SECTION IV. - MICROSCOPIC STRUCTURAL DATA

A. General Statement

The style and orientation of megascopie structures have been stated in Section III. Metamorphism of rock types with particular reference to relation between metamorphism and deformation has been discussed in Section II. In the present Section an attempt has been made to study the lattice orientation of some minerals in the rocks in order to observe the penetrative nature of the movements which affected the rocks. There is no publication so far on the microfabrics of the Delhi System of rocks of the area. In the specimens studied the microfabrics have been considered together with visible megascopie structures (such as - bedding-schistosity, S_1; axial plane cleavage, S_2; lineation, L_2) in order to assess if there is any direct correlation between microfabrics and megascopie structures particularly regarding symmetry of fabric.

B. Selection of rock types for study of lattice orientations of quartz, calcite and micas.

The locations of the specimens used in the microfabric analyses are shown in Map 14. The metamorphosed rocks, which exhibit visible planar and linear structures, have been selected for work. In these recrystallized rocks there is no evidence of survival of clastic grains and texture.
Usually thin sections have been prepared normal to planar and linear structures in the specimens. If no linear structure is visible section has been cut normal to strike of planar structure. For a few specimens two thin sections, which are perpendicular to one another, have been made. This has been done to test homogeneity of fabric. In test cases the fabric diagram obtained in one section has been rotated into the plane of another and compared with the actual fabric obtained in the latter (cf. Knopf and Ingerson, 1938).

For calcite grains orientations of C-axes have been measured. Recent studies on calcite fabric suggest that it is preferable to measure the orientations of C-axes of calcite rather than their twin lamellae because the latter often indicate only the effect of late strain (Turner and Weiss, 1963, pp. 408-413). Much twinned calcites could not be measured. Such grains are few in the sections studied. For quartz and micas, orientations of C-axes and poles to cleavage have been measured respectively.

(1) The Quartz Microfabric in Alwar quartzites

Specimen E.52    Location: Subarea II.

Orientations of C-axes of quartz have been measured from two sections: E.52A which is perpendicular to S₂ and L₂, and E.52B which is perpendicular to E.52A. In the rock
the recrystallized quartz grains are elongated in habit along $S_2$ (Fig. 12a and b). In section E.52A the C-axes are arranged to form a partial peripheral girdle with maxima at high angle to trace of cleavage, $S_2$ and pole to lineation, $L_2$ (Fig. 108a). In section E.52B the main concentrations of C-axes occur away from the periphery although a weak peripheral girdle is present (Fig. 108b). The quartz C-axes fabric is, therefore, not strictly homogeneous. A notable feature is that although quartz is dimensionally elongated along $S_2$ the C-axes are at high angles to elongation.

Specimen C.36(l) Location: subarea XXIV.

The section is at high angle to the prominent bedding-schistosity, $S_1$. The equant quartz grains exhibit sutured or straight margins. A peripheral girdle pattern of C-axes is present (Fig. 108c). The symmetry of the diagram is nearly orthorhombic. The symmetry is retained even when the megascopic schistosity, $S_1$, is plotted on the diagram.

Specimen E.3(l) Location: subarea VII.

The section is at high angle to $S_1$. The quartz grains are equant, recrystallized and disclose slight strained extinction. The rock contains some tourmalines and carbonates. The C-axes are arranged in a partial peripheral girdle (Fig. 108d). The maximum occurs close
to the trace of $S_1$.

(2) The Calcite Microfabric in Kushalgarh crystalline limestones.

**Specimen PKG(0)-1** Location: subarea XXIII.

The specimen shows well-developed cleavage, $S_2$ and cleavage-bedding intersection lineation, $L_2$ (Fig. 72). The section has been cut normal to $S_2$ and $L_2$. It shows two contrasting shapes of calcites. Large porphyroblastic calcites, which are remarkably elongated along $S_2$, occur in a matrix made of fine-grained nearly equant calcites. The C-axes of the elongated calcites are arranged in a peripheral girdle; some form clusters away from the girdle (Fig. 109a). The maxima occur at high angles to the trace of $S_2$ and pole to $L_2$. In order to test whether there is any periodicity in the spatial distribution of measured calcites belonging to different direction groups, axial distribution analysis or A.V.A. (cf. Turner and Weiss, 1963, pp. 376-77) has been performed for this fabric diagram. The results are shown in Figs. 46 and 70. It is seen that grains belonging to different direction groups are nearly uniformly distributed in the domain of the thin section.

**Specimen R.14** Location: subarea VII.

The section is normal to $S_2$. Calcite grains are elongated parallel to $S_2$. The C-axes are arranged in clusters which spread to form a cleft-girdle (Fig. 109b). The maxima
occur at $60^\circ-70^\circ$ to the girdle axis. The symmetry of the diagram is monoclinic.

**Specimen C.25**

Location: subarea VIII.

Sections C.25(2) and C.25(1) are respectively strike and dip of perpendicular $S_2$. The calcites in the rock are elongated along $S_2$. Scapolite grains in the rock define lineation, $L_2$. Calcite C-axes in C.25(2) indicate weakly developed peripheral girdle (Fig. 109d). Girdle pattern is more well defined in C.25(1) as seen in Fig. 109c. However, comparison between fabric in the two mutually perpendicular sections suggests that the fabric is inhomogeneous in this rock.

**Specimen I.6**

Location: subarea XVII.

The specimen shows cleavage, $S_3$ at low angle. Section has been cut at high angle to $S_3$. The cleavage, $S_3$, is defined by recrystallized elongated calcite, quartz and biotite; the bedding-schistosity, $S_1$, is emphasized by mosaic of equant calcite and quartz, and some biotites. The calcites along $S_3$ are coarse grained and those along $S_3$ have been measured (Fig. 109e). A partial peripheral girdle with monoclinic symmetry is observed. The strong C-axis maximum is nearly normal to the cleavage, $S_3$, marked by dimensional parallelism of lensoidal grains; the texture and lattice orientation of these calcites suggest syntectonic crystallization with respect to $S_3$ (cf. Bain, 1940, pp. 11-12).
Specimen KSH/T/2  Location: subarea XXII.

Sections KSH/T/2A and KSH/T/2B have been prepared normal to S₂; the former is perpendicular to direction of strike and the latter perpendicular to direction of dip of S₂. The specimen has been collected from the limb a F₂ fold and S₂ occurs at low angle to compositional banding. Microscopic observations of the thin sections indicate that flattened and elongated calcites as well as quartz and biotite occur along S₂ (Figs. 30 and 31). In section KSH/T/2A the C-axes of calcites define a cleft-girdle (Fig. 109f) and in section KSH/T/2B a partial peripheral girdle (Fig. 109g). The symmetry of the diagrams are monoclinic. In order to test the homogeneity of the fabric the fabric diagram for KSH/T/2A has been rotated to the plane of KSH/T/2B. The rotated diagram (Fig. 109h) suggests partial cleft-girdle pattern and do not resemble the actual fabric (Fig. 109g) obtained for KSH/T/2B. The calcite C-axes fabric in the specimen is, therefore, inhomogeneous. The status of the fabric obtained can only be considered in the domain of the thin section considered.

(3) The Calcite and Quartz Microfabric in Ajabgarh calc-silicate rocks.

Specimen Qtz. Sr. 3  Location: subarea XVI.

The rock is a recrystallized marble and contains ptygmatically folded quartz vein (Fig. 27). The schistosity,
S₂ is parallel to axial plane of ptygmatic folds and it has been deduced from study of the folds that the rock has been strongly compressed normal to schistosity (vide Section III D). The recrystallized calcite grains are notably elongated along S₂ (Figs. 27 and 42). The thin section used for petrofabric analysis has been prepared normal to S₂ and axis of ptygmatic fold. The C-axes of calcites in the marble have been measured in nine different fields (F₁ to F₉) around the vicinity of a ptygmatic fold in the thin section (Fig. 43). The results of measurements are represented in Fig. 110 (a to i). A notable feature is the consistency of the pattern of orientation of the calcite C-axes in the different fields. The C-axes are concentrated in clusters at high angles to the schistosity, S₂. The maxima are either on the periphery or slightly away from it. Two pairs of concentrations are observed in Figs. 110 d, e and g. The symmetry is monoclinic but approaches orthorhombic. In other diagrams, Figs. 110 a, b, c, f, h, i, only one cluster of concentration is notable. The symmetry is monoclinic. In Fig. 110 i the maximum is nearly normal to S₂. The strong C-axis maximum, which is normal to schistosity marked by dimensional parallelism of elongated calcite grains, resembles the pattern reported by Bain (1940, pp. 11-12) and mentioned by Turner and Weiss (1963, pp. 410-411). The nature of the fabric is compatible with the suggestion that the calcites have undergone
syntectonic recrystallization, the C-axes being subparallel to the principal stress (Turner and Weiss, op. cit.). The microfabric of the specimen, therefore, corroborates the conclusion that the rock has been compressed normal to schistosity deduced from a study of pytymatic folds (Section III D).

**Specimen E.15**
Location: subarea I.

The rock is tremolite marble. Calcites are elongated along $S_2$ whereas tremolites and biotites occur across $S_2$. Section E.15(1) is normal to strike of $S_2$ and E.15(4) is at high angle to dip direction of $S_2$. $S_2$ is at low angle to compositional banding.

In E.15(1) calcite C-axes occur in a strong concentration which spreads into partial peripheral girdle (Fig. 111 a) and in E.14(4) the C-axes give partial girdle (Fig. 111 b). Comparison between Figs. 111 a and b indicates that the fabric is inhomogeneous in the specimen. In the domain of section E.15(1) the occurrence of C-axes maximum along trace of $S_2$ is notable.

**Specimen E.18A**
Location: subarea I.

The rock is a siliceous marble (Fig. 39). Schistosity, $S_1$ is parallel to compositional banding. Calcites are few and only C-axes of quartz grains have been measured. The
quartzes are equant in shape. The quartz C-axes define a partial peripheral girdle (Fig. 111 c). Maximum occurs close to trace of $S_2$ and symmetry is monoclinic.

**Specimen C.31** Location: subarea VIII.

The rock is a tremolite marble with flattened and elongated calcites along $S_2$ (Fig. 34). The calcite C-axes occur in a well-defined cleft-girdle (Fig. 111 d). The maxima are on a small circle at $60^\circ - 70^\circ$ to the girdle axis. The symmetry of the diagram is monoclinic.

**Specimen E.37** Location: junction between subareas XVI and XIV.

The rock is a marble. Two sections have been prepared: C.37(1) is perpendicular to strike of $S_2$ and C.37(2) is perpendicular to dip direction of $S_2$. Calcites are lensoidal along $S_2$ (Fig. 35). In C.37(1) calcite C-axes occur in peripheral partial girdle; the symmetry is monoclinic and maximum is close to trace of $S_2$ (Fig. 111 e). In C.37(2) calcite C-axes constitute a weak cleft-girdle (Fig. 111 f). Comparison between the two diagrams suggests that the fabric is inhomogeneous in the specimen.

**Specimen E.14** Location: subarea I.

The rock is a tremolite-schist. Calcite is recrystallized along $S_2$ and tremolite occur as rosettes across $S_2$.  
Quartz is common and slightly flattened or equant in shape (Figs. 9 and 13). Sections E.14(1) and E.14(2) are perpendicular to dip and strike directions of $S_2$ respectively. Only quartz C-axes have been measured.

In E.14(1) the quartz C-axes give peripheral girdle (Fig. 111 g) and in E.14(2) the C-axes are arranged in clusters which spread to form weakly developed cleft-girdle (Fig. 111 h). The results obtained from the two thin sections suggest that the quartz fabric is inhomogeneous in the specimen.

**Specimen E.33**

Location: subarea XVI.

The rock is a marble with $S_2$ at low angle to compositional banding. The calcites are elongated along $S_2$ and exhibit lensoidal shape. Sections E.33(1) and E.33(2) are nearly normal and parallel to $S_2$ respectively.

In E.33(1) the calcite C-axes define a strong maximum which partially spreads into a peripheral girdle (Fig. 111 i). The symmetry is monoclinic and maximum occurs at 25° to the trace of schistosity, $S_2$. In E.33(2) the C-axes of calcites occur in three well defined clusters (Fig. 111 j). The maxima occur at 30°-40° to $S_2$. The attitudes of C-axes forming maxima in both the diagrams are, therefore, nearly consistent with respect to the megascopic schistosity in the rock.
Specimen D.33 Location: subarea XVI.

The rock is a siliceous marble. Elongated calcite and quartz occur along $S_2$ (Fig. 38). Sections D.33(2) and D.33(3) are perpendicular to directions of dip and strike of $S_2$ respectively. In the rock schistosity, $S_2$ is strongly developed and occurs at low angle to compositional banding.

In D.33(2) calcite C-axes define a partial peripheral girdle (Fig. 111 k) and in D.33(3) the C-axes constitute a cleft-girdle (Fig. 111 l). The symmetry is monoclinic, which is reduced to triclinic if the megascopic schistosity is also considered. Rotation of fabric diagram from one plane of section to another suggests that the fabric is not homogeneous if details are critically considered. However, the general girdle pattern is apparently homogeneous in the specimen. This has been verified by rotating one diagram into the plane of another and comparing the same with actual fabric obtained in that plane.

(4) The Mica and Quartz Microfabric in Ajabgarh mica-schists

Strongly developed schistosity and lineation defined by constituent muscovite, biotite and quartz have been observed in these rocks. These megascopic structures are earlier than structures of second generation but their relationship with first generation isoclinal folds is not
known. Hence the 'schistosity' and 'lineation' in the mica-schists have been termed "Structures of Uncertain Age" (vide Section III). The constituent minerals of the rock have suffered post-crystalline deformation because of distortion on $F_2$ puckers. The specimens, BR IIIB and BR IA, have been chosen so that these are free from such post-crystalline deformation. Specimen BR II contains $F_2$ puckers superimposed on schistosity and lineation. For convenience the megascopic structures are noted as 'schistosity' and 'lineation' on the fabric diagrams.

**Specimen BR IIIB**

Location: subarea XIII.

The section has been cut perpendicular to lineation and schistosity. Fig. 112a shows the poles to cleavage of muscovite. The poles constitute a strong maximum normal to schistosity. Fig. 112b shows the poles to cleavage of biotite in the same thin section. A peripheral girdle whose axis coincides with lineation is observed. The maximum in this girdle occurs nearly normal to schistosity. The symmetry of the diagram is monoclinic.

**Specimen BR IA**

Location: subarea XIII.

The section is perpendicular to lineation and schistosity. Poles to cleavage of muscovite form strong concentration (Fig. 112d). The maximum is normal to schistosity.
However, another weak concentration occurs nearly at right angle to the maximum. It suggests another plane normal to schistosity although megascopically no such plane is seen. In the same thin section the poles to cleavage of biotite spread into a partial girdle (Fig. 112c). The axis of the girdle is parallel to lineation. The maximum, although at high angle to schistosity, does not strictly define schistosity.

**Specimen BR II**

*Location: subarea XIII.*

The rock shows $F_2$ puckers at high angle to mineral lineation. Two sections have been prepared. Section BR II (3) is perpendicular to schistosity and lineation. Section BR II(1) is perpendicular to schistosity and $F_2$ pucker axis; it is nearly parallel to mineral lineation. Some micas and quartzes are bent and exhibit strained extinction. The strongly distorted grains have not been measured.

In section BR II(3) measurements have been made on muscovite, quartz and biotite. Fig. 112 e shows poles to cleavage of muscovite. It shows maximum at right angle to schistosity. The quartz $C$-axes are arranged in a partial peripheral girdle with axis parallel to lineation (Fig. 112 f). The symmetry is monoclinic although an approach to orthorhombic is noticed. The poles to cleavage of biotite indicate broken peripheral girdle (Fig. 112 g). The symmetry is monoclinic but approach to orthorhombic is notable.
In section BR II(1) measurements have been made on quartz, biotite and muscovite as in BR II(3). The quartz C-axes indicate a partial peripheral girdle whose axis is parallel to F₂ pucker (Fig. 112 h). Comparison between Figs. 112 h and 112 f suggests that quartz C-axes do not indicate homogeneous fabric in the specimen. Figs. 112 i and j represent plots of poles to cleavages of biotite and muscovite respectively. Both indicate strong concentration at high angle to schistosity. However, maximum in the diagrams are not strictly normal to schistosity. Comparison between Figs. 112 i and 112 g indicates that orientation of biotite is not homogeneous in the specimen.

C. Discussion on the results of Microfabric Analyses.

The lattice orientation of minerals have been studied to assess the extent of penetrative nature of movement and the symmetry of the fabric. A special reason for this attempt is that no publication on this aspect of the Delhi System of rocks in the area is available. The status of microfabric, therefore, needs to be clarified.

The calcites in the Kushalgarh crystalline limestones and Ajabgarh calc-silicates and marbles have proved to be obvious choice because of two reasons. Firstly, calcareous assemblages are common in the area and secondly, the mechanism of orientation of calcite has been studied
by experts experimentally and in natural tectonites (cf. Turner and Weiss, 1963). For caution two mutually perpendicular sections have been studied by the present author. Critically considered, the calcite fabrics in the 'Kushalgarh' and 'Ajabgarh' rocks are inhomogeneous. Only in a few specimens the general pattern appear to be homogeneous although details in the mutually perpendicular sections do not strictly correspond. The status of the fabric can, therefore, be discussed only within the domain of the thin section considered. The details obtained in each thin section has been described previously. The usual symmetry of the diagrams is monoclinic; rarely approach to orthorhombic symmetry has been observed. Most of the sections chosen disclose cleavage, $S_2$ which is dominant throughout the area. The calcites are flattened and elongated in this plane. In some sections these calcites apparently indicate some significant fabric. Strong $C$-axis maximum nearly normal or high angle to $S_2$ has been observed. This orientation, along with texture of the rock, may indicate syntectonic recrystallization and suggest that $C$-axes are subparallel to principal stress. Studies of mutually perpendicular thin sections confirm that $C$-axes are usually at high angle to dimensional elongation of calcites. This observation corroborates the conclusion, which has been derived from megascopic structures, that the rocks have been compressed normal to $S_2$. In a few
diagrams a cleft-girdle pattern of calcite C-axes with maxima on a small circle at 60° to 70° to the girdle axis has been observed. The pattern is consistent with axially symmetric extension parallel to the axis of minimal principal stress. The mechanism of orientation is called 'Einengung' by Sander - radial squeezing within what becomes the symmetry plane of fabric, with extension normal to the symmetry plane (Turner and Weiss, 1963, p. 413). Measurements of C-axes of quartz in Ajabgarh calc-silicates have yielded partial peripheral girdle in selected sections. Critical examination of mutually perpendicular sections has proved that the fabric is inhomogenous and applicable only to the domain of thin section.

In the Alwar quartzites the C-axes of quartz have yielded peripheral girdles. The pattern is shown by equant grains along S1 as well as by elongated grains along S2. Symmetry of the fabric is monoclinic. Critically considered the fabric is not homogeneous although the general girdle pattern is discernable.

In the Ajabgarh mica-schists the microfabric is well developed. The muscovite cleavage poles define the megascopic schistosity. The biotite cleavage poles define the schistosity as well as spread into a peripheral girdle whose axis coincides with mineral lineation. Similar girdle pattern is suggested by quartz C-axes in the same rock.
The symmetry is monoclinic with approach to orthorhombic. The megascopic and lattice fabric are, therefore, homotactic and suggest the penetrative nature of deformation which produced schistosity and lineation in these rocks. In some mica-schists the lattice orientation is distorted due to superposition of $F_2$ puckers on the schistosity and lineation.