CHAPTER V

STRUCTURE OF THE AREA

Introduction:

The area under investigation covers parts of the Krol unit and the autochthonous Siwalik belt. The rocks of the Krol unit have been subjected to moderately intense deformation, as a result of which a number of structural elements have been developed in them. The Siwalik rocks are largely nontectonites except in the vicinity of the major dislocations.

In the present investigations a study of the various structural features developed on a microscopic, mesoscopic, and macroscopic scales (Weiss, 1953) has been made. Statistical studies were to some extent hampered by the difficult terrain and by the fact that the lithological units along the steep slopes are generally displaced because of weathering and local slips. Within these limitations efforts were made to record data at a number of stations uniformly distributed over the entire area.

For structural analysis each formation was roughly separated into eastern and western sectors. The Krol unit was thus divided into 10 sub-areas (K₁ to K₁₀) and the 'sandstone' facies of the Siwaliks into two sub-areas (S₁ & S₂).
Fig:5.1
STRUCTURAL MAP OF
TOTA AM AREA
ALMORA AND NAINITAL
DISTRICTS,
UTTAR PRADESH.
For each sub-area fabric diagrams were constructed for some critical 'S' structures and lineations by plotting orientation data of these elements in the lower hemisphere of Lambert equal area project net. These diagrams are given at the relevant places in the following text.

**Mesoscopic Structures:**

Mesoscopic structures are those structures which can be studied in three dimensions by direct observations. They include features observed in bodies ranging in size from hand specimens to large but continuous exposures (Turner and Weiss, 1963). The mesoscopic structures are here considered under three headings namely, 'S' structures, folds and lineations.

**'S' Structures** - The broad and nongenetic term 'S' surface was recommended by Sanders (1930) for penetrative and parallel planes of mechanical inhomogeneity in deformed rocks. Weiss (1955, p.227) recognised two types of 'S' surfaces, namely,

(a) 'S' surfaces including discrete visible and more or less continuous surfaces like bedding and foliation, and

(b) 'S' planes including features not visible in hand specimens but defined by the preferred orientation of the constituent minerals.
In practice every gradation between 'S' surface and 'S' planes have been observed. Therefore, following Whitten (1966), these planar structures are here grouped under the heading 'S' structures.

These 'S' structures may be primary or secondary in origin and may be due to layering marked by colour, mineralogical and textural changes, preferred orientation of platy minerals, development of fractures along the planes of weakness etc.

The different 'S' structures observed in the area under study are bedding (S₀), continuous cleavage (S₁), crenulation cleavage (S₂), fracture cleavage (S₃) and joints (S₄).

Bedding (S₀) - Bedding is a general term used here to describe the layering of sedimentary origin observed in the different kind of rocks. In the rocks of the Krol unit it is marked by the variation in the grain size, colour or lithology of the rocks. Primary bedded structures such as cross bedding, graded bedding, lenticular bedding etc are often seen and these have been described earlier with the geological setting (Chapter II). In the Krol metasediments bedding is generally found to be parallel to the continuous cleavage described below, except at fold closures, where the two intersect at high angles. Both normal and reverse graded bedding is noted in the Krol quartzites and this indicates that individual beds are isoclinally folded.
In the Siwalik sediments bedding is the most important 'S' structure. Reversal in the dip of bedding is observed in the Kumaria-Garjia and Okaldhunga-Garjia mule paths, indicating folding of the Siwalik sediments. A statistical study of sedimentary bedding ($S_0$) in the Siwalik sediments has been carried out. The fabric diagrams for the sub-areas $S_1$ and $S_2$ are given in Figs. 5.2a & b. The salient features of these diagrams are summarised in Table 5.1. The fabric diagrams for sub-areas $S_1$ and $S_2$ exhibit a triclinic symmetry pattern in which two partially developed girdles are clearly demarcated. Corresponding to these two girdles two \( \overline{\tau} \) axes are recognised in each sub-area. In sub-area $S_1$ the $\overline{\tau}_1$ axis plunges in the WNW direction and $\overline{\tau}_2$ axis plunges towards ENE. In the sub-area $S_2$, $\overline{\tau}_1$ axis plunges in E3R direction while $\overline{\tau}_2$ axis plunges towards N. It is seen that in both sub-areas $\overline{\tau}_2$ axes plunge in nearly the same direction while, $\overline{\tau}_1$ axes plunge in approximately opposite directions.

**Continuous cleavage** ($S_1$) : Following Dennis (1967, p.19) the term continuous cleavage is adopted for 'S' structures resulting from the continuous parallelism of platy minerals throughout a rock. It includes both slaty cleavage and schistosity. As mentioned earlier, $S_1$ is parallel or sub-parallel to $S_0$ except at fold closures. In the quartzites bedding joints are parallel to the continuous cleavage of interlayered pelitic sediments. Hence in
Fig. 5.2: Fabric diagrams showing orientation of So in Siwaliks
<table>
<thead>
<tr>
<th>Fig. no.</th>
<th>Sub-area no.</th>
<th>Number of $S_0$ readings</th>
<th>Contour intervals</th>
<th>Symmetry</th>
<th>Orientation of $T_1$</th>
<th>Orientation of $T_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.2a</td>
<td>11</td>
<td>125</td>
<td>0.80, 2.40, 4.00, 5.60 &amp; 7.20%</td>
<td>Triclinic</td>
<td>48°/N285°</td>
<td>52°/N25°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>per 1% area</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.2b</td>
<td>12</td>
<td>82</td>
<td>1.22, 3.66, 6.10, 8.54 and 10.98%</td>
<td>Triclinic</td>
<td>67°/N110°</td>
<td>50°/N345°</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>per 1% area</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
the statistical studies the orientation of these bedding joints have been grouped with \( S_1 \) measurements. There is considerable variation in the orientation of the continuous cleavage. Fabric diagrams for the different sub-areas \( K_1 \) to \( K_{10} \) are given in Fig. 5.3a - j, combined diagrams for domains \( K_1, K_2 \) and \( K_5, K_6 \) are given in Fig. 5.3 k and l. The important features of these diagrams are summarised in Table 5.2.

It is observed from the fabric diagrams that in sub-areas \( K_1, K_2, K_7 \) and \( K_9 \) the symmetry pattern is highly distorted monoclinic to triclinic. In each case there is a clearly defined \( S_1 \) girdle, while vestiges of a second girdle are also seen. \( \Pi_1 \) axis trends approximately NW-SE in all four sub-areas. In sub-areas \( K_1 \) and \( K_7 \) it plunges at low angles towards NW and in sub-areas \( K_2 \) and \( K_9 \) towards SE. In sub-areas \( K_3 \) and \( K_5 \) the symmetry is monoclinic with a less clearly defined \( S_1 \) girdle and the corresponding \( \Pi_1 \) axes plunging NW at about 20°. In sub-areas \( K_4, K_6, K_8 \) and \( K_{10} \) the \( S_1 \) pole distributions do not yield a girdle pattern. The nearly axial symmetry suggests that in these sub-areas \( S_1 \) dips uniformly in the N to NE directions.

**Crenulation cleavage (\( S_2 \))** - The term crenulation cleavage was introduced by Rickard (1961, p. 325) for "cleavage planes, whether micaceous layers or sharp breaks, which are separated by thin slices of rock containing a crenulated cross lamination". This term is preferred to its
Fig. 5.3: Fabric diagrams showing orientation of $S_1$ (contoured), $mF_1$ (crosses), and $mF_2$ (dots) in the Krol Unit.
Fig. 5.3: Fabric diagrams showing orientation of $S_1$ (contoured), $mF_1$ (crosses), and $mF_2$ (dots) in the Krol Unit.
Table 5.2: Details of \( L_2, L_3 \) and \( T \mid S_1 \) diagrams of Krol unit.

<table>
<thead>
<tr>
<th>Fig. No.</th>
<th>Sub-area No.</th>
<th>Number of ( L_2 ) readings</th>
<th>Number of ( L_3 ) readings</th>
<th>Number of ( S_1 ) readings</th>
<th>Contour intervals</th>
<th>Symmetry</th>
<th>Orientation of ( T \mid 1 )</th>
<th>Orientation of ( T \mid 2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.3a</td>
<td>1</td>
<td>3</td>
<td>23</td>
<td>78</td>
<td>( S_1: 1.27, 3.71, 6.35, 8.89 ) and 11.43% per 1% area.</td>
<td>Tri-clinic</td>
<td>20°/N310°</td>
<td>76°/N55°</td>
</tr>
<tr>
<td>5.3b</td>
<td>2</td>
<td>13</td>
<td>62</td>
<td>85</td>
<td>( S_1: 1.17, 3.51, 5.85, 8.19 ) and 10.53% per 1% area.</td>
<td>Tri-clinic</td>
<td>12°/N134°</td>
<td>70°/N42°</td>
</tr>
<tr>
<td>5.3c</td>
<td>3</td>
<td>7</td>
<td>17</td>
<td>34</td>
<td>( S_1: 2.94, 5.98, 8.82 ) and 11.76% per 1% area.</td>
<td>Mono-clinic</td>
<td>18°/N325°</td>
<td>-</td>
</tr>
<tr>
<td>5.3d</td>
<td>4</td>
<td>4</td>
<td>14</td>
<td>36</td>
<td>( S_1: 2.80, 5.60, 8.40, 11 ) Axial 11.20 &amp; 14.00% per 1% area.</td>
<td>Axial</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5.3e</td>
<td>5</td>
<td>8</td>
<td>21</td>
<td>71</td>
<td>( S_1: 1.40, 4.20, 7.00 ) and 9.28% per 1% area.</td>
<td>Mono-clinic</td>
<td>20°/N320°</td>
<td>-</td>
</tr>
<tr>
<td>5.3f</td>
<td>6</td>
<td>3</td>
<td>12</td>
<td>32</td>
<td>( S_1: 3.10, 6.20, 9.30 ) and 12.40% per 1% area.</td>
<td>Axial</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

(continued)
Table 5.2 (contd.) : Details of L₂, L₃ and \( \Pi \Sigma \), diagrams of Krol unit

<table>
<thead>
<tr>
<th>Fig. Subarea No.</th>
<th>Number of L₂ readings</th>
<th>Number of L₃ readings</th>
<th>Number of S₁ readings</th>
<th>Contour intervals</th>
<th>Symmetry</th>
<th>Orientation of ( \Pi \Sigma )</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.3g</td>
<td>7</td>
<td>6</td>
<td>3</td>
<td>85</td>
<td>S₁ : 1.17, 3.51, 5.85, 8.19 &amp; 10.53% per 1% area</td>
<td>Triclinic</td>
</tr>
<tr>
<td>5.3h</td>
<td>8</td>
<td>8</td>
<td>-</td>
<td>90</td>
<td>S₁ : 1.11, 3.33, 5.55, 7.77, &amp; 9.99% per 1% area</td>
<td>Axial</td>
</tr>
<tr>
<td>5.3i</td>
<td>9</td>
<td>4</td>
<td>7</td>
<td>75</td>
<td>S₁ : 1.33, 3.99, 6.66 &amp; 9.33% per 1% area</td>
<td>Triclinic</td>
</tr>
<tr>
<td>5.3j</td>
<td>10</td>
<td>6</td>
<td>15</td>
<td>80</td>
<td>S₁ : 1.25, 3.75, 6.25, 8.75 &amp; 11.25% per 1% area</td>
<td>-</td>
</tr>
<tr>
<td>5.3k combined</td>
<td>1 &amp; 2</td>
<td>85</td>
<td>163</td>
<td>( S₁ : 1.22, 3.66, 6.10 ) &amp; 8.54% per 1% area</td>
<td>Triclinic</td>
<td>( 10°/N132°, 74°/N46° )</td>
</tr>
<tr>
<td>5.3l combined</td>
<td>5 &amp; 6</td>
<td>32</td>
<td>103</td>
<td>( L₃ : 3.10, 6.20, 9.30 ) &amp; 12.40% per 1% area</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>
synonym: 'strain-slip cleavage' because the latter has a genetic implication. The crenulation cleavage is best seen in phyllitic rocks of the Dewael and Manila formations. It is generally developed parallel to the axial planes of the small scale folds described later.

As the crenulation cleavage is rather sporadically developed it has not been considered in the systematic analysis given later.

Fracture cleavage ($S_3$) - Following Billings (1954, p.339) and Whitten (1966, p.260) the term fracture cleavage is used here for close spaced jointings of non-penetrative nature. It is generally developed parallel to the axial planes of the mesoscopic folds in quartzitic rocks.

Joints ($S_4$) - Joints are ubiquitously developed in the area. They are best seen in the quartzitic rocks. The bedding joints are the most prominent. However, highly dipping joints are also well developed. The latter are frequently slickensided and in some cases show plumose markings. In the vicinity of the major dislocations there is the presence of quartz veins along the joint planes (Pl.2.2, Ph.2). The orientation of the strikes of joint sets in the different sub-areas is illustrated in Fig.5.4a by means of strike frequency diagrams. The number of joints recorded in each sub-area is given below each joint rosette.
Fig: 5.4a
STRIKE FREQUENCY DIAGRAMS FOR JOINTS IN TOTA AM AREA ALMORA AND NAINITAL DISTRICTS, UTTAR PRADESH
Fig. 5.4b: Fabric diagrams showing orientation of joints ($S_4$) in Krol unit (a), Siwaliks (b).
The orientation of joints recorded in the Krol unit and the Siwaliks have been plotted on equal area nets to give the fabric diagrams of Fig. 5.4b. These diagrams suggest that the major joint sets in these two units are as follows:

Krol unit:
1) Strike N 130°; Dip N 40° amount 40°
2) Strike N 195°; Dip N 105° amount 75°
3) Strike N 225°; Dip N 315° amount 80°

Siwaliks:
1) Strike N 140°; Dip N 50° amount 45°
2) Strike N 185°; Dip N 95° amount 85°
3) Strike N 210°; Dip N 300° amount 70°.

From these diagrams it is apparent that the most prominent joint set is the bedding joint. The oblique joints occur in conjugate pairs, in all sub-areas except in sub-areas K1 and K4, where only one set is developed. The dihedral angle between the conjugate joint sets is indicated above each rosette. In the case of sub-areas K1 and K4, the angle between the joint set and the perpendicular to bedding joint has been doubled to give the dihedral angles. The dihedral angle seen to vary from nearly zero to sixty degrees.

As is detailed later the orientation of the Krol thrust front and the macroscopic fold axis is NW-SE. This suggests that in the area under study the principal stress axis was oriented NE-SW. It is generally accepted that shear
fractures make an angle of $30^\circ$ with the principal stress direction and are commonly slicken-sli^sken-sliced (Badgley, 1965, p.101). Extension fractures (Griggs and Handin, 1960, p.348) on the other hand are oriented parallel to the principal stress direction. It is thus apparent that most of the highly dipping joint sets are of shear origin. The low dihedral angle between conjugate joint sets noted in some sub-areas is of interest. Such conjugate joints with low dihedral angle have been noted previously by Parker (1942), Spencer (1959) and Muhlberger (1961). There is some difference of opinion as to whether they are of shear or extensional origin. Muhlberger has mathematically analysed diagonal fractures with small dihedral angles and has concluded that they are transitional in nature between extension and shear fractures. This transitional nature is substantiated in cases, like the present, where plumose markings are also developed. The available data thus suggests a shear to transitional origin for the joints of the area under review.

Muhlberger (1961) suggests that the region in which the dihedral angle is smallest is the one, where stress redistribution was greatest before rupture and it also must be the region where rupture first occurred. The occurrence of small dihedral angles in the sub-areas adjacent to the NW-SE trending dislocations supports this conclusion.
Folds - In the area under study the rocks of the Krol belt exhibit mesoscopic folds of three generations.

1) inclined to recumbent folds on $S_0$ ($mF_1$),
2) small scale folds on $S_1$ ($mF_2$),
3) open folds resulting from the warping of the axial planes of $mF_1$ ($mF_3$).

The inclined to recumbent folds of the first generation vary considerably in size; the folds in quartzites being generally larger than those in the pelitic rocks. While, the larger folds are of the inclined type, the smaller ones tend to be recumbent. The folds in the quartzites are generally of the similar type. They range in wave length upto as much as 40 feet. The folds in the pelitic rocks are comparatively smaller and often show a certain amount of flowage. It is observed that the continuous cleavage ($S_1$), when developed, is more or less parallel to the original bedding ($S_0$) except at fold closures. The folds of this type are especially well developed in the Tota Am formation along the Ramganga river, near Deokhand, and north of Tota Am. Their style is shown in Fig.5.5.a–c.

The small scale folds resulting from the bending of the continuous cleavage ($S_1$) are particularly well developed in the pelitic rocks. They usually range in size from a millimeter to ten centimeters or more with the amplitude being upto four centimeters. Somewhat larger folds are sometimes seen. Within this type are included the minor
Fig. 5.5: Style of mesoscopic folds (mF₁)
Fig. 5.6: Style of mesoscopic folds (mF$_2$)
Crenulations or puckers which are commonly observed to be superimposed on the continuous cleavage. The style of different folds observed in these pelitic rocks is illustrated in Fig. 5.6 a-d. The folds are seen to vary in form from isoclinal to open with the hinges being rounded to angular. The folds are usually of the parallel type. In the larger folds reverse folding is sometimes observed. In a few folds some layers show thickening of the hinges and attenuation of the limbs. Crenulation cleavage is frequently developed parallel to the axial planes of the folds. The folds in the slates of the Sair formation are usually of the chevron type, with angular hinges and straight limbs and with well developed cleavage parallel to the axial planes of the folds (Pl. 5.1, Ph. 1).

The mesoscopic folds of the third generation ($mF_3$) are largely open in form and are developed due to the warping of the axial planes of $mF_1$. They are particularly well seen in the pelitic rocks of the Sair formation, near Sair and east of Chkimtakhal (Fig. 5.5 e).

**Lineations** - In the present study, following Cloos (1946), the term lineation is used as a nongenetic and descriptive term for all types of linear elements in a rock. The important types recognised in the rocks of the Krol belt are:
$L_1$ : intersection of $S_0$ and $S_1$,

$L_2$ : axes of larger mesoscopic folds ($mF_1$) on $S_0$.

$L_3$ : axes of small scale folds ($mF_2$) on $S_1$.

$L_4$ : intersection of $S_1$ and $S_2$.

$L_5$ : mineral lineation.

$L_6$ : Grooves and striae on slicken-sides.

**Lineation due to intersection of $S_0$ and $S_1$ ($L_1$)** - This type of lineation is not frequently observed because in general $S_0$ and $S_1$ tend to be parallel. Wherever this lineation is developed it is seen to be more or less parallel to the fold axes of associated mesoscopic folds of the first generation. A systematic study of this linear element has not been made.

**Axes of larger mesoscopic folds ($mF_1$) on $S_0$ ($L_2$)** - The orientation of this linear element in different parts of the area studied is shown in the structural map (Fig.5.1). It is observed that the general trend of the fold axes is in an approximate NW-SE direction. The orientation data for $mF_1$ fold axes is indicated in the fabric diagrams Fig.5.3 a-j by means of a cross. In view of the small number of readings available for each sub-area the plots have not been contoured. Plunge at low angles between $0^\circ$ and $25^\circ$ towards NW or SE are recorded.

**Axes of small scale folds ($mF_2$) on $S_1$ ($L_3$)** - As stated earlier the small scale folds are developed largely in the pelitic rocks. In many cases two sets of $L_3$ are present and
these intersects at an angle of 15° to 30°. The attitudes of the fold axes are shown in the structural map (Fig. 5.1), and in the fabric diagrams (Fig. 5.3). In the latter the plots are indicated by small dots. The plots of the sub-areas within the Manila and Dewael formations have been combined in Fig. 5.3 k and 5.3 l respectively. The concentration is indicated by broken contours.

In general it is observed that the orientation of L₃ is more or less identical to that of L₂. The fold axes trend with plunge in both NW and SE directions. The maxima for L₃ is seen to correspond with T₄₁.

Intersection of S₁ and S₂ (L₄) - In the pelitic rocks showing the development of (mF₂) folds the intersection of S₁ and S₂ is marked by indistinct fracture traces of the folded S₁ surfaces. These traces are parallel to L₃.

Mineral lineation (L₅) - This type of lineation is observed in the micaceous quartzites especially those of the Paisiya formation. It is marked by the unidirectional orientation of flakes of mica and iron oxides. This lineation trend is in an approximate NE-SW direction.

Grooves and striae on slickensides (L₆) - Grooves and striae are often well developed on slickensided, highly dipping and NNE-SSW trending joint surfaces. They are especially abundant in the vicinity of the N-S trending faults along the Patlion and Nair gadheras.
Microscopic Structures:

In order to determine the symmetry of fabric on microscopic scale and to secure information which may not have been reflected in the mesoscopic fabric, a study of the orientation of $\gamma$ axes of quartz grains in quartzites, quartzose phyllites and sandstones was made. The orientation of (0001) axes of quartz were recorded on the universal stage following the procedure outlined by Sanders (1970, p.243-245). For this purpose thin sections were prepared from slices cut perpendicular to the foliation and lineation (where present) of the oriented specimens and in a few cases parallel to the lineation. In each slide 300 $\gamma$ axes orientation were recorded. In the case of grains showing undulatory extinction the mean orientation of (0001) was recorded. The results of these studies are presented in this section. The location of the specimen chosen for microfabric studies is shown in the structural map (Fig.5.1).

Grain orientation in quartzites - Six specimens of quartzites, three each from the Tota Am and Paisiya formations, were selected for petrofabric studies. Of these one specimen was from near the N-S trending fault traced along the Nair gadhera. The fabric diagrams for the quartzites specimens are given in Fig.5.7 a-f, and the details of the fabric data are tabulated in Table 5.3. Except for the specimen from near the Nair fault, the symmetry of the fabric is nearly orthorhombic with a characteristic cross girdle.
Fig. 5.7: Fabric diagrams showing orientation of C-axes of Quartz grains in Quartzites.
Table 5.3: Details of the petrofabric diagrams of Tota Am and Paisiya quartzites from the Krol unit.

<table>
<thead>
<tr>
<th>Fig. No.</th>
<th>Formation</th>
<th>Location</th>
<th>Orientation of section</th>
<th>No. of grains</th>
<th>Contour intervals</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.7a</td>
<td>Tota Am</td>
<td>near Shavanikhal</td>
<td>bc</td>
<td>300</td>
<td>1,3,5 &amp; 7% per 1% area</td>
<td>A cross girdle pattern with maxima of 7% near centre. A near orthorhombic symmetry.</td>
</tr>
<tr>
<td>5.7b</td>
<td>Tota Am</td>
<td>1/ mile SW of Deokhand</td>
<td>ac</td>
<td>300</td>
<td>1,3,5 &amp; 7% per 1% area</td>
<td>A cross girdle pattern with maxima of 7% near periphery. Four sub-maxima of 5% on the cross girdles. A near orthorhombic.</td>
</tr>
<tr>
<td>5.7c</td>
<td>Tptta Am</td>
<td>1 mile S of Tusrani</td>
<td>ac</td>
<td>300</td>
<td>1,3,5 &amp; 7% per 1% area</td>
<td>Cross girdles with four maxima of 7%. Comparatively more axes free area. A near orthorhombic symmetry.</td>
</tr>
<tr>
<td>5.7d</td>
<td>near Paisiya</td>
<td>near Dhanasuri</td>
<td>ac</td>
<td>300</td>
<td>1,3,5 &amp; 7% per 1% area</td>
<td>A cross girdle pattern with a maxima of 7% near periphery. Five sub-maxima of 5% on the cross girdles. A near orthorhombic symmetry.</td>
</tr>
<tr>
<td>5.7e</td>
<td>Paisiya</td>
<td>1 mile SW of Kaligaon</td>
<td>ac</td>
<td>300</td>
<td>1,3,5 &amp; 7% per 1% area</td>
<td>Single or split maxima of 7% with cross girdles. Two additional maxima of 7%, one on the girdle and other on periphery. A near orthorhombic symmetry.</td>
</tr>
<tr>
<td>5.7f</td>
<td>Paisiya</td>
<td>near Dhabara</td>
<td>ac</td>
<td>300</td>
<td>1,3,5 &amp; 7% per 1% area</td>
<td>A near monoclinic symmetry with a single girdle.</td>
</tr>
</tbody>
</table>
pattern (Fig. 5.7 a-e). In the case of the specimens from near the Nair fault a monoclinic symmetry is observed (Fig. 5.7 f).

Grain orientation in quartzose phyllites - Two specimens of quartzose phyllite from the Manila formation showing small scale folds were selected for petrofabric analysis. For this purpose thin sections were prepared from the slices cut perpendicular to the fold axes. Of the two folds one is an open and the other appressed. These folds are here designated as Fold 1 and Fold 2. Fold 1 is a gently folded syncline. The siliceous layers in it are made up of medium sized quartz elongated parallel to the axial plane; especially in the hinge portion of the fold. The mica rich layers are made up dominantly of coarse and continuously bent mica flakes. Finer mica flakes mark a well developed axial plane cleavage. Fold 2 is an angular and closely appressed anticline. The siliceous layer within it shows considerable variation in grain size. The other characteristics are similar to those in Fold 1.

For petrofabric analysis each fold was subdivided into three domains as shown in Figs. 5.8 and 5.9. For each domain $c$ axes orientation of about 100 quartz grains were measured and petrofabric diagrams were prepared. The petrofabric diagrams for Fold 1 and 2 are given in Figs. 5.8 and 5.9 respectively and the details of fabric data are summarised in Table 5.4. It is seen that all the diagrams show a concentration of $c$ axes in a small circle around $b$. 
Fig. 5.8: Orientation of c axes of quartz grains in fold 1
Fig. 5.9: Orientation of $c$ axes of quartz grains in fold 2
<table>
<thead>
<tr>
<th>Fig. No.</th>
<th>Sector</th>
<th>No. of grains</th>
<th>Contour interval</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 a</td>
<td>A</td>
<td>120</td>
<td>0.83, 2.50, 4.17 and 5.83% per 1% area.</td>
<td>Small circle of concentration around b with maxima of 5.83% coinciding with b; two other sub-maxima 4.17% within the circle. Monoclinic symmetry.</td>
</tr>
<tr>
<td>3 b</td>
<td>B</td>
<td>130</td>
<td>0.77, 2.23, 3.86 and 5.40% per 1% area.</td>
<td>Pattern same as above. Maxima of 5.40% coinciding with b and three sub-maxima of 3.86% nearly peripheral ac girdle. Distorted monoclinic symmetry.</td>
</tr>
<tr>
<td>3 c</td>
<td>C</td>
<td>100</td>
<td>1, 3, 5 &amp; 7% per 1% area.</td>
<td>Pattern same as above. Maxima of 7% coinciding with b. Sub-maxima of 5% on ac girdle. Near monoclinic symmetry.</td>
</tr>
<tr>
<td>3 d</td>
<td>combined</td>
<td>350</td>
<td>0.86%, 2.57, 4.30 and 6.0% per 1% area.</td>
<td>Pattern same as above. Maxima of 6% coinciding with b. Distorted monoclinic symmetry.</td>
</tr>
<tr>
<td>4 a</td>
<td>A</td>
<td>100</td>
<td>1, 3, 5, 7 and 9% per 1% area.</td>
<td>Pattern same as above. Maxima of 9.00% coinciding with b. Sub-maxima of 5% on ac girdle. Distorted orthorhombic symmetry.</td>
</tr>
<tr>
<td>4 b</td>
<td>B</td>
<td>110</td>
<td>0.99, 2.73, 4.54, 6.36 &amp; 8.20% per 1% area.</td>
<td>Pattern same as above. Maxima of 8.20% coinciding with b. Distorted orthorhombic symmetry.</td>
</tr>
<tr>
<td>4 c</td>
<td>C</td>
<td>100</td>
<td>1, 3, 5 and 7% per 1% area.</td>
<td>Pattern same as above. Maxima of 7% coinciding with b. Sub-maxima of 5% near it. Three sub-maxima of 5% on ac girdle. Monoclinic symmetry.</td>
</tr>
<tr>
<td>4 d</td>
<td>combined</td>
<td>310</td>
<td>0.97, 2.91, 4.83, 6.77 and 8.71% per 1% area.</td>
<td>Pattern same as above. Maxima of 8.71% coinciding with b. Distorted orthorhombic symmetry.</td>
</tr>
</tbody>
</table>
Within a small circle one or two sub-maxima are developed. All the diagrams show development of peripheral ac girdles. It is observed that all diagrams for Fold 1 exhibit a near monoclinic symmetry. In the case of Fold 2 only one diagram shows a monoclinic symmetry. In the other diagrams the pattern approximates to that of orthorhombic symmetry. The departure from the ideal symmetry pattern may to some extent be due to the smaller number of grains measured and heterogeneity of original grain size. To a greater extent it probably represents overprinting of fabric.

**Grain orientation in the Siwalik sandstones** — Six sandstone samples, two from relatively undisturbed areas between the Kumaria thrust and Garjia dislocation and two each from the vicinity of the two dislocations were selected for petrofabric studies. Except for the sample from near Garjia, in all others thin sections were prepared from the slices cut perpendicular to the bedding and the direction of the dip. In case of sample from near Garjia, a thin section was prepared from a slice cut perpendicular to the bedding in the direction of the dip. In the absence of any visible lineation the dip direction was considered to be the a direction. The fabric diagrams for the sandstones are given in Fig. 5.10 a-f and the details of the fabric data are summarised in Table 5.5. The samples from the undisturbed areas have yielded diagrams with little axes free areas (Figs. 5.10 a-b). This is characteristic of
Fig. 5.10: Fabric diagrams showing orientation of C-axes of Quartz grains in Sandstones.
<table>
<thead>
<tr>
<th>Fig. No.</th>
<th>Location</th>
<th>Orientation of Section</th>
<th>No. of grains</th>
<th>Contour intervals</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.10a</td>
<td>3 miles from Kumaria on Kumaria to Garjia mule path.</td>
<td>ac</td>
<td>300</td>
<td>1 and 3% per 1% area.</td>
<td>Nearly homogeneous distribution; a little axes free area.</td>
</tr>
<tr>
<td>5.10b</td>
<td>3½ miles from Okalhunga on Okalhunga to Garjia mule path.</td>
<td>ac</td>
<td>300</td>
<td>1 and 3% per 1% area.</td>
<td>Nearly homogeneous distribution; a little axes free area.</td>
</tr>
<tr>
<td>5.10c</td>
<td>Near Kumaria</td>
<td>ac</td>
<td>300</td>
<td>1, 3, 5 &amp; 7% per 1% area.</td>
<td>A maxima of 7% near b and well developed peripheral ac girdle. Near orthorhombic symmetry.</td>
</tr>
<tr>
<td>5.10d</td>
<td>Near Okalhunga</td>
<td>ac</td>
<td>300</td>
<td>1, 3, 5, 7 &amp; 9% per 1% area.</td>
<td>A maxima of 9% near b with partially developed peripheral ac girdle and two cross girdles. Distorted orthorhombic symmetry.</td>
</tr>
<tr>
<td>5.10e</td>
<td>One mile N of Dhangari</td>
<td>ac</td>
<td>300</td>
<td>1, 3, 5, 7 &amp; 9% per 1% area.</td>
<td>A maxima of 9% near b and partially developed peripheral ac girdle. Near orthorhombic symmetry.</td>
</tr>
<tr>
<td>5.10f</td>
<td>1/2 mile NE of Garjia.</td>
<td>be</td>
<td>300</td>
<td>1, 3, 5, 7 &amp; 9% per 1% area.</td>
<td>A split maxima of 9% on periphery near b and partially developed near ac girdle. Distorted Monoclinic symmetry.</td>
</tr>
</tbody>
</table>
non-tectonites. The samples from near the thrusts have given diagrams (Figs. 5.10 c-f) with well developed girdles and concentration around $b$.

**Macroscopic Structures:**

In the area under study the rocks of the Krol unit have been brought over the Siwaliks along a well defined dislocation which is here designated as the Kumaria thrust. This thrust can be traced in an approximate NW-SE direction from the region of Sankar in the west to the Okaldhunga in the east (see structural map, Fig. 5.1). Along this dislocation the slates and quartzites of the Sair formation are brecciated and often ramified by quartz veins. Slickensided joint surfaces are frequently observed. These features are well developed in the road cuttings between Kumaria and Sair. The outcrops on either side of the dislocation plane show haphazardly oriented dips. Further, as mentioned earlier, quartz $\mathbf{g}$ axes fabric diagrams for Siwalik sandstones from near this dislocation show a peripheral $\mathbf{a\sigma}$ girdle with maxima near $b$. This pattern is considered to be characteristic of fault planes (Balk, 1952). In view of the fact that this dislocation brings the rocks of the Krol belt over the Siwalik sediments, it is equated with the Krol thrust (Auden 1934).

**Structures in the Krol unit** - There is a difference of opinion regarding the tectonic status of the Krol unit. Auden (1937) suggested that the Chandpur-Tal sequence constituted a nappe thrust over the autochthonous Simla
slates, Dagahai, Nummulites and Siwaliks. Recently Ranga Rao (1968, 1970) put forward the view that the rocks of the Krol belt are autochthonous. However, most recent workers (e.g. Valdiya, 1964; Frank and Fuchs, 1970; Ravindra Kumar and Pande, 1972; Pande and Ravindra Kumar, 1972) regard the Krol unit to be paraautochthonous. The Krol thrust has been traced along the entire length of the Krol belt (Bhargava, 1972). Moreover, as Frank and Fuchs (1970) point out, its structural pattern is quite different from that of documented nappes. The Krol unit forms a narrow belt in the Lower Himalaya. Considerable translation has nowhere been demonstrated for this unit. Hence the present writer concurs with the view that the Krol unit is paraautochthonous.

Within the Krol paraautochthon two important imbrications which trend approximately parallel to the Krol thrust front, are recorded in the area under study. These are designated as the Manila dislocation and the Ramganga dislocation.

The Manila dislocation occurs in the northern part of the area. It separates rocks of the Manila formation from those of the Paisiya formation. The quartzites of the Paisiya formation show considerable brecciation and slickensiding. Thin sections of the Paisiya quartzites show considerable recrystallization with the development of second generation quartz. In the Manila formation small scale folding is abundantly developed. There is also a small but significant difference in the grade of metamorphism and deformation of
the Manila - and Paisiya formations. Biotite is the common foliated mineral in the Manila formation. It is rare in the Paisiya formation. The quartz in the Paisiya formation includes detrital and recrystallized grains. In the Manila formation the quartz grains are polygonal with straight contacts. The quartz in the rocks of Paisiya and Manila formations respectively represent type two and type three of quartz types recognised by Wilson (1973) in a deformed quartzite sequence at Mount Isa, Australia.

The Ramganga dislocation is traced along the Ramganga valley in the central part of the map area. It has caused widespread brecciation and slickensiding in the quartzites of the Tota Am formation. The trace of this dislocation has been disrupted by a number of faults trending approximately north-south. The more important among these are the Patlion and Nair faults respectively traced along the Patlion and Nair gadderas. The strike slip nature of these faults is indicated by the displacement of the formation boundaries and macroscopic fold axes. Development of quartz veins and slickensides on joint planes parallel to these faults substantiate this conclusion.

The study of the mesoscopic elements detailed above shows that the rocks of the Krol unit have been folded on a NW-SE trending axes. Traces of the axial surfaces have been delineated on the structural map (Fig.5.1). It is seen that these mesoscopic folds are largely isoclinal with the axial planes
dipping towards NE at about 20° to 25°. With regard to fold axes MF, the sub-areas K₁, K₃, K₅ and K₇ may be grouped into one homogeneous domain in which the mesoscopic fold axes plunge to the NW. In sub-areas K₂ and K₉, the fold axes plunge towards SE (Fig. 5.3). This suggests that the area has been subjected to cross folding along an approximately NE-SW trending fold axes. In all sub-areas this fold axes MF₂ is seen to plunge at an angle of 45°. Folding on a smaller scale, sympathetic to this later folding, is responsible for plunge of T₁ and T₂ in both NW and SE directions, observed in most sub-areas.

Structures in the Siwaliks — The rocks of the 'sandstone' facies of the Siwaliks have been brought over those of the conglomerate facies along a reverse fault here designated as the Garjia dislocation. This dislocation is clearly defined only in the central part of the Siwaliks under study. In the western and eastern parts where there is a thick cover of quaternary alluvium, its presence cannot be verified. The presence of this fault is suggested by the sudden change in lithology, brecciation in the sandstones and the petrofabric criteria namely, development of a girdle and b maxima in the 'sandstone' facies rocks.

The mesoscopic data reveals that, as in the case of the Krol unit, the Siwaliks have also been subjected to two phases of macroscopic folding. The fold axes MF, corresponding to the first phase of folding trends NW-SE. In sub-area
It plunges to the NW and in sub-area $S_2$ to the SE. $M_{F_2}$ axes plunges at about $45^\circ$ as in the Krol unit towards N to NNE. In the structural map (Fig. 5.1) the axis of an anticlinal structure ($M_{F_1}$) is delineated. The axial plane dip to the NE at about $20^\circ$.

To summarise, within the area under review, two tectonic units, namely, the Krol paraautochthon and the Siwalik autochthon are recognised. These are separated by the Krol thrust. The lithological units have been tightly folded with the axes of the folds trending NW-SE and the axial planes dipping to NE. Within the Krol paraautochthon two secondary imbrications (Manila dislocation and Ramganga dislocation) are recognised. The Ramganga dislocation is disrupted by two N-S trending strike-slip faults. Within the Siwalik autochthon, the 'sandstone' facies rocks have been brought over the conglomerate facies rocks along the Garjia dislocation. In both tectonic units there is cross-folding along NNE-SSW trending axes. These features are shown in the structural map and geological section.

**Tectonic Synthesis**:

From the structural data presented in the foregoing pages a fairly consistent kinematic picture emerges for the area under study. There is evidence of at least two distinct episodes of deformation. The first episode resulted in the development of the macrofolds $M_{F_1}$ with NW-SE trending fold axes, secondary imbrication and faulting. The second episode
was responsible for the formation of the macrofolds $M^F_2$ with NE-SW trending axes.

**Episode I** - The first episode of deformation is correlated with the movement of the Krol unit. Auden (1934) in his classical study of the Krol belt has shown that the Krol 'nappe' is constituted of normal sections. On the basis of his observations Gansser (1964) concluded that the Krol unit represents proper thrust sheets and not recumbent nappes. Pande and Saxena (1968) suggested that the Krol unit was constituted of different sheets which slipped over the underlying ones. Powar *et al* (1969) interpreted the different nappes of the Himalaya to be peel thrust sheets which moved under the influence of gravity. According to them resistance to gliding resulted in folding, shearing and overriding within individual units.

The present writer, for reasons already indicated (p.168) considers the Krol unit to be a parautochthon. It is tectonically overlain in the Kumaon Himalaya by the allochthonous Almora Crystalline Mass (Gansser, 1964). From published data (Sarkar *et al*, 1965; Merh and Vashi, 1965; Powar, 1970, 1971; Ravindra Kumar *et al*, 1970; Vashi and Laghate, 1972), it is evident that the orientation of the mesoscopic fold axes and other structural elements in the rocks of the Krol parautochthon and the Almora Crystalline Mass is the same. The development of the structural elements in the Almora Crystalline Mass have been correlated by
Sarkar et al. (1965) and Powar et al. (1969) to its translation. From this it is concluded that the movement of the Almora Crystalline Mass over the then autochthonous Krol unit initiated sympathetic displacement of the latter. The movement, once started, was probably continued by gravitational gliding over a suitable slope and resulted in the Krol unit being pushed over the Siwalik autochthon and the deformation of the latter. The NW-SE trends of the mesoscopic fold axes, the $MF_1$ axes and Krol thrust front, and the NE wards inclination of the axial planes of the $MF_1$ folds all suggest overall transport of the Krol parautochthon towards the SW. The near monoclinic symmetry observed in the fabric diagrams for the mesoscopic elements is consistent with such a translation movement. The present writer believes that during the first phase of translation flexure-slip folding on $S_0$, accompanied by some flowage in the more incompetent rocks, resulted in the formation of mesoscopic $MF_1$ folds. Concomitantly there was the development of the continuous foliation $S_1$. With continued application of stress the $MF_1$ folds were flattened, small-scale folds $MF_2$ were superimposed on $S_1$ and crenulation cleavage $S_2$ developed parallel to the axial planes of these $MF_2$ folds. The common observed development of two sets of $MF_2$ axes at angles of about $15^\circ-30^\circ$, probably reflects slight changes in the direction of movement. Mineral lineation ($L_5$) may have developed due to flowage and stretching parallel to the $a$ tectonic direction. During the forward movement
The Siwalik autochthon probably provided considerable resistance to forward movement of the Krol parautochthon. Because of this resistance the Krol unit was shortened with the formation of the macrofolds $MF_1$ and subsequent development of the secondary imbrications (the Ramganga dislocation and the Manila dislocation) and strike-slip faults (Patlion and Nair faults). The formation of much of the fracture cleavage ($S_4$), joints ($S_5$) and grooves and striae on slickenides is related to this rupture phase. The numerous quartz veins are probably the result of 'sweating' during this period. The similarity in the trends of the macroscopic fold axes in the Siwalik and Krol units suggests that the deformation of the former was a direct consequence of the Krol unit overriding the Siwalik autochthon. The geometry and position of the Gargia dislocation, which has brought the 'sandstone' facies of the Siwaliks over the conglomerate facies, suggests that it is a break thrust.

**Episode II** - The second episode of deformation was of relatively small intensity. It resulted in the cross-folding of $MF_1$ folds and consequent development of $MF_2$ folds with axes plunging NE wards at moderate angles. On a mesoscopic scale the axial planes of the $MF_1$ folds were warped giving $MF_3$ folds. Some of the joints are related to this period. It may be pointed out that a similar chronology for the development of mesoscopic structures has been proposed by Revindra Kumar et al (1970) for the Mukteshwar-Nathukhan-
Ramgarh area of the Almora and Nainital districts and by Panda and Ravindra Kumar (1972) and Ravindra Kumar and Panda (1972) for the Halog area of the Simla Himalaya. The episodes I and II of the area under study correspond to phases II and III observed by Panda and Ravindra Kumar in the Halog area. The evidences of Phase I mentioned by them have not been observed in the area under study and these may have been obliterated during the later episodes.

The microfabric analysis not only substantiates the tectonic history reconstructed above but also adds valuable information to the movement picture. Thin sections cut perpendicular to the fold axes of mesoscopic folds $m_F^2$ in quartzosephyllites yield fabric diagrams (Fig. 5.8 and 5.9) showing partial to well developed $ac$ girdles. Such $ac$ girdles around fold axes have been recorded by Sanders (1930), Phillips (1937) and a number of successive workers. Sanders believes that the girdles are developed due to forward movement parallel to $a$ associated with rotational movement about $b$. The distorted monoclinic symmetry recorded in five of the eight fabric diagrams also testifies to an original translatory and rotational forward movement (Fairbairn, 1939).

Three of the fabric diagrams for the thin section of the appressed fold exhibit orthorhombic symmetry. This symmetry pattern is exhibited by all quartzite samples except for the one from near the Nair fault. In the fabric diagrams for the quartzites a crossed-girdle is also present. This crossed-
girdle type of preferred orientation of quartz g axes has been reported from various parts of the world and their origin has been discussed by a number of workers. Earlier workers believed that crossed-girdles developed because of overprinting of one fabric on another during the course of two independent deformations (Larsen, 1938; Phillips, 1945). However, the majority of more recent workers favour the view that this pattern is a distinct type of preferred orientation which originated during a single deformation due to flattening perpendicular to the foliation (Sanders, 1930, 1934; Turner, 1948; Fairbairn, 1949; Weiss, 1959; Christie, 1963; Turner and Weiss, 1963; Sylvester and Christie, 1968).

It may be emphasised that the orthorhombic symmetry is developed in quartzites from all over the area studied. This suggests the existence of a fairly homogeneous flattening phase which overprinted an orthorhombic symmetry on the original monoclinic symmetry developed during translation and noted in the mesoscopic fabric. Slight departure from orthorhombic symmetry in quartz orientation in some specimens may reflect the earlier monoclinic phase which was not completely obliterated. In the case of quartzose-phyllites the cushioning effect afforded by the pelitic layers probably prevented a more forceful implanation of the orthorhombic fabric. This is supported by the fact that the orthorhombic symmetry though not developed in the open fold is observed in the more appressed one.
It may, therefore, be concluded that the initial translative movement normal to the mesoscopic fabric was followed by a phase of flattening and elongation. Christie (1963, p.406) has recorded a similar movement plan in the Moine thrust zone of the Assynt region in Northwest Scotland. He has explained the flattening phase as follows:

"If a body of rock is shortened by folding or thickening of the strata the vertical dimension becomes increasingly greater. Eventually a stage will be reached when the lower rocks are flattened under the influence of the weight of superincumbent rocks. The mass is constricted in the direction of shortening and the elongation produced by this flattening will be parallel to the horizontal axis, that is, normal to the direction of shortening, that is, the fold axis. I consider that ... the quartz was reoriented during the final stages of the sequence, after the translative movement normal to the fold axis had ceased."

The quartz sample from near the Nair fault exhibits a monoclinic symmetry. This is apparently the result of a second monoclinic movement plan related to the shearing which resulted in strike-slip movement along the fault.

**Metamorphic Grade and Structural Regimes**:

The metasediments of the Krol unit exhibit, in the area under study, low grade metamorphic changes. As in the Simla area (Pilgrim and West, 1928, p.79) the dynamic factor,
which has been largely responsible for the conversion of the sediments into slates and phyllites appears to have played a more important role than temperature in bringing about these changes.

The pelitic horizons in the Nagthat sub-group, are composed of quartz, white mica and chlorite. Biotite is rarely seen. In the mafic bodies associated with this sub-group there is a general tendency for the original calcic plagioclase-augite assemblage to change to less calcic plagioclase-actinolite-chlorite assemblage thus suggesting that the rocks of the Nagthat sub-group have been metamorphosed in the quartz-albite-muscovite-chlorite sub-facies of the Greenschist facies of Winkler (1967). The characteristic presence of biotite in the Manila formation (Chandpur sub-group) suggests slightly higher grade of metamorphism corresponding to the Quartz-albite-epidote-biotite subfacies of the Greenschist facies. The Siwalik sediments do not show any sign of metamorphism.

Holland and Lambert (1969), in an attempt to correlate rheological behaviour (deformation) in an orogenic environment with metamorphic facies, have sub-divided the earth’s crust into five regimes.

Regime 1 is an essentially non-metamorphic regime below the level of diagenesis whose deformational pattern is governed by the initial elastic response of the rocks to stress,
Regime 2 represents the level of low-grade metamorphism. This zone is the soft zone of the earth's crust and in it the development of similar folds commences, the rocks acquire widespread schistosity and recumbent isoclinal folds on all scales are formed.

Regime 3 occupies levels corresponding to the epidote-amphibolite and amphibolite facies. All common rock types have similar rheologies and deformation is by grain boundary or intra-lattice diffusion at a rate lower than regime 2.

Regime 4 is equated with the upper amphibolite facies where there is a partial anatexis. In this there is the development of gneissose structures and extensive flow folding and possibly diapirc movements.

Regime 5 corresponds to the granulite facies extending into the mantle. In it the deformation is by prolonged laminar flow and results in simple structural styles.

In the area under study the unmetamorphosed Siwalik rocks do not exhibit any mesoscopic structures apart from joints. However, on the macroscopic scale they are seen to be folded and faulted. These rocks can be included within the regime 1 of Holland and Lambert.

The Krol unit is metamorphosed in the greenschist facies and exhibit folding on all scales with development of continuous cleavage of the axial plane type and the crenulation cleavage. The sequence of deformation detailed above is very much similar to that described by Dewey (1967) in
the Dalradian rocks of the Mayo Country, Eire. This latter area is considered by Holland and Lambert to represent regime 2. On the basis of the grade of metamorphism and the deformatinal pattern, the Krol unit can be equated with regime 2, examples of which are, according to Holland and Lambert (1969, p.206), 'not numerous'.
Photo 1: Slate from Sair formation showing chevron folds with fracture cleavage parallel to axial planes.

Photo 2: Quartzose phyllite from Manila formation showing development of two sets of $mF_2$ folds.
Plate 5.1

Photo 1

Photo 2
Photo 1: Quartzose phyllite from Manila formation showing intersection of continuous cleavage ($S_1$) and crenulation cleavage ($S_2$).
C.N.*, x75

Photo 2: Quartzose phyllite from Manila formation showing folding on $S_1$.
C.N.*, x75
CHAPTER VI

SUMMARY AND CONCLUSIONS

This work embodies the results of detailed petrological and structural studies of the Tota Am area in the Kumaun Himalaya. In this concluding chapter the salient observations and conclusions detailed in the preceding pages, are summarised in an attempt to present a comprehensive picture of the geology of the area.

The area studied during the course of the present investigations, some 240 square miles in extent, covers parts of the Almora and Nainital districts of Uttar Pradesh, India (topographic sheets 53 0/2 and 53 0/3 of the Survey of India). It lies to the west of the geologically well known Almora-Ranikhet-Nainital sector of the Kumaun hills. Surprisingly, however, only preliminary geological work has been conducted in this area and a geological map of the northern two-thirds of the area is being presented for the first time in this thesis.

Physiographically, the area covered by the present investigations can be separated into three divisions, namely, the talus covered fringes of the Gangetic plain known as the Bhabhar, the densely forested Siwalik foothills, and the rugged ranges of the Lesser Himalaya. The general elevation varies from about 1,500 feet in the Bhabhar belt to over 6,200 feet in the northernmost part of the area forming a part of the