

Specimen 11211, the quartz axes diagram of which is given in Fig 61, comes from the same spot as specimen 5611 (Fig 57). It is a well cleaved quartzite showing a lineation which is roughly

\* The right hand side (i.e. the eastern end) of the axis b, looking along the direction of regional dip, has been taken, in all cases, for convenience of comparison, as the positive end.
parallel to the direction of dip of the foliation. It shows, also, a close spaced set of well developed joints whose modal strike is parallel to the trend of the lineation. As in the case of the first diagram the lineation was taken to be parallel to \( a \). The joints are then nearly parallel to \( ac \). The fabric shows a nearly peripheral \( ac \) girdle, three fourths complete. The axes spread somewhat to form a second girdle, almost half complete, intermediate in position between the \( ac \) and the \( bc \) planes.

Only 60 grains were plotted. The high order of preferred orientation seen may not, thus, be truly indicative of the fabric. One maximum has been developed close to \( a \) (maximum I).

A specimen of quartz-sillimanite gneiss (14a156), coming from a spot close to the eastern extremity of the Ramchandrapur hill very near to the spot from which the specimen 13156 (Fig 59) comes, shows two girdles as in Fig 61. Of these the diagonal girdle is more prominent and the peripheral \( ac \) girdle is only half complete (Fig 62).

The common feature about the quartz fabric of the four specimens of the metamorphites, all occurring at considerable distances from the porphyritic granite massif, is the presence of a more or less well defined \( ac \) girdle, except in a few which show besides this a diagonal girdle intermediate between \( ac \) and \( bc \). This diagonal girdle is, in one of the diagrams, comparatively more prominent. In all the cases there is no prominent maxima, the axes being somewhat equally dispersed throughout. The positions of the little zones of maxima coincide with the maxima I, II and V. In all the cases the \( b \) axis is very nearly parallel to the direction of the regional strike.

An \( ac \) girdle may form by internal grain rotation round \( b \) under a fixed strain, rotation of \((h0l)\) slip planes or production of microfolds. There is no evidence, unequivocal, in support of the one or the other of the above explanations, except that no
microfolds could be recognised in these rocks. The lack of strong maxima, the axes being almost equally distributed along the girdles, suggests that possibly rotation about \( b \) was the controlling mechanism in the process of grain orientation.

If the deformation at the earlier stages had produced elongated fragments of quartz grains with their needle axes and bounding planes having definite crystallographic orientation the orientation of the tectonites could be explained to have taken place by rotation of such grains. The needle axes in the present case would presumably then be parallel to the horizontal edges \((m : r, m : z, r : c, z : c \text{ and } m : c)\) so that the \( c \) - crystallographic axis was at right angles to the direction of elongation of the fractured grains. At the first stage of deformation the needle axes would be rotated parallel to \( b \), and in their approach towards \( b \), the axes would lie in intermediate positions, giving "axes maxima (having) orientation different from those known to occur" (Fairbairn, 1942 p.69). A long sustained deformation would, however, rotate all the needle axes parallel to \( b \). Further deformation with forward movement parallel to \( b \) by rolling of the axes about \( b \), would cause no new positions of axes maxima, as suggested by Fairbairn (op cit supra), but an ac girdle with/or the maxima I, II and V.

When orientation is carried to perfection, such needles, with their bounding planes parallel to \( m \) (1011 or z 0111) and \( c \) would give the three maxima I, II and V respectively. The girdle is explained by the suggestions that either the orientation could not attain perfection due to early closure of the movement of deformation, or that the deformation was carried too far so that the grains having reached the positions of the maxima were pushed away due to the continuance of the motion.
Fig 63, the quartz axes diagram of an ultrametamorphic (Sp 285) almost a granite in composition (Page 49) is more or less similar to the first two diagrams (Figs 56 & 57). It shows a distinct peripheral ac girdle with the maximum concentration not exceeding 6%. The maxima, only two paired zones could thus be defined, are all peripheral, one equivalent to the maximum I and the other to the maximum V. The diagram is non-selective and includes quartz grains that are seen to have been introduced, entrapping the earlier assemblage.

Fig 64 is the quartz axes diagram of a granite gneiss (Sp. 13a), a non-selective diagram of 200 quartz axes from a single slice. It shows, again, a girdle fabric with a well-formed peripheral ac girdle. Selective diagram of 80 axes of "flat" quartz from the same oriented slice shows a similar ac girdle (Fig 65). Both the diagrams show maxima I and V, the last one being more prominent.

Thus the quartz fabrics of the granite gneiss and the passage types (the ultrametamorphites) are identical to those of the metamorphites.

The flat or ribbon shaped quartz grains found in these rocks resemble, as mentioned before, the typical granulitic quartz of the German authors. It is significant that the quartz fabrics of these rocks are homogeneous, both the flat quartz and the fine grain quartz showing identical orientation of space lattice.

The fabric of the granulitic quartz has been ascribed by several investigators to a 'flattening' parallel to ab by a compression at right angles to it. Sahama has made an extensive study of the granulites in Finnish Lapland. The quartz grains have typically an inhomogeneous fabric. The granulitic grains of quartz show a strong preferred orientation while post-deformational crystallisation in the higher grades of metamorphism has obliterated completely any preferred
FIG. 63
100 QUARTZ AXE
CONTOUR
0.5 - 2.5 - 4.5
(max 6%)
orientation of space-lattice of the fine grained quartz. In the granulites of Rosswein, Saxony, on the other hand, described by Sander, the quartz fabric is homogeneous, as in the present case (Sander 1930). Sander's diagram shows a nearly complete peripheral ac girdle, almost orthorhombic in symmetry and with strong maxima near maxima II of the synoptic diagram.

As the entrance of quartz in ribbon or lens shaped strips is traceable in the successive stages of transformations from the metamorphites to the granite-gneiss, in the present area, the orientation of these quartz could only be explained as mimetic, definitely post-deformational, an example of added quartz retaining the original tectonitic fabric of the metamorphites at whose expense the granite was derived. In short, in both the migmatites as well as the granite gneiss the fabric is "migmatitic" suggesting a neocrystallisation by metasomatisos that did not disturb the original space-lattice orientation and that was controlled by the original ab plane left undisturbed, effecting a complete mimicry. The "granulitic" quartz in the leptynites and granites are, thus, not really granulitic.

In specimens successively closer to the wall of the porphyritic granite, a gradual change is noticed in the quartz fabric. The original girdles break down and finally disappear.

The first stage is marked by a complete shattering of the girdle, though a major proportion of the axes retain the original orientation which is mainly a peripheral ac girdle fabric. Thus Fig 66, the ac fabric of 300 quartz axes of a fine grained leptynitic granite gneiss (12a), shows a comparatively poor orientation, the contour above 1% distribution showing a complete ac girdle. The maximum concentration is 5.5%. There are four comparatively smaller zones along which the
FIG. 66
300 QUARTZ AXES
CONTOUR:
0.5 - 1.5 - 2.5 - 4.5
(max 5.8%)
concentration is from 2% to 4% or slightly greater. One of these is close to the maximum III, the second near maximum V and the other two close to maximum II. None of the last three are exactly peripheral. There are also small concentrations near maximum I.

Specimen 2146, a sillimanite - quartz - almandine gneiss, similarly has a poor orientation, showing a broad ac girdle (Fig 67). The diagram is of 200 quartz axes measured from a plane slightly inclined to the ac plane (20°), and shows only a centre of symmetry. There are two maxima rather close to one another, one near maximum VI and the other in between VII and VIII, closer to VII about 35° from b.

Two quartz axes diagrams were prepared from two specimens, a granite gneiss and a quartzite, both occurring very close to the porphyritic granite. (Figs 68 and 70).

The specimen of the granite gneiss comes from near Jhanpra (M 105001, 73 1 37) lying at a distance of about a hundred yards from the porphyritic granite massif. The modal directions of the intersecting shear joints (Set II, Chapter VIII) and tension joints have been plotted on the ac fabric (Sen 1949, 1949a). The tension joints are seen to be very nearly parallel to the ac plane and could be represented by the Miller symbol (010) with reference to the fabric axes. The conjugate planes of the compression joints lie intermediate between ab and bc (hol).

This diagram, of 150 quartz axes, shows a high degree of preferred orientation, with a somewhat thick girdle about half complete. The axes are, however, more concentrated round a comparatively small zone. The girdle, diagonal with respect to the axes of the megascopic fabric, is round an axis which is coincident with the direction of the acute bisectrix of the conjugate planes. The planes of a second set of shear joints, which is rather more prominent in the spot from which the specimen comes, were not plotted in the published diagram (Sen op cit). When the modal strikes are plotted on the ac fabric, the obtuse bisectrix of these
planes is seen to be nearly coincident with \( b \) of the megascopic fabric, lying on a plane intermediate between \( ab \) and \( bc \). This plane contains the acute bisectrix of the former intersecting set. The relation of the different structural elements and the fabric is shown in the idealised block diagram (Fig 69).

The fabric shows a monoclinic symmetry with reference to the bisectrices of the intersecting sets of joints, the obtuse bisectrix of the former set being situated centrally about the scattering of the axes, containing the maximum. The maximum, with reference to the megascopic fabric, occupies a position intermediate between the maxima VI and VII of the synoptic diagram.

Figure 70 is the \( ac \) fabric of a quartzite that comes from near Kotra (23°25'N; 86°27'E; 73°7') and occurs close to the porphyritic granite. As only 50 axes were plotted, the diagram gives a false impression of having an exceptionally high degree of preferred orientation. The rock, which was not oriented in the field, does not also show in the hand specimen sufficiently distinct lineation to help fixing up the \( b \) direction. Oriented in the laboratory, the section might have been cut parallel to either the \( ac \) or the \( bc \) planes and on either side, negative or positive, or any one of the above planes. In one of these four cases it fits well in Fig 68, only the maximum is a bit closer to the conjectured \( b \) axis. In another case, which seems more probable, the maximum lies on the acute bisectrix of one of the sets (Set II) of shear joints and an incomplete girdle forms round the obtuse bisectrix. The joints measured from the hand specimens have been plotted on the \( ac \) diagram.

Both the diagrams show a complete reconstitution from the original fabric. The original tectonitic (and partially mimetic, in the granite gneiss), \( ac \) and \( ab \) \& \( ac \) diagonal girdles have been completely broken down close to the porphyritic granite. This establishes a definite relation between the compressive force
Block diagram to show the spatial relation of the planes of joints of set I and II and the trend of the granite wall, (see text).
Fig. 50: Joints in the granite gneiss, close to the porphyritic granite, near Juludih and Amlatora (see text)

Fig. 50a: Stereogram of the intersecting planes of the joints of set III, showing the position of the obtuse bisectrix.
due to the emplacement of the granite; and the fabric shows a symmetry about the bisectrices of the joints which have been produced by the intrusive emplacement of the granite.

The development of strain shadows in the "granulitic" quartz, cataclastation of the rocks close to the porphyritic granite and production of tension joints, lend support to the suggestion that the re-orientation of the fabric was caused by the compressive force incidental on the intrusion of the granite. The effect was evidently more prominent in the immediate vicinity of the granite (Chapter VIII).

The relation of the fabric with the generalised direction of compression, which is parallel to the obtuse bisectrix of the conjugate shear planes of set II (Chapter VIII), is apparent. In one case the maximum lies on it (Fig 68), with an incomplete girdling in the same plane, round an axis coincident with the acute bisectrix which is contained in a vertical plane and is near to the a axis of the megascopic fabric (Fig 71). In the second case (Fig 70) the maximum is on the acute bisectrix and the girdling is round an axis coincident with the direction of compression, with a little concentration on the obtuse bisectrix (Fig 72)*. In Fig 68 there is a scattering sideways showing an incipient girdle similar to that in Fig 70 round the obtuse bisectrix.

The Griggs - Bell rupture hypothesis seems to offer the most plausible explanation, especially in view of the extensive occurrence of cataclastic structures. This involves a fracture of the quartz grains due to compression, and a subsequent rotation of the grains (Griggs and Bell 1938, Sen 1949, 1949a). The compression pushed away the original fabric into the new position without affecting or disturbing the original ab plane. Indeed in the deformation these planes served as the structure control planes for the fabric re-orientation, which was further helped by interplanar slips on these surfaces induced by the compression.

* In case of the alternative orientation.
The girdling round the obtuse bisectrix in Fig. 70, which occurs in a plane at right angles to the direction of compression, is, thus, in implication, an ab' girdle with reference to the axes of deformation, and it appears as an ab \( \cap \) bc diagonal girdle with respect to the megascopic fabric. The girdle, however, is only half complete, but that may be due to the fact that only 50 grains were measured. The somewhat strong maximum noticed makes it difficult to explain the ab girdle by a process of mechanical flattening, and moreover such an explanation does not seem feasible in view of the fact that the process should have given rise to at least an incipient ab' plane diagonal to the original and nearly at right angles to the direction of compression. No such plane is discernible in these rocks.

In Fig. 68 similarly the girdle is a bc girdle with reference to the direction of compression, appearing as an ab \( \cap \) bc diagonal girdle which lies in the same plane as the compression.

The maxima could better be explained by the rupture hypothesis. At the earlier stages of the emplacement, mechanical effects due to the compression had been more important. Thus the catastrophic impact of the intrusion would have ground the quartz grains into elongated needles with needle axes parallel to \( r : z \) (or \( z : r \)) and bound by \( a \) (or \( a' \)) needle surfaces, as suggested by the maximum (Fairbairn 1942). But the needles were more probably multifaced and had the unit rhombohedrons \( r \) or \( z \), the possible directions of best cleavage in quartz (Fairbairn 1939, 1942), well developed. The deformation rotated these fractured grains such that their needle surfaces came to lie on the megascopic ab plane.

The rocks rupturing forthwith with the application of stress, and with the direction of maximum relief normally lying in a vertical plane, the needle axes should be rotated parallel to \( a \) the new direction of maximum strain. But since the original ab
planes controlled the rotation, the needle axes would come to lie parallel to \(a\) with \(r\) or \(z\) parallel to the megascopic \(ab\) plane. The fabric shows a complete reconstitution and represents a mature state of deformation effecting a total obliteration of the original fabric.

As tension gained the upper hand in the deformation of the walls and plastic stretching was effected parallel to \(b\), as proved by the spatial relations of the latter formed shear joints (Chapter VII), this direction, that is \(b\), became the direction of maximum elongation and the needle axes were rotated parallel to \(b\). In this rotation the more prominent \(m\) (or \(a\) ?) needle faces were made parallel to the original strong \(ab\) plane, giving finally an incomplete \(ab \cap bc\) diagonal girdle (in Fig 70). It may also be quite likely that the needle surfaces were only parallel to \(m\) and they lie parallel to \(ab\'), that is to say in a plane at right angles to compression, giving an \(ab\)' girdle, due to the later rotation from \(a'\) to \(b'\). The rotation might, however, have been chiefly controlled by the original \(ab\). This seems to offer a somewhat better explanation for the \(ab \cap bc\) girdle, and the maxima is in such a case peripheral on \(a'b'\). But it should have given rise to a second recognizable plane which is lacking in these specimens. The girdle in Fig 68 suggests a further scattering - its derivation from an original \(ac\) girdle is otherwise difficult to conceive - after complete reconstitution in the lines pictured above, into an half complete \(b'a'\) girdle.

**Mineral Orientation in the Porphyritic Granite:**

The choice of the fabric axes in the granite is again easy, except where no lineation has been developed. The lineation which is more or less parallel to the strike of the flow layers (Chapter VII) was taken as the \(b\) axis. Where no lineation is evident, the strike direction was taken to be parallel to \(b\), which is found to be very nearly correct on comparison with the above diagrams. The direction of lineation has been found to be the rotation axis of the biotite girdles. Only in Bero, Raidih etc (Chapter VII) the lineation has a different significance, and in these rocks where the linear structure is nearly parallel to the dip of the layers, not the lineation but a direction at right angles (nearly parallel to the
at right angles (nearly parallel to the strike) is again the rotation axis in biotite fabric.

**Biotite Fabric:**

The biotite fabric \((ac)\) of specimen 253 (from Beko Wadi R 220098, 73-11) is a non-collective diagram prepared from a single slide. It shows a good concentration round \(g\) with an almost complete peripheral \(ac\) girdle (Fig 73).

**Fig 74** is the biotite diagram of a specimen (11911) which comes from a spot (M 362075) about south of Jamduara (M 360081) and north of Bero (M 362068, 73-11). A very good lineation has been developed in the rock. The lineation trends roughly with the dip of the layers. The flow layers dip at a steep angle of 78° W. The section was cut at right angles to the layers and parallel to the lineation. The diagram shows a distinct peripheral girdle round an axis at right angles to the lineation, more or less parallel to the strike of the flow layers. This direction being, obviously, the \(b\) axis, the lineation marks the direction of \(a\).

**Quartz Fabric:**

Four quartz fabric diagrams were prepared from four widely spaced specimens. The most striking feature of the quartz fabric is its independence from the fabric of the wall rocks.

**Fig 75** gives the \(bc\) quartz axes diagram of a specimen 253 (c.f. Fig 73). The flow layers at the spot strike 72° dipping 30° NW. Two sets of perfect joints are developed, one with a modal strike of 110° dipping on an average 63°33' and the second with a modal strike of 45° and an average dip of 65°33'. These have been plotted on the \(bc\) diagram to show their relation to the fabric axes. The acute bisectrix of these planes, the acute angle being 43°, is very nearly coincident with the strike of the flow layers. The fabric shows a high degree of preferred orientation and an incomplete girdle which appears diagonal if the strike direction be chosen as the \(b\) axis. The maximum
concentration does not exceed 14% per 1% area. Though the specimen does not show any distinct lineation, only a few yards north, the granite does show a good lineation which trends at 56° pitching 14° so that it makes an angle of about 19° with the horizontal in the plane of the flow layers. If this lineation is interposed on the above diagram, it is seen to be the axis round which the incomplete circle occurs. If this direction be chosen as the $y$ axis, the maxima is seen to be close to maximum $II$ of the synoptic diagram.

Figs. 76 and 77 are the quartz axes fabrics, respectively of the specimens 11211 and 11311. The former comes from a spot near the junction of two Railroad tracks (W 290040, 73 1/10), 146° from Peak 1045 ft (W 289049, 73 1/10) south of Raghunathpur. The latter comes from near Bero (cf. Fig.74). The strike of the flow layers at the first spot is 90°, the planes dipping 46° northwards. There is one set of well developed joints, which have a nodal strike of 28°. The planes are in most cases vertical.

Fig.76 shows an almost complete, thick, peripheral ac girdle and also a partially complete peripheral $bc$ girdle. The maximum concentration is 7% per one per cent area. There are only three small zones with a concentration of 3% upwards, which could be described as maxima, one of which is close to maximum $V$ the second near maximum $II$ and the third in between $VI$ and $VIII$ but very close to $VI$. The distribution of the axes is, however, more uniform throughout the girdle.

Fig.77, prepared from a section on the dip plane, is inclined from the $ac$ plane (about 23°), the lineation dipping 65° northwards. The flow layers, at this spot, dip 76° towards WSW (339°). The lineation, lying on the flow layers, is thus close to the dip. The diagram shows an well developed, peripheral, $ac$ girdle, with a maximum axes concentration of 13% per one per cent area. There are two zones that could be described as maxima, both
FIG. 7

CONTOUR

0.5-1.5-3-5-7-11

max (13%)
The fourth quartz axes diagram (Fig. 78) of a specimen (41811) from a point (M 332068, 73 1/10) WSW of Khajura, does not show any preferred orientation, and is statistically isotropic. In the spot from which the specimen comes, the arrangement of the feldspars is in most cases haphazard, with the banding getting faint or not developed at all; though not very far off e.g. in the rise south of the spot (M 332063, 73 1/10) and in the rise 684 ft, the banding is perfect enough.

The most striking feature about the quartz axes fabric (whether isotropic or otherwise) of the porphyritic granite is its distinction from the fabric of the wall rocks close to the granite massif. This independence of the macroscopic as well as the microscopic fabric proves the structural independence of the granite. Taken together with the profound influence on the structure of the wall rocks, the feature in the porphyritic granite could only be ascribed to a motion of intrusion towards the last stage of its complete consolidation, that is to say in the late solid stage. On these premises, then, the fabric could be ascribed to a viscous flow.

Girdling of the fabric round a nearly horizontal axis proves the granite to have moved up roughly along a vertical plane. The seed crystals of quartz were rotated round $b$ with the little remnant quartz liquid crystallising mimetically to give a more or less perfect ac girdle. The peripheral girdle suggests that the seed crystals were elongated parallel to $m$ or $c$.
SECTION III

(Conclusions)

SUMMARY OF PETROGENETIC EVOLUTION.

"My conclusions have been reasonably attained in so far as I have been able to discount my prejudices, . . . to collect the relevant evidence and to weigh that evidence in accordance with logical principles."

L. S. S.