CHAPTER III

STRUCTURAL PETROLOGY

III.a Introduction

What has so far been detailed in chapter II is the mesoscopic analysis of the component rocks of the schist belt.

During the course of this analysis the author struck upon an idea of attempting the microscopic fabric analysis for a more elaborate and refined approach to the subject matter of fabric studies. Such studies are undertaken for metamorphic rocks which exhibit tectonic fabrics. These studies embody investigation of smaller domains (not on mesoscopic scale), notably crystallographic domains, such as, the optic axis of quartz grains, (001) cleavages of mica, and the long axis of hornblende prisms that are amenable for study only on the microscopic scale. This analytical approach, which has earned the appellation of petrofabric analysis, has developed into a new branch called 'Structural Petrology', the fundamental tenets of which were laid down after long years of painstaking investigation by that indefatigable worker, Bruno Sander (1930, 1948-50), and developed later into a more secure branch of knowledge by new data added to it by his associates and later workers among whom Schmidt (1932), Knopf and Ingerson (1938), Phillips (1937, 1945), Fairbairn (1949), and Turner and Weiss (1963) stand supreme.
But the Hugglehalli schistose rocks, unfortunately, are not amenable to this mode of analysis, for the fabric elements suited for the analysis are absent in them. However, the rock types bordering the schist belt, namely, the gneisses, quartzites, and the lone rock, amphibolite, within the belt, have tectonite minerals ideally suited to this analysis; but as they fall outside the scope of the subject matter of this thesis, as implied by its title, it may appear superfluous to analyse the fabric of the adjoining rocks. However, if one becomes conscious of the fact that rocks are not isolated entities occurring in circumscribed limits, but members of a vast group of rocks in a wider regional geological setting pertaining the long history of geological events, while each reveals the history of its own in its local distribution, it will be found necessary to study the border rocks also in their proper environs. Thus, keeping in view that rock should be studied in their geological setting, in relation to the associated rock types, though each may have different mode of origin and developed during different geological periods, petrofabric analyses of gneisses, quartzites, and amphibolites have been carried out.

Granting that these rocks are totally unrelated to the schists, it is a common knowledge that a later geological episode would leave a common impress on all of them that is bound to be revealed in a more detailed fabric study. Complete analysis of the orientation pattern of several minerals in a few carefully
chosen specimens closely associated in the field will unfold more fabric details than would normally be available solely from microscopic elements. It will also clarify time relations between crystallization and various phases of deformation.

III. b Analytical Procedure

Analysis carried out on the microfabrics of quartzite, gneiss, and amphibolite are detailed in this chapter. Structural elements like optic axes of quartz grains, (001) cleavages of mica, and the long axis of hornblende prisms are measured and plotted on a stereographic projection by universal stage techniques, and any tendency for regular orientation obtained in the cumulative plot is interpreted.

For the study of the internal structure of the rock by applying universal stage techniques, oriented specimen, by which is meant the exact arrangement of specimen in space, were collected as detailed by Knopf and Ingersoll (1938), Fairbairn (1940), and Turner and Verhoogen (1960). On the specimen, the horizontal plane (H), north (N), and downward direction (D) were marked. As most specimens have foliation, schistosity, and lineation, the attitude of these were also marked on the specimen, or recorded in a field note book for subsequent orientation of the specimen in the laboratory. The presence of planar and linear elements enabled to fix the three mutually perpendicular coordinate axes a, b, and c with reference to which the fabric
of the rock is usually described. The S-plane (foliation, schistosity, cleavage and bedding plane) here is taken as the ab plane. The axis a parallels the direction of movement, or the direction of dip of S-plane. The axis b is parallel to lineation, if present, or to the strike of S-plane in the absence of lineation. The intersection of a number of S-planes, as well as the axis of the fold, was also taken to mark the b direction of the fabric.

Oriented specimens were cut from the hand specimen normal to a, b, or c. Wherever found necessary, three mutually perpendicular sections were cut normal to a, b, and c from a single specimen to find the homogeneity or the heterogeneity of the fabric. On each section, two directions of mutually perpendicular fabric axis were marked with a single barbed arrow. The section is mounted on the universal stage such that the shorter edge of the mounted section is brought into parallel contact with the thinner arm of the schmidt rectangular ruler set in a groove in the upper hemisphere. The section moves freely east-west along the thinner inner arm while the entire ruler with the section together can move north-south as a unit. This movement helps the fabric axes to maintain a fixed relation to the graduated scale of the innermost rotation axis, N. Since the plane of projection is that of the thin section, it may be correlated with any planes of the hand specimen. The orientation of the section, that is, a, or b, or c axis corresponding
to the zero reading of the inner vertical axis, \( I \), is noted. These readings are then transferred to the projection overlay. They then provide axes of reference against which all fabric data may be plotted. The other universal stage axes used are the north-south axis, \( N \), and the east-west axis, \( E \). With these universal stage axes, \( N \), \( E \), and \( I \), the grains are oriented to the desired direction. Each grain is brought successively to the intersection of the cross hair and the optic axis of the quartz grains, or the poles of the cleavage of mica or hornblende as the case may be, are plotted on the lower hemisphere of the equal area net. Thus, more than 200 axes were plotted for each section examined. From the point diagrams thus obtained, contoured diagrams were prepared on the methods outlined by Fairbairn (1949, p.285-290). The pattern of orientation of the axes in the fabric diagram which indicates the kinematics of flow was interpreted. One of the difficulties in universal stage studies is to differentiate uniaxial quartz crystal from the feldspars which are biaxial. The following procedure is adopted to test the uniaxiality or biaxiality of the grain selected and to bring the optic axis of quartz either parallel to the east-west axis of the stage or to the axis of the microscope.

III.b.1 Measurement of (0001) axis of quartz

For a random grain

**Step 1:** With \( K \) and \( N \) axes at zero readings, a quartz grain is brought to extinction by rotation on \( N \) axis. The extinction
is tested by a rotation on \( H \) or \( K \) axis. In one of these rotations the extinction persists, while in biaxial crystals, the extinction will be destroyed in both the axes of rotation. If the extinction persists by rotation on \( H \), it indicates that the east-west axis contains the optic axis. Optic axes of all the quartz grains must be made to lie along east-west plane for the purpose of plotting on the east-west diameter of the projection net.

*Step 2:* The second step is to turn the grain on the \( K \) axis, when the extinction will be destroyed. The extinction is restored by a tilt on \( H \) axis and again tested on rotation on \( K \) till extinction persists. Two positions are possible, either the optic axis is parallel to the east-west cross hair, or to the axis of the microscope. Rotation of microscope stage will reveal which of these positions is correct. If the mineral remains dark when rotated on microscope stage, the optic axis coincides with the axis of microscope; if illuminated, the optic axis is parallel to the east-west cross hair. The tilt on \( H \) reading is recorded and the optic axis is plotted on the equal area net on the horizontal diameter counting the angle from the circumference or the center of projection depending upon whether the optic axis is parallel to the east-west or the microscopic axis respectively.
grain with optic axis parallel to the plane of the section:

Special care was taken for orienting grains whose optic axes lie in the plane of the section. Such grains remain dark on rotation on both $N$ and $K$ axes. Such cases are met with in biaxial crystals also. To know whether the optic axis is parallel to east-west or north-south axis, the grain that is brought to extinction is tested on $K$. If the extinction persists, the optic axis lies on the north-south axis. The grain is then rotated $90^\circ$ on $N$ axis to the alternative extinction position, again tilted on $N$ and tested by rotation on $K$. The extinction will be destroyed. This indicates that the optic axis is parallel to the east-west axis. With zero angle of tilt on $K$, the optic axis is plotted on either end of the east-west diameter of the net. In biaxial crystals also, extinction persists when rotated on $K$ or $N$. But the extinction will be destroyed by rotation on $N$ and tilt on $K$ for each alternative position of extinction.

Sections of grains perpendicular to the optic axis:

Such sections remain dark throughout rotation on $N$ axis. They also remain dark when rotated on $K$ with $N$ at zero and on rotation of $N$ with $K$ at zero. In such cases a point is marked at the center of the projection. In biaxial crystals, the extinction will be destroyed in one of the rotation on $K$ or $N$.

Following this procedure, more than 200 optic axes were plotted for each section examined.
III.b.ii Measurement of (001) cleavages in mica

Flecks of mica are present in quartzite and granitic gneiss, and they are the fabric elements that impart planar fabric to the rocks. Muscovite is present only in quartzite, whereas both muscovite and biotite are present in granitic gneiss. In this study poles of cleavage planes of biotite in gneisses and of muscovite in quartzite are plotted by bringing the visible cleavage planes parallel to the north-south cross hair. As biotite flake shows deep absorption when the cleavage flakes are brought parallel to the vibration direction of the polarizer, which is aligned north-south in the Leitz microscope used for this study, the traces of cleavages become less clearly visible. Hence the polarizer was rotated to bring its vibration direction aligned in the east-west direction so that the cleavage flakes when brought parallel to north-south cross hair show the least absorption and thus bring cleavage traces to a clear visibility. Of course, no such problem arises in the case of muscovite flakes.

Each mica flake was centered, and by rotating on N axis the cleavage traces were brought parallel to north-south cross hair. By tilting on H axis, the cleavage traces were made to stand vertical, that is, parallel to the axis of microscope which is indicated by the sharpest possible definition that the cleavage traces exhibit. The poles of the cleavage plane were plotted on the east-west diameter of the net. More than
200 cleavage flakes were plotted for each section examined following the above procedure.

III.b.iii Measurement of Hornblende Prism

The mineral hornblende is present in gneisses and amphibolites as prismatic grains contributing to both planar and linear fabric to the rock. In section cut perpendicular to b fabric axis, hornblende grains turned up to show their basal planes more or less parallel to the plane of the section. Most of them have rhombus shape with two sets of cleavages parallel to the sides of the rhombus. They are the prismatic cleavages. The poles of these cleavages are plotted, and the intersection of the trace of the planes drawn polar to the points fixes the c axis of hornblende. The pattern of orientation of the c axis of hornblende, which is the long axes of the hornblende prism, is studied in relation to the pattern of orientation presented by quartz axes. c axes for as many grains as possible in the section were measured.

III.e Description of the Petrofabric Diagrams

In the section on field relations and structures, the mesoscopic fabric features have been described commencing from the Central Byrapur block, as this happens to be the most representative portion of the area. This order of representation is not adopted for the microscopic analytical description. As the microscopic analysis is through petrofabric diagrams of only a few selected rock types, it has been
found desirable to present the orientation diagrams related to each rock type in the order commencing from the north of the schist belt to the south at Jambar. This would render possible visualization of the changing patterns of preferred orientation from north to south and, consequently, of the varying stress directions. Similarly, localities and other details concerning these specimens collected for petrofabric analyses and shown in tables 2 to 6 are listed in the order commencing from north to south. Localities of the specimens collected for petrofabric analyses are shown in map 7.

III.c.i Pansamundra Area

III.c.i.1 Fabric of Quartzite

Two distinct bands of quartzite occur and they strike N 60° W and dip 50°-80° towards N 30° E. Sericite and fuchsite are the micas present in quartzite. They are arranged in parallel planes to render the rock schistose. They can as well be described as micaceous quartzite. The quartzites are medium-to fine-grained in texture with grains of quartz of all sizes which are seriate. Micas occur in parallel bands alternating with bands of quartz. Quartz grains are angular with irregular outline, lacking in dimensional orientation. The smaller grains of quartz are seen associated with bands of mica and surrounding larger quartz grains.

Five specimens of quartzite (S.100, 104, 107, 112, and 115) were collected from this block at random spacings representing
both the bands. Figures 26, 28, 30, 32, and 34 are the mica
diagrams for these five specimens. The corresponding quartz
diagrams are shown in figures 27, 29, 31, 33, and 35. Details
of the specimens collected for petrofabric analyses are given
in Table 2.

Table 2

<table>
<thead>
<tr>
<th>Rock</th>
<th>Specimen No.</th>
<th>Mesoscopic element</th>
<th>Dip</th>
<th>Fabric element</th>
<th>Diagram</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Quartzite</td>
<td>S.100</td>
<td>Schistosity 62°-N 45°E</td>
<td>Mica</td>
<td>Fig. 26</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>-do-</td>
<td>-do- 51°-N 40°E</td>
<td>Quartz</td>
<td>27</td>
</tr>
<tr>
<td>2. -do-</td>
<td>S.104</td>
<td>-do-</td>
<td>-do- 51°-N 40°E</td>
<td>Mica</td>
<td>28</td>
</tr>
<tr>
<td>4. -do-</td>
<td>S.112</td>
<td>-do-</td>
<td>-do- 60°-N 50°E</td>
<td>Mica</td>
<td>32</td>
</tr>
<tr>
<td>5. -do-</td>
<td>S.115</td>
<td>-do-</td>
<td>-do- 62°-N 70°E</td>
<td>Mica</td>
<td>34</td>
</tr>
<tr>
<td>7. -do-</td>
<td>S.111</td>
<td>-do-</td>
<td>Vertical</td>
<td>Mica</td>
<td>38</td>
</tr>
<tr>
<td>8. -do-</td>
<td>S.113</td>
<td>-do-</td>
<td></td>
<td>Mica</td>
<td>39</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-do-</td>
<td>-do-</td>
<td>Quartz</td>
<td>41,45</td>
</tr>
<tr>
<td>10. Mica Gneiss</td>
<td>S.102</td>
<td>-do-</td>
<td>-do- 70°-S 53°E</td>
<td>Quartz</td>
<td>43</td>
</tr>
<tr>
<td>11. Amphibolite</td>
<td>S.50</td>
<td>Schistosity 60°-N 30°E</td>
<td>Quartz</td>
<td></td>
<td>67</td>
</tr>
</tbody>
</table>
A well-defined pole diagram with point maximum at \( o \) is characteristic in figures 26, 28, 30, 32, and 34. Transition to \( ac \) girdle is seen in figures 28 and 34.

The quartz diagrams, figures 27 and 33, show diagonal girdle lying in \( h0l \)-plane. In figure 29, two diagonal girdles cross at right angles to form an oblique cross girdle fabric intersecting in \( h \) at the centre of projection. The girdles are broad in all cases, indicating the scatter of the quartz axes in the zones at right angles to the girdle. The maximum in all the diagrams coincides with the \( b \) fabric axis. In figure 33, quartz axes show a scatter and a random preferred orientation. Such departures in the pattern of orientation in a single rock type suggest local discontinuities or to annealing recrystallisation of the tectonite mineral. The random orientation perhaps expresses the imposed structure which is entirely discordant with the mesoscopic fabric and with the quartz fabric shown by different specimens taken from the same band at different parts. The mica diagrams do not match with the quartz diagrams in quartzite. The polar cap at \( o \) for the mica fabric lacking in girdle stands in contrast with the diagonal girdle in the quartz fabric. The heterotactic nature of the fabric is evident here. Since the quartz grains are crushed in the quartzite, the quartz grains must have had their earlier orientation destroyed by later earth movements. From symmetry considerations, quartzites exhibit triclinic symmetry.
III.c.1.3 Fabric of Gneisses

Gneisses often grade into augen gneiss at the contact of the schist belt.

The augen structure in the gneiss, bordering the schist belt in the eastern margin, presents features typical of the classic examples cited by Spy (1909), Gater and Kroushkov (1941), and Cannon (1964). Opinion offered on the origin of augen gneiss follows the familiar lines of their having formed by deformation of granite. The differing opinions are only concerning minor details. Augen gneiss has been described to have been derived from protoclastic of granite rocks. The protoclastic origin visualises a period of mechanical movement which is supposed to interrupt the course of consolidation and granulation of earlier solidified minerals. In such cases, mylonitic matrix and cataclastic texture will be absent. Gater's explanation of augen of feldspar formed by crushing and rolling of feldspar within the foliation plane due to the rising of fluid core with stationary, partially crystallised, low temperature wall rock, is an elaboration of this process of protoclastia. The second view considers the augen gneiss to possibly represent relict structures after igneous porphyritic granite (Hamberg, 1952). The metasomatic origin of feldspar is advocated by others (Turner and Verhoogen, 1960). According to them, feldspars grow as porphyroblasts during metamorphism which usually accompanies tectonic deformation. The augen
gneiss may also develop by metasomatic replacement of minerals within the country rock (alkali metasomatism due to high permeability of sandstone).

One or the other of these origins, or a combination of them, may be applicable to a given specific case. Each case has to be examined from the evidence obtainable in the field, at its geological setting, and from a study of microsections.

The feldspars of augen gneiss of Kuguehalli schist belt, which are distinctly lenticular, are confined to quartz-feldspathic bands. The augen gneiss has concordant contact with the adjoining schist.

Sections were cut from one specimen of augen gneiss (S.99) and four specimens of banded gneiss (S.102, 106, 111, and 113) (Table 2). In augen gneiss, biotite flakes are seen arranged in narrow parallel bands alternating with broad quartz-feldspathic bands. Turned and twisted of biotite flakes around lenticular feldspars are common. Quartz grains are equidimensional but have irregular angular outline indicating the total absence of linear fabric. Biotite flakes have similar planar disposition in the mica gneisses. Almost all the mica diagrams (Figs. 36, 42, 40, 44, 46, and 42) have sharply defined pole maxima which serve accurately to determine the S-planes. The foliation plane determined in the field is shown as plane ab. Generally mica diagrams produce strong pole concentration at a lacking in girdle development. This is due to the mesoscopically
conspicuous tendency for many crystals of micas to be aligned with (001) cleavage parallel to prominent S-surface. Maxima for the poles of (001) cleavages for mica coincide with the pole of prominent macroscopically visible S-surface, which is the c axis of the fabric. It is, however, seen that the maximum falls in an bc girdle. This may indicate the folded nature of the gneisses, or the undulating nature of the S-surfaces, or a tendency for an incipient development of another S-surface (S₂) parallel but inclined to ab plane and partly parallel to bc plane. Similar girdles are also seen for the mica fabric in biotite gneisses, Figures 36 and 38. The mica sub-fabric for the garnetiferous mica gneiss was studied in ac and bc planes, Figures 40, 42, and 44. A partial girdle is observed in the ac section, Figure 44. The girdle has a bulge towards the b axis indicating the possibility of the alignment of mica flakes parallel to the ac plane. Since there is always a chance for mica flake, because of its tabular habit, to lie in the plane of the section or slightly inclined to the plane of section, its pole remains unlocated. Hence it will be worthwhile to examine the mica crystals in different orientations. For this, sections were cut parallel to bc plane. In the non-selective diagram, Figure 43, a bc girdle with maximum at g shows that at least a few flakes lie parallel to the ac plane and to the okl-planes. Another section of the same specimen was cut parallel to g and inclined to b and c, to test the degree of girdle development. There is a possibility of such
sections intersecting all the mica flakes at high angles leaving very little chance for any flake to lie in the plane of the section. The diagram obtained is reproduced in figure 40. Maximum at \( g \), characteristic for mica sub-fabrics, is demonstrative as usual. The \( g \) axis remains unoccupied. A girdle is obtained sub-parallel to the \( bc \) plane, but, however, inclined to all the three planes. The girdle follows the trend of an \( hkl \) plane. It becomes evident from all this, that there has been post-tectonic crystallization of mica crystals along \( S_2 \) surfaces which are inclined to \( S_1 \). In all these diagrams, except in figures 40 and 42, there is lack of coincidence of the kinematic axis, \( g \), with the mica pole maximum, suggesting that mica flakes occupy planes which are sub-parallel to schistose planes. This lack of coincidence is seen in both the \( ac \) and \( bc \) planes for the augen gneiss, figures 40 and 48. This is not a chance departure. This departure is more pronounced in figure 36 where the maximum occupies a position midway between \( g \) and \( e \) in the \( ac \) girdle. This suggests the reorienting influence of \( S_2 \) plane by which the mica flakes, that occupied the schistose plane, \( ab \), have been completely reoriented to a growth in the \( S_2 \) plane, inclined to \( ab \). The pattern of mica subfabrics in the gneisses suggests the growth of mica flakes in more number of \( S \)-planes with a conspicuous tendency to get fixed in the \( S_1 \) plane, which marks the primary foliation in this area and which survives as passive markers even when subjected to later deformation. Orientation of the micas in \( S_2 \)
is a case of post-tectonic crystallisation which has rather inadequately proceeded to completion.

Diagrams for the quartz subfabric prepared show a diverse pattern of orientation and bear no relation to the foliation and schistosity. In the augen gneiss, the smaller grains of quartz associated with larger, angular ones indicate crushing. This crushing might have destroyed any elongation that the quartz grains might have had in an earlier fabric. The crushed grains of quartz are scattered out of position as indicated by the random extinction direction revealed by them. These features are reflected in the augen gneiss by the imperfect girdle, the wide scatter of the quartz axis all over the diagram, and the chance position occupied by the maxima.

Figure 49 is a non-selective diagram of the quartz subfabric for the augen gneiss on ac plane. It is prepared by plotting the optic axis of every grain visible in the field of view. The diagram shows a wide scatter but still has a tendency to form a maximum of 90° midway between a and c but slightly inwards from the perimeter. The position of maximum corresponds to maximum IV of Sander (op cit). According to Sander, maximum IV controls the development of ac girdle along with maxima I and VII. This development is due to grain rotation relative to the fixed strain axes. Here the ac girdle along the perimeter is not seen. But there are two different girdles lying along two great circular arcs inclined towards
each other. This is similar to the one given by Phillips (1945, p.316, Fig. 21). Figure 47 represents the quartz fabric on the bc plane. The maximum here falls at a. The utter lack of coincidence of the quartz fabric in the ac and bc planes is striking and is suggestive of inhomogeneity of the fabric. The circle patterns have no similarity and the maximum in figure 47 occurs in a chance position at a with sub-maxima occupying irrational positions. This lack of similarity of quartz fabric in ac and bc sections taken from the same specimen, is suggestive of the tendency of the quartz grains to have their earlier fabric pattern erased and to occupy new chance positions under the impact of newly applied force. The quartz sub-fabrics of figures 47 and 49 are discordant with reference to foliation and are also in conflict with mica diagrams (Figures 46 and 48) prepared from the same specimen, indicating heterotactic fabric. Though examples are cited by others (Phillips, 1937) of homotactic fabric in which quartz axes and mica pole maximum fall in the same girdle even in rocks subjected to later deformation, such cases are conspicuous by their absence in the augen gneisses of the area. This lack of conformity between mica and quartz fabric may be attributed to the effects of later deformation which is responsible for the development of augen gneisses. One effect of this deformation is to crush the quartz grains and thus destroy the earlier orientated fabric. The effect of crushing is least on the mica fabric, because mica always tends to retain its earlier orientation direction, on account of its
strong dimensional character, even during strong rotational movement. This is evident from the transition of the mica fabric from the well-defined pole diagram to girdle diagram. These movements instead of elongating the quartz in the plane of foliation have disturbed the crushed grains out of their original orientated fabric. The effect of later movement here appears to be the displacement of the earlier fabric of quartz which had perhaps a well-oriented fabric with elongate quartz grains. Phillips draws a distinction between the readiness with which quartz suffers recrystallisation and reluctance with which it undergoes reorientation. This statement is not applicable to the quartz fabric of the augen gneisses. Actually, the effect is the opposite, the crushed grains have reoriented in random direction without suffering recrystallisation.

The quartz subfabric of the mica gneiss, figure 43, adjacent to augen gneiss shows maximum at b, corresponding to maximum VIII of Sander. The quartz axes here lie in the ab plane. In figure 39, which is from another specimen of banded gneiss, the maximum falls on b. But in another specimen of gneiss, figure 37, collected far away from augen gneiss exposures, the maxima are randomly distributed. The quartz axes orientation in the gneisses bears no similarity with each other. There is thus the general lack of homogeneity in the fabric of gneisses from place to place which can be attributed to local strain perturbation. The area of gneisses is composed of bodies
which are heterogeneous in the scale examined. They undergo displacement discontinuities which may be displacements along grain boundaries or along slip surfaces, or to discontinuity due to intense strain along narrow zones.

The garnetiferous gneiss shows a well-marked preferred orientation. The selective diagram, figure 41, measured on bigger quartz grains shows well-defined diagonal girdle parallel to a great circle, hol. It has one maximum and a number of submaxima in the girdle. Figure 45 is a non-selective diagram where the axes fall in the same hol girdle. The submaxima present in figure 41 regroup into a prominent maximum at h. The maximum of figure 41 is eliminated here. The presence of garnet, a mineral higher in the crystalloblastic series, in mica gneiss appears to have had a greater orienting influence on the quartz sub-fabric. This suggests how different types of minerals in a polycrystalline phase tend to produce different orientation patterns to a similar stress history. An obvious inference that emerges from the study of the fabric of the gneisses is that the quartz axes tend to exhibit either preferred or random orientation depending upon the local discontinuities, both crystallographic and non-crystallographic. It is also quite likely that post-tectonic, or annealing crystallization may be one of the factors for the development of an unoriented fabric in most tectonites.
III.c.1.3  Fabric of amphibolite

The quartz subfabric of amphibolite (S.50) was examined. Though 300 optic axes were plotted, the development of the maximum is poor (Fig. 67). There is only one maximum at four per cent level. A number of sub-maxima show a wide scatter. No symmetry relations can be established either, and the fabric is unrelated to the mesoecotic subfabric. Also, the quartz subfabric is totally unrelated to the quartz subfabric in quartzites and augen gneisses.

III.c.1.4  Salient points of the tectonite fabric of Pensamudra

The quartzites have the same strike and dip as the adjoining augen gneiss, and the similarity of the mica fabric of the quartzite with that of the augen gneiss suggests that both were formed by the same stress system. But the same interpretation does not hold good when the quartz diagrams of the quartzites are compared with those of the augen gneiss. The quartz diagrams of quartzites show diagonal girdles which are absent in augen gneiss. The quartz subfabric of quartzite is thus heterotactic with the quartz sub-fabric of the augen gneiss.

Homotactic fabric described by Phillips (1947) for the micaeous quartzose-feldspathic rock of the Moine schists in which quartz and mica diagrams present similar symmetry patterns and the similarity in fabric of quartz and biotite of Stockholm granite and wall rocks described by Loberg (1959) are due to the
simultaneous deformations these rocks have suffered. The bimolar fabric of augen gneiss and quartzites rules out this possibility of simultaneous deformations (Bhuyanrayana and Subbaray, 1976). Quartzite which is of an earlier formation had already been deformed into a schist before augen gneiss, which is of later origin, developed its fabric due to another later period of earth movement. The stress system that developed the fabric of augen gneiss aligned itself in the direction that induced schistosity in the quartzite; and this explains the parallelism of the planar fabric of quartzite and augen gneiss; but this parallelism is absent where their respective quartz subfabrics are examined. This lack of identity is due to the influence of fabric neighbours on each other’s fabric as expounded by Sander (1930, p.150). In the presence of biotite and feldspar in the augen gneiss, the quartz is apt to be much less perfectly oriented, which, in the presence of muscovite alone in the quartzite, gets more perfectly oriented, because of the guidance it receives during its reorientation under the applied force from the already well-oriented fabric position attained by the mica flakes. This also marks the inherited subfabric, that is, the bedding plane remaining passive while the imposed stress on it acting at an angle to the bedding plane influenced the development of quartz fabric in a direction in conformity with the applied forces.
III.c.iii Gobihalli area

III.c.iii.1 Fabric of quartzite

In the regional map (Map 1), a band of quartzite (S.76), which parallels the quartzite of Pencemudra, is shown for west of Gobihalli. It strikes N 20° W and dip 62° towards N 70° E. This has gradational contacts with the gneiss along the dip. Muscovite mica and quartz sub-fabrics prepared for sections cut perpendicular to \( b \) are shown respectively in figures 50 and 51 (Table 3).

Table 3

Details of specimens collected for petrofabric studies — Gobihalli

<table>
<thead>
<tr>
<th>Rock</th>
<th>Specimen No.</th>
<th>Mesoscopic element</th>
<th>Dip.</th>
<th>Fabric element</th>
<th>Diagrams</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Quartzite</td>
<td>S.76</td>
<td>Foliation</td>
<td>62°-N 70°E</td>
<td>Quartz</td>
<td>Fig. 51</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Muscovite</td>
<td></td>
</tr>
<tr>
<td>2. Garnetiferous gneiss</td>
<td>S.110</td>
<td>—do—</td>
<td>45°-S 55°E</td>
<td>Quartz</td>
<td>53</td>
</tr>
<tr>
<td></td>
<td>S.117</td>
<td>—do—</td>
<td>—do—</td>
<td>Diorite</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>54</td>
</tr>
</tbody>
</table>

A split girdle with a strong maximum is characteristic of mica sub-fabric. The dotted line \( ab \) marks the original bedding plane \( S_0=S_1 \) as determined in the field. The maximum
gives another statistical c-plane, \( S_2 \), intersecting \( S_1 \) at 45°. 
\( S_2 \) may be considered to be shear planes (hol) developed at an 
angle of 45° with the direction of the stress acting perpendi-
cular to \( S_1 \). Mica flakes got recrystallised and grew along 
the shear planes, \( S_2 \). Thus annealing crystallisation can not 
only alter the quartz axes orientation but also that of the mica. 
This marks a clear case as to how the shear planes developed in 
a rock have been emphasized by the alignment of the rekrexy-
tallized mica flakes along the shear planes. This manner of 
orientation of mica along shear planes is particularly empha-
sized by Sander (46-50, p.464).

The quartz sub-fabric shown in figure 51, has two girdles 
oblique to each other indicating the \( D \wedge B' \) fabric. This 
indicates a change in the direction of movement from its direction 
in an earlier phase. Both the girdles are oblique to \( S_1 \) and \( S_2 \) 
planes. This serves as an example of a triclinic tectonite 
with \( D \wedge B' = 74^\circ \) which marks the setting up of other coordinate 
axes due to oblique overprinting.

III.c.11.2 Fabric of Gneisses

Garnetiferous gneiss that has gradational contact with 
quartzite is described here. Sections cut perpendicular to \( D \) 
were examined. Mica and quartz sub-fabrics were examined from 
specimen S.116 for the folded gneiss and the respective diagrams 
are shown in figures 52 and 53.
(001) poles of biotite form a broad girdle (Fig. 52) around b with a single maximum and other sub-maxima within the girdle. The axis b appears to be an axis of crumpling. The specimen was collected from a folded zone of the grey banded gneiss and this folded character is revealed by the girdle pattern of the diagram (Fig. 52). This bears resemblance to diagram 53 of Sander. As in Sander's diagram 52, the maximum lies between a and c indicating the control of the hol shear plane, S₂, for the development of the maximum. The girdle can also be visualized as having developed along widely spaced set of shear planes. The un unfolded part of the garnetiferous gneiss (S.117) was also examined, the mica and quartz diagrams of which are shown in Figures 54 and 56 respectively. In figure 54, a broad girdle slightly open at a with a maximum and a few sub-maxima in a girdle resembles figure 52. The girdle is due to the realignment and bending of each mica before a major crumpling could take place. The S₂ drawn perpendicular to the maximum makes an angle of 16° with S₁. This bears resemblance to diagram 57 of Sander.

The quartz diagram (Fig. 53) for the folded gneiss shows an irrational oblique cross girdle with quartz axes showing several maxima. This indicates rotation of quartz axes, or to the presence of number of S-planes. Quartz sub-fabric is completely heterotactic with the mica sub-fabric. The quartz axis has been completely reoriented in different directions. This is a clear case of quartz and micas having responded
differently to the applied force. The cross girdle fabric of quartz resembles the cross girdle fabric of quartzite with which the gneiss has gradational contact. The maximum at 3 is found in both the fabric (Figs. 31 and 50). Statistical S2 planes making an angle with 3 is found in the nica diagram for quartzite and gneiss (Figs. 50 and 51). These common factors suggest that the gneiss must have been derived by the granitization of the quartzite. The fabric of both is due to syntectonic crystallization probably accompanied by sufficient rotation around 3, by which new shear planes developed; and along the new shear planes grow quartz and mica to impart the fabric features now seen in these rocks. Quartz sub-fabric of unfolded gneiss (Fig. 53) shows an indistinct diagonal girdle with maximum at 3. As usual, the quartz sub-fabric is heterotactic with mica sub-fabric (Fig. 54). In having maximum at 3 and a girdle, it bears resemblance to quartz sub-fabric of folded gneiss (Fig. 53). In essence the quartz and mica sub-fabrics of folded gneiss resemble the corresponding fabrics of unfolded gneiss. Slight departure from absolute identity may be attributed to the transition from unfolded to the folded part of the rock.

III.c.iii Ryrapur Area

III.c.iii.1 Fabric of Gneisses

The area included in Ryrapur block has augen gneiss (S.122) in the eastern margin. This augen gneiss is the
comparatively extension of the augen gneiss of \textit{meso}-
block. Details of the specimens collected for petrofabric
analysis are given in Table 4.

Table 4

details of the specimens collected for petrofabric
studies - Tyndur area

<table>
<thead>
<tr>
<th>Rock</th>
<th>Speci-</th>
<th>Textural</th>
<th>No.</th>
<th>Fabric</th>
<th>Diagrams</th>
</tr>
</thead>
<tbody>
<tr>
<td>S.122 Augen gneiss</td>
<td>Foliat</td>
<td>65°-N 45°</td>
<td></td>
<td>quartz</td>
<td>Fig. 57</td>
</tr>
<tr>
<td></td>
<td>ion</td>
<td></td>
<td></td>
<td></td>
<td>Muscovite 56</td>
</tr>
<tr>
<td>S.46 Grey gneiss</td>
<td>Foliat</td>
<td></td>
<td></td>
<td>Folded-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ion</td>
<td></td>
<td></td>
<td>horizontal</td>
<td>quartz</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>axial</td>
<td>Muscovite</td>
</tr>
<tr>
<td>S.121 Pencil gneiss</td>
<td>Lineat</td>
<td>Plunge</td>
<td></td>
<td>10°E</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ion</td>
<td>15°</td>
<td></td>
<td>towards</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Quartz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Muscovite</td>
<td></td>
<td>60, 62</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>66</td>
<td></td>
</tr>
<tr>
<td>S.118 Amphibolite</td>
<td>Foliat</td>
<td>35°-N 45°</td>
<td></td>
<td>Quartz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ion</td>
<td></td>
<td></td>
<td></td>
<td>67</td>
</tr>
<tr>
<td>S.120 Epidosite</td>
<td>Foliat</td>
<td>75°-N 55°</td>
<td></td>
<td>Quartz</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ion</td>
<td></td>
<td></td>
<td></td>
<td>68</td>
</tr>
<tr>
<td>S.11 Lauerite</td>
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<td>Plunge</td>
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<td>20°E</td>
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<tr>
<td></td>
<td>ion</td>
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<td>Quartz</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hornblende</td>
<td></td>
<td>70,71</td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>east</td>
<td></td>
</tr>
</tbody>
</table>

Mica present is muscovite and its fabric is shown in
Fig.56. A typical b-girdle with a number of sub-maxima are
the prominent features of the mica sub-fabric. The only maximum
lies near c along ab plane. The c can be marked at the maximum
itself for there is a possibility of not having cut the section
exactly perpendicular to b. Hence $S_1$ plane parallel to ab is
well-developed here. Submaximum in the girdle indicates the presence of a number of S-planes, but $S_2$, $S_3$, and $S_4$ are more conspicuous. Thus the girdle is due to the presence of a number of S-planes intersecting at $b$. Since the rock is an augen gneiss, the mica flakes might have been rotated or might warp around the augens to produce a girdle fabric. In either case, the gneiss has been subjected to strong deformation to produce a number of intersecting S-planes with local rotations about augens. Quartz sub-fabric shows a diagonal girdle-anelhol girdle-with scattered maxima. This resembles the fabric of gneiss (Fig. 55) of the Gobihalli area. Knots of garnets and feldspar augen appear to have influenced the development of girdle fabric in both, though the two rock types do not occur in the same margins. This means that the geological situation is not the only controlling factor in the development of tectonite fabric, but it is also the individual mineral constituents that make up the fabric of the rock. The quartz sub-fabric is as usual heterotactic with the mica sub-fabric.

The fabric of a granite gneiss (s.48) occurring as xenolith within the talo-chlorite-actinolite schist has been analysed. The granite gneiss exhibits recumbent folding reference to which has been made in page 27 of chapter II 2.a.i. In the section cut perpendicular to $b$ (Fig. 58), an open or split girdle is seen. Majority of the (001) poles subtend an angle of 45° with $g$ fabric axis. $S_2$ thus makes an angle of 45° with $S_4$ as in the case of the mica
diagram for quartzite of figure 56. This again records a case of recrystallization of slate flakes along the shear plane, $S_2$. Another plane, $S_3$, making an angle of 30° with $S_1$ can be visualized from this. The circle with maximum and sub-maximum reflects the folded nature of the slate gneiss.

The quartz axes measured in the same section show irrotational distribution (Fig. 59) with maxima nearer $b$. The quartz sub-fabric is heterotactic with the slate sub-fabric for the xenolithic gneisses.

A xenolithic patch of pencil gneiss (6.132) occurs within talc-chlorite-actinolite schist (Plate V, Fig.2). Long cylindrical fragments of this pencil gneiss are found scattered around the exposure indicating the linear fabric that characterizes this rock. The pencil gneiss is a fine-grained quartzofeldspathic rock of about 30 ft x 10 ft dimension having multiple set of closely spaced coaxial slip planes which dissect the rock to produce long rods and pencils. The axis of intersection of these planes is taken as the fabric axis, which at the same time marks the plunge direction (b-axis) of the pencil gneiss. The pencil gneiss plunges 134° at an angle of 15°.

Microscopic features of sections taken parallel and perpendicular to $b$ emphasize the nature of the slip planes which is the characteristic feature of the fabric of the rock. In section cut parallel to $b$, thin fine-grained layers of crushed and stretched quartz and feldspar are found arranged alternately.
with coarse-grained layers of the same minerals (Plate V, Fig. 3). Streaks of micas are arranged in these layers. However, layers with thin rods of quartz alone along the slip planes are not wanting. Elongation of the grains parallel to \( b \) is very much greater in the fine-grained layers.

Sections cut perpendicular to \( b \) show fine-grained crushed layers of quartz and feldspar criss-crossing, with intervening more or less irregular, circular areas of coarse grains (Plate V, Fig. 4). These equant zones are well-marked by the concentric arrangement of mica, muscovite, and biotite, lying in those zones. Grains of quartz in section perpendicular to \( b \) are equidimensional irrespective of their size. The pencil gneiss of Byrapur thus has all the characteristics of a model pencil gneiss described by Knopf and Ingersen (1939, p. 121). The way in which the traces of the slip planes criss-cross reveals the varying angles of intersection without any symmetrical development of \( S \)-planes about the axis of maximum compressive stress as experimentally demonstrated (Turner and Weiss, 1963, p. 372). This would strongly suggest \( \sigma_1 = \sigma_2 > > \sigma_3 \) i.e. no single axis of maximum stress. In terms of strain \( \varepsilon_1 > \varepsilon_2 = \varepsilon_3 = \varepsilon \), being the maximum strain axis.

The extinction behaviour of quartz arranged in these layers, both in section parallel and perpendicular to \( b \), emphasizes the style of orientation of these slip planes with reference to the plane of the section. In the section cut
perpendicular to \( b \), quartz grains show maximum birefringence
with more or less uniform pale yellow colour of the first order.
Retrofabric diagram prepared for such sections show quartz
axes arranged in the \( ac \) girdle about the \( b \) circle axis indicating
the parallelism of the quartz axes to the \( ac \) plane of the
fabric (Fig. 60). In the section parallel to \( b \), the grains of
quartz are isotropic, or show low order dark grey or grey
interference colour. Narrow, elongate quartz grains lying in
the slip planes are generally isotropic. The slip planes in
the middle of the section have majority of the quartz grains
exhibiting isotropism, whereas the quartz grains in the slip
planes towards the margin of the section show anisotropism with
lower order interference colours. It is clear from this that
the quartz axes lie in the slip planes and perpendicular to \( b \).
It is also clear from this behaviour of quartz that the slip
planes in the middle of the section having majority of the
quartz grains showing isotropism are perpendicular to the plane
of the section and others towards the margin are inclined at
various angles with the plane of the section. The quartz axes
lying in the slip planes form an \( ac \) girdle with \( b \) as girdle
axis (Fig. 62). The maximum at the center of the projection
and the density of the quartz axes about the center is an
indication of the orienting influence of the slip planes on the
alignment of the optic axis of the quartz and the various angles
at which the slip planes intersect the plane of the section
taken parallel to \( b \).
The alignment of the optic axis of quartz in the slip plane cells for a comparison to be made with the slickensided mylonites (Sander, 1930, p.296-291), which have quartz axes similarly arranged in the slip planes. In the shear zones (slip planes) of the Belibaske granite, the quartz grains have their optic axes in the slip planes parallel to the a axes of the fabric in which axis a is regarded as the direction of displacement. The optic axes lying in the slip planes of pencil gneiss of Syrapur suggest the direction of displacement and in turn also fixes the a axis of the fabric at the maximum. Another additional feature observed is that the quartz axis is normal to the elongation suggesting movement along slip planes in a direction normal to the linear structure. Similar findings have been made by Suryanarayana (1971) for a mylonitised quartzite along a fault plane and for two bedded quartzites in both of which the quartz axes are arranged parallel to the a fabric axis and hence parallel to the direction of displacement.

The a-tectonite fabric marked by a distinct ae girdle is due to the intersection of a number of slip planes, each of which can be regarded as an ab plane of the fabric, because quartz axes are arranged in each slip plane perpendicular to b; a lying in the slip plane thus seems apparently to oscillate along the plane of the girdle (Fig.63) indicating the frequently changing position of the a fabric axis - also of a perpendicular to each slip plane - in the ae plane. Compression along a, indicated by the flattening of the grains perpendicular to a,
with movement parallel to $g$ for each slip plane and with the shifting of $g$ and $e$ directions as they continue to lie in the deformation plane $ge$, is the possible movement picture of deformation for this pencil grains. Movement parallel to $h$ indicates rotation of the grains about the axis $h$ due to the movement in the deformation plane $ge$. Straining along $b$ has the effect of producing secondary all planes (invisible in the section) as the $ae$ girdle is partially pulled apart along the great circle $be$ (Fig. 64). Figure 64 is obtained by rotation of Figure 60 about the axis $e$ for producing a plane of projection parallel to $b$. Figure 62 is the diagram prepared by plotting of the quartz axes in the section cut parallel to $b=e$. Figure 62 is similar to Figure 64 in all its essential features that is, in the maximum at $g$ and the $ae$ girdle, but the girdle in Figure 62 is broad as it is prepared by plotting grains of all sizes (non-selective) whereas Figure 60 (rotated to get Figure 63) is prepared by selecting only bigger grains (selective). However, the essential homogeneity of the fabric is indicated by the reproducibility of the fabric pattern of Figure 60 in Figure 62 by actual preparation of the fabric diagram by grain counting in the section parallel to $b=e$. A non-selective diagram for quartz axes orientation in the $ae$ plane is shown in Figure 65. As in selective diagram of Figure 60, this also has maxima about $g$. But the diagram has a more number of maxima and also a number of sub-maxima as contrasted with Figure 60. The unoccupied areas of Figure 60 occur as islands or optic axes
minima. This is to be expected in the case of a non-selective
diagram, but the two diagrams, bring out the departure in steps
as one proceeds from a selective to a non-selective study of
the same fabric element.

Diagrams for mica sub-fabric prepared by plotting the
poles to (001) is shown in figures 61 and 63. In figure 61, the
poles lie in a perfect girdle whose axes coincides with b. The
girdle axis already located from the quartz fabric (Fig. 60) finds
coincidence with the girdle axis for the mica sub-fabric. Since
micas have strong tendencies to be aligned with (001) parallel to
prominent г-surface, despite the fact that they form girdle due
to rotation about b, the maximum generally would mark the position
of the г-axis of the fabric. The г-axis of the fabric has already
been fixed in the quartz diagram to coincide with the quartz
maximum. The study of the mica and quartz sub-fabrics together
has enabled us to fix a and г coordinate fabric axes for the
pencil gneiss for which b axis has been fixed from the mesoscopic
study. Another outcome of this study is the realisation of the
homotactic nature of the quartz and mica sub-fabrics and their
concordance with the mesoscopic sub-fabric, lineation b. Both
quartz (Fig. 60) and mica sub-fabrics (Fig. 61) have гг girdle,
the optic axes maximum of quartz at a being the mica pole
minimum in figure 61, and conversely the mica pole maximum of
figure 61 being the quartz axes minimum in figure 60. The total
symmetry of the fabric is homotactic, monoclinic, or nearly
orthorhombic. The concentration of points in the maximum for.
both quartz and mica (Figs. 60, 61, and 62) is more or less the
same indicating the hemostatic nature of the fabric in the in-
tensity of the development of the maximum. Mica poles were also
plotted on the plane parallel to b, figure 63. While quartz
diagrams on planes parallel and perpendicular to b indicate
homogeneity, the same is not suggested by the mica diagrams for
the same planes. Figure 63 lacks girdle because of the inherent
limitations in the location of the poles to (001). In section
perpendicular to b, the mica flakes wrap round the grains of
quartz and feldspar, and hence the cleavage traces can be easily
recognised by a slight rotation on the horizontal axis of the
universal stage. In the section parallel to b, though mica
lying along the traces of the slip planes show up their cleavage
traces, many also lie parallel to the plane of the section whose
poles as such cannot be measured, but their poles should never-
theless fall at the center of the diagram when an ac girdle as in
figure 64 can be obtained. In figure 63, the diagram lacks
girdle, but what is significant is the bulge of the contoured
area from q towards p indicating the possibility of obtaining an
ac girdle as in figure 61, if consideration is given to the mica
flakes lying in the plane of the section. The maximum in
figure 63 has a concentration of 15% higher than that in figure 61.
This is to be expected, for if flakes lying in the plane of the
section are also accounted for, the percent concentration of
the maximum would be reduced to the level in figure 61. From
this point of view figure 61 is homogeneous with figure 63 for
the fabric of the mica also.

As the pencil gneiss here described is characterized by slip planes with flakes of muscovite mica lying in these planes, the rock can be termed a quartz-feldspathic schist bearing resemblance to Hietanen's portrayal of the fabric features of quartzites and quartz-feldspathic schists (Turner and Verhoeven, 1960, p.545). Really the pencil gneiss here has an ε-tectonite fabric, transitional towards a non-rotational ε-tectonite.

The closely-spaced multiple set of slip planes finds reflected in the micro-fabric analyses. The quartz axes lie in the slip planes, the maximum marking the direction of displacement in the slip planes. This strengthens the findings long ago made by Sander based on the very reliable and unambiguous instance of slipping on slicken-sided surfaces, the quartz grains in these slip surfaces having their axes parallel to the direction of movement which is fixed as the ε fabric axis. In spite of the vagaries and the diverse pattern of orientation exhibited by quartz axes in various rock types, reference to which is replete in every published work on petrofabric, the parallel alignment of [0001] axis of quartz in the direction of displacement (ε of the fabric) seems well-established for rocks having marked S-planes. Per contra, S-planes can be statistically established if visible S-planes are not forthcoming. Further, parallel alignment of the quartz axes in the direction of ε should revive the longheld belief on the part played by the prism face as an
effective glide plane in the orientation of quartz axes in the development of tectonite fabric.

Homogeneity of structure is well-established as the fabric pattern is identical for sections parallel and perpendicular to $\mathbf{b}$ for both quartz and mica sub-fabrics. The fabric is also homotactic for quartz, mica, and mesoscopic lineation. Lineation $\mathbf{b}$ forms the common girdle axis for both mica and quartz axes circles. Monoclinic, or near orthorhombic symmetry, is exhibited by all the sub-fabrics. Though in each diagram $\mathbf{a}$ and $\mathbf{c}$ can be established on the basis of the position occupied by the maximum, they frequently indicate the shifting attitude of $\sigma_1$ and $\sigma_2$ in the deformation plane $\mathbf{a}$ with $\sigma_3$ fixed which would be parallel to the maximum elongation $\epsilon_1$, probably $\mathbf{b}$. Each direction of shifting has its own slip plane perpendicular to it contributing to the development of multiple sets of slip planes. It will be useful to find out if this stress mechanism has had any effect on the development of lenticular bodies of chromite in this area.

It will not be out of place to put forward the view that one single rock type, quartzo-feldspathic rock in this case, having within it all the structural details, can provide a more unequivocal evidence for visualising the mechanism of stress and movement picture than a plethora of complex structural data that would be obtained by a regional study which is more likely to complicate a straightforward interpretation drawn from of a single rock type.
III.c.iii.3 Fabric of Amphibolite

The fabric of amphibolite (S.118) occurring in contact with chlorite-talc-serpentine schist was examined for quartz orientation. Diagram (Fig. 67) shows a perfect broad ac girdle with a single maximum. The fabric has features of rotation tectonites (A-tectonite) with rotation around axis b=0. The amphibolite occurs about 200 ft away from the pencil gneiss. The pencil gneiss (Fig. 61) has also ac girdle for the quartz sub-fabric. It is evident that both amphibolite and pencil gneiss, occupying similar stress fields, owe their fabric to a similar stress system.

III.c.iii.3 Fabric of Epidosite

An exposure of epidosite (S.120) occurs in close contact with amphibolite. In the diagram prepared for the quartz axes orientation (Fig. 66), an indistinct diagonal girdle with maximum near b is revealed. To that extent it has resemblance to quartz sub-fabric of augen gneiss (Fig. 57) of Byrapur, and of quartzite and garnetiferous gneiss of Gobihalli. All these rocks must have developed their orientated fabric in a similar stress field.

III.c.iii.4 Fabric of Eucrite

The fabric of eucrite was examined by studying the C-axis orientation of hornblende. The rock (S.11) consists of hornblende and labradorite-biotinite feldspar. Microscopically, it exhibits
well-defined lineation due to parallel elongate aggregation of prismatic hornblende grains. Section cut perpendicular to linear direction, which is taken as the $b$ fabric axis, contain basal sections of hornblende grains which are rhombus with two sets of cleavages. The longer axes of the rhombus have diverse orientation. The poles of the cleavages therefore form an $ac$ girdle (Fig. 70) with a number of maxima in the girdle. The $c$ axis diagram obtained from the intersection of cleavages in each grain shows clustering of points in a circular area centered at $b$ (Fig. 71). $b$ therefore indicates the axis of rotation, $B$. The girdle here does not indicate any flexure or folding, but rolling and rotation of the hornblende needles around their $c$ axes which coincides with the $B$ axis of rotation. An $R$ tectonite fabric characterises the schistite just as in the case of pencil gneiss.

III.e.iii. 5 Salient points of the tectonite fabric of Gobhilalli and Byrapur areas

The fabric diagrams prepared for the rocks of Gobhilalli and Byrapur have several features in common. The mica diagrams of all the rocks have perfect $ac$ girdle (Figs. 52, 54, 56, 58 and 60). Many show the development of $S_2$ planes and also $S_3$, and $S_4$ of subordinate importance. Mica diagrams present evidence of rotation about $b$ = $B$. The diagrams for quartz orientation generally show a girdle fabric (Figs. 53, 55, 57, 62, 66, and 68). They are either $bc$ girdle or $ac$ girdles.
Though the quartz sub-fabric is heterotactic with the mica sub-fabric, there is homogeneity of fabric for each single fabric element in all the rocks. For example, (001) poles of mica in all the rock types have similar orientation with respect to the fabric axes indicating the essential homogeneity of the fabric. Similarly, quartz axes orientation has similar patterns i.e. a girdle pattern in all the rocks examined.

It will be relevant to point out in this connection that amphibolite, epidote, and ecrite are the constituent rocks of the schist belt. Whereas the gneisses fall outside the schist belt. If the fabric features of all these rock types are similar, then a common stress system must be visualised. All the rocks, whatever may be their mode and time of origin, must have yielded similarly to develop more or less the same internal fabric pattern to a stress acting in a direction perpendicular to $S_1$ or $S_2$. The stress perpendicular to $S_2$, appears to be more intense than the earlier ones.

III.c.iv Tagadur Area

III.c.iv.1 Fabric of Gneisses

The area has gneisses both in the eastern and the western border. The fabric of the gneisses in the eastern border will be discussed first (Table 5).
Table 5

Details of the specimens collected for petrofabric studies - Tagapak

<table>
<thead>
<tr>
<th>Rock</th>
<th>Specimen No.</th>
<th>Polished</th>
<th>Dip</th>
<th>Fabric element</th>
<th>Diagram element</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Augen gneiss</td>
<td>S.133</td>
<td>Foliation</td>
<td>50° S 25° E</td>
<td>Quartz 73, 60</td>
<td>Diorite 72</td>
</tr>
<tr>
<td>2. -do-</td>
<td>S.136</td>
<td>-do-</td>
<td>60° S 30° E</td>
<td>Quartz 75, 62</td>
<td>Diorite 74</td>
</tr>
<tr>
<td>3. -do-</td>
<td>S.23</td>
<td>-do-</td>
<td>65° N 65° E</td>
<td>Quartz 79</td>
<td>Muscovite 76</td>
</tr>
<tr>
<td>4. Grey gneiss</td>
<td>S.134</td>
<td>-do-</td>
<td>50° S 45° E</td>
<td>Quartz 81</td>
<td>Muscovite 80</td>
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<tr>
<td>5. -do-</td>
<td>S.135</td>
<td>-do-</td>
<td>51° S 65° E</td>
<td>Quartz 77</td>
<td>Diorite 70</td>
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<tr>
<td>6. Diorite gneiss</td>
<td>S.142</td>
<td>-do-</td>
<td>50° N 70° E</td>
<td>Quartz 85</td>
<td>Diorite 84</td>
</tr>
<tr>
<td>7. Shin structure</td>
<td>S.21</td>
<td>-do-</td>
<td>90° S 65° E</td>
<td>Quartz 83</td>
<td>Diorite 83</td>
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<tr>
<td>8. Augen gneiss</td>
<td>S.131</td>
<td>-do-</td>
<td>50° N 63° E</td>
<td>Quartz 87</td>
<td>Diorite 86</td>
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<tr>
<td>9. Grey Gneiss</td>
<td>S.130</td>
<td>-do-</td>
<td>60° east</td>
<td>Quartz 89</td>
<td>Diorite 90</td>
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<tr>
<td>10. Dark grey gneiss</td>
<td>S.127</td>
<td>-do-</td>
<td>60° N 50° W</td>
<td>Quartz 91</td>
<td>Diorite 90</td>
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<tr>
<td>11. Light grey gneiss</td>
<td>S.128</td>
<td>Pebble</td>
<td>-</td>
<td>Quartz 92</td>
<td></td>
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<tr>
<td>12. Quartzite</td>
<td>S.57</td>
<td>Foliation</td>
<td>63° east</td>
<td>Quartz 95</td>
<td></td>
</tr>
<tr>
<td>13. Quartzite</td>
<td>S.58</td>
<td>Lineation</td>
<td>Axis plunge 28° eastwards  S 20° W</td>
<td>Quartz 94</td>
<td></td>
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<tr>
<td>14. Amphibolite</td>
<td>S.137</td>
<td>Hornblende lamination</td>
<td>Plunge 50° S 22° W</td>
<td>Quartz 93</td>
<td></td>
</tr>
<tr>
<td>15. -do-</td>
<td>S.51</td>
<td>-do-</td>
<td>60° Plunge 60° towards S 45° E</td>
<td>Hornblende 98, 91</td>
<td></td>
</tr>
<tr>
<td>16. -do-</td>
<td>S.141</td>
<td>Foliation</td>
<td>45° S 60° E</td>
<td>Quartz 97</td>
<td></td>
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The mica diagrams for the augen gneisses (S.133, 136, and 23, Plate VI, Fig.1) are shown in figures 72, 74, and 78, and for the adjoining grey gneisses (S.134, 135 and 143) in figures 80, 76, and 84. All the mica diagrams have a sharply defined pole which serves to determine accurately the S-planes. The foliation plane determined in the field is shown as plane ab. Mica poles in all the diagrams fall in an imperfect girdle. Lack of coincidence of g with pole maximum is seen in figures 72, 80, and 74. The angle between g and pole maximum varies from 5 to 10°. In figure 72, the two maxima on the ag girdle are equidistant from g, both making an angle of 10° with g.

This suggests the presence of two S-planes demarcated in the figure as S₂ and S₃, and intersecting at b=0. The planes S₂ and S₃ are also shown in figure 80. The statistical B axis within the triangle of error won't coincide with the fabric b axis (Fig. 80). This is a clear indication of superposition of S₂ and S₃ planes on S₁, with B lineation making an angle with b to produce triclinicity. In figures 78, 76, and 84, g coincides with pole maximum. In figure 76, plane S₂ is less well-developed than in figure 80. The mica diagram of figure 78 for augen gneiss shows an incomplete ag girdle. This is a coarse-grained augen gneiss occurring in the southern part of Tagadur area. The girdle is more well-developed in the fine-grained augen gneisses (Figs. 72 and 74) of the northern part of the Tagadur area. This suggests that the coarse-grained gneisses have suffered less rolling and rotation. Those to the
north which are fine-grained have been more intensely crushed and rolled to give rise to a girdle fabric.

The quartz axes diagram for augen gneisses is shown in figures 73, 69, 75, 86, 79, and 87. Low quartz axes maxima are seen in all the figures; the preferred orientation is random. However, there are cases where the maxima fall on the S-planes. In figure 75, there are slip planes parallel to the foliation plane. The maximum lying on the slip plane shows orienting influence of the slip plane on the quartz axes (Turner and Verhoogen, 1960). This orienting influence is also evident in figure 73, in which S₂ and S₃ obtained from figure 72 for the mica diagram of the same specimen are shown. The maximum here lies on S₂. However, the two diagrams reveal (Figs. 73 and 75) the irregular fashion in which the maxima appear. These two substantiate the inhomogeneity of the fabric of augen gneiss in two different specimens collected from the same area. The homogeneity of the fabric within a single specimen of an augen gneiss was tested. Figure 69, is the bo diagram of the same specimen from which ao diagram (Fig. 73) is prepared. In figure 69, the maximum falls on S₂ plane as in figure 73. The maximum and sub-maxima occupy similar positions in both figures 69 and 73 to suggest homogeneity.

From the specimen 2,136, quartz axes orientation was tested on ao and bo planes for homogeneity. There is ab girdle in figure 83 (bo plane) with maximum midway between a and b on
an ab girdle. This is not matched in any way on the ac plane (Fig. 75). So inhomogeneity is not uncommon within the same specimen.

The augen gneisses in the southern part of Tagadur area has quartz diagram as shown in figure 79. This has maximum at b. The grey gneisses adjoining the augen gneiss exhibit the quartz sub-fabric as in figures 77, 81, and 85. The maxima in these diagrams occupy irrational positions and bear no relation to the mesoscopic fabric. Not only the quartz orientation is markedly discordant with mesoscopic 9-planes, but even the quartz orientation within itself lacks any symmetry. Hence, the movement picture of direct and indirect componental movements may have been different (Turner and Weiss, 1963, p.370).

Biotite gneisses at portions exhibit a sheet structure (S.21) because of the presence of thin sheets of granular quartz in parallel planes. The quartz fabric diagram shows a bc girdle with maximum at b (Fig. 83). bc girdles develop due to a second strain at right angles to the first with movement occurring in the bc zone. The bc girdles might have been generated by a later strain by which certain number of quartz grains had their optic axes oriented in the bc plane.

The gneisses of the western margin of the Tagadur were examined. Mica pole diagrams generally show incomplete girdle (Figs. 88 and 90), and the lack of coincidence of g with in figures 86 and 88. Figure 86 has an bko girdle for the
mica fabric. The spread of contours along ac fixes b=B as a rotation axis, but the hko girdle should give another oblique axis of rotation, B, which lies on S₂. There is thus evidence of superposition of later strain to produce hko girdle on the earlier one that has given rise to S₁, S₂ planes. In figure 86, the maximum is on the bc plane midway between b and g. The plane S₂ has the same strike as S₁, but is inclined to S₁ at an angle of 40°. The axis of intersection g here is therefore B'. However, plane S₃ intersects S₁ at b. Hence bcB. This also indicates two axes of strain B B' at right angles to each other.

Figure 90, is an ideal diagram of a mica pole maximum showing spheroidal symmetry. The maximum is on the bc plane towards b at 10° from g. As in figure 88, S₂ is parallel to S₁, but inclined to the latter at 10°. Mica pole diagrams of the gneisses of the western margin are dissimilar to those of eastern margin. The stress acting on the western and eastern margins must be different.

The quartz axes orientation, as usual, show a discordant pattern with reference to the mica pole orientations. The quartz sub-fabric is heterotactic with the mica sub-fabric.

Figure 87 for the same specimen as in figure 86, shows maxima and sub-maxima along a great circle close to S-plane. Quartz axes maximum (Fig. 87) is the mica pole minimum (Fig. 86). Similarly in figures 88 and 89 from specimen 9,130, and in figures 90 and 91 for a specimen of a dark grey gneissic
xenolith (S.127), the quartz axes maximum is the mica pole minimum. Such cases are not uncommon (examples). This probably indicates that the quartz axes tend to orient parallel to the S-planes in the gneiss.

As in every other cases, the quartz sub-fabric of the gneisses on the western margin is heterotactic with mica sub-fabric.

III.e.iv.2 Fabric of Quartzite

Figure 95, is the quartz diagram for the quartzite (S.57) which is exposed on the western margin of the block. The figure has a sharply defined, narrow, diagonal girdle in the hol plane. Another notable feature of this diagram is the extension of the quartz axes in a partial girdle along ag at right angles to the main girdle. This has a typical feature of a cross girdle fabric in development. The quartzite shows drag folds at places along its trend. The specimen of the quartzite (S.58) taken at the crest of the fold shows a bo girdle for the quartz sub-fabric (Fig. 94). According to Sander (in Fairbairn, 1949, p.231), the bo girdle develops when b forms a rotation axis and with continuous elongation of strain axis, b. bo here provides an evidence of crossed strain which develops after an initial hol girdle has formed. As both the diagrams (Figures 94 and 95) are from the same specimen, it may even be quite possible that hol girdle of figure 95 is transposed to occupy the bo plane in figure 94 due to a later strain.
The Tagadur quartzite has no mica flakes. Hence its quartz fabric is distinctive from those of Pensamudra quartzite, though there is resemblance in so far as all of them have diagonal girdles.

III.e.iv.3 Fabric of Amphibolites

The amphibolites (S.51, 131, and 147) of Tagadur area were examined for quartz axes orientation (Figs. 93, 96, and 97). The maxima have irrational distribution and have no relation with mesoscopic fabrics. However, the hornblende grains have their $c$ axes falling round $b$ with a spread along the $ab$ plane (Fig.98). The cleavage pole diagram (Fig. 99) shows a sharp $ac$ girdle by which is meant that $c$ axes of hornblende would fall at $b$.

III.e.iv.4 Salient points of the tectonite fabric of Tagadur area

As contrasted with Byrapur area, the mica diagrams of augen gneisses of Tagadur area show an imperfect girdle. For $S_2$, $S_3$ planes (Fig.74), B axis intersection is obtained which is oblique to $p$. In figure 96, there are two B axes making $B\wedge B'$ indicating a later strain $B'$ oblique to $B$. There is also a case where $a=B'$ (Fig.88) such that $B\perp B'$ characterises fabric of the gneisses. The later strain here is completely $90^\circ$ apart from the earlier one. The quartz axes, as in other cases, show a random preferred orientation. This apart, the control of quartz axes orientation by $S$-planes is evident in some part of the gneisses (Figs.73 and 75). Generally, the
quartz axes orientation is inhomogeneous and heterotactic. The quartz axes give a girdle fabric in the quartzite. These girdles are comparable with those in Pensamudra and Gobhahalli areas. In contrast, amphibolite shows a random pattern for quartz axes orientation.

III.c.v Jambur Area

III.c.v.1 Fabric of Augen Gneiss

The mica pole orientation (Fig.100) of the augen gneiss (S.144) of Jambur area which forms the southernmost part of the schist belt, follows the same pattern as those of other areas in having a partial **a** girdle and the maximum subtending a small angle with the **g** fabric axis. The corresponding quartz axes diagram in figure 101 has a random distribution of its maximum and sub-maximum. As in all other cases, the quartz sub-fabric is heterotactic with the mica sub-fabric.

Table 6

<table>
<thead>
<tr>
<th>Rock</th>
<th>Specimen No.</th>
<th>Mesoscopic Element</th>
<th>Dip</th>
<th>Fabric Element</th>
<th>Diagram</th>
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<tr>
<td>Augen gneiss</td>
<td>S.144</td>
<td>Foliation</td>
<td>55°-S 65°E</td>
<td>Mica</td>
<td>100</td>
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<td>Quartz</td>
<td>101</td>
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<td>Amphibolite</td>
<td>S.19</td>
<td>Hornblende</td>
<td>Plunge 61°</td>
<td>Hornblende</td>
<td>102, 103</td>
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<td>(Ragahalli)</td>
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<td>Lamination</td>
<td>towards</td>
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<tr>
<td></td>
<td></td>
<td>(down dip)</td>
<td>N 70° E</td>
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<td>104</td>
</tr>
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</table>
III.c.v.2 Fabric of Amphibolite

The cleavage pole diagram of hornblende in the amphibolite (S.19) has an ac girdle (Fig. 102). The cleavage pole intersection, marking g axis of hornblende falls around b (Fig. 103). This feature characterises the linear fabric in the amphibolite. As a matter of fact, down dip lineation formed by the parallel alignment of the hornblende needles is clearly seen in the amphibolite outcrops. In cases where amphibolites are foliated, the g axis of hornblende spreads along ab plane. Hence, strong lineation and clustering of g axis of hornblende around b fabric axis are indicative of rolling and rotation of hornblende needles due to repeated deformation.

Quartz sub-fabric (Fig. 104) shows well-defined maxima but they occupy random positions. This is again an illustration of the vagaries of quartz axes orientation which does not conform to any fixed pattern as do the micas and hornblende.