CHAPTER IV

STRUCTURAL GEOMETRY
The different structural elements that have been measured in the field and analysed in subsequent sections of this chapter are plotted in Plates 1 and 2.

4.1 Planar Structural elements (Plate 1)

4.1.1 Compositional layering ($S_o$)

Compositional layering is observed within Nandna marble, calc-silicate rocks and banded amphibolites.

Marble is very ductile and deforms easily; colour and compositional bands in deformed marble is often a transposition structure and is likely to represent an unmodified primary structure (Turner and Weiss, 1963, Weiss and McIntyre, 1957). Within the Nandna marble, thin discontinuous layers of micaceous material are seen, which show complex isoclinal fold forms preserved as rootless hinges (Fig. 4.1). These layers are thought to be disrupted primary compositional bands within the marble.

A regularly spaced planar colour lamination is observed within the Nandna marble in mesoscopic as well as microscopic scale (Figs. 3.7, 3.8 and 4.2), and is parallel to the axial planes of the rootless hinges. This thin but regular lamination in the very fine grained Nandna marble is interpreted as a deformation induced banding (Passchier and Trouw, 2000) and is a mylonitic lamination.

Regularly spaced compositional bands are also observed within the calc-silicate gneisses (Figs. 3.18, 4.3 and 4.4). The lighter coloured layers in most cases are composed of quartzo-feldspathic material while the darker layers are made up of amphibole, epidote, biotite (Fig. 4.5). Over a large part of the area the planar compositional banding in calc-silicate gneiss is a composite primary and secondary fabric. The regularity of the bands, the sharp nature of the band boundaries and the alignment of the platy minerals parallel to the banding indicates that the banding is at least partly of secondary origin. A secondary compositional banding axial planar to the minor folds cuts across the folded banding in the hinge zones but the two are parallel on the long limbs (Figs. 3.18, 4.6). Amphibole and biotite crystals are aligned parallel to this secondary fabric (Fig. 4.5).
Secondary compositional layering axial planar to folds on primary layering within the calc silicates of the Sendra Complex is also reported by Gangopadhyay and Mukhopadhyay (1984).

Gneissic banding is seen within the banded amphibolites, and is also interpreted to be a secondary structure (Figs. 4.7, 4.8 and 4.9). The darker bands contain amphibole, biotite, epidote, sphene, apatite etc., while the leucocratic bands contain mainly quartz and feldspar with a few grains of hornblende and epidote.

Within the mica schists, a compositional layering is observed, in which biotite-rich domains alternate with quartz-rich domains, probably representing the argillaceous and arenaceous precursors. This possibly represents a primary compositional layering. These layers are seen to be folded into W or M shaped folds.

4.1.2 Schistosity (Sᵢ)

It is a pervasive planar fabric in most of the rocks though the degree of development varies from one rock type to another. It is best developed in mica schist, conglomerate, and metamorphosed acid volcanics.

Within the matrix of the conglomerate the schistosity is defined by the parallel to subparallel alignment of muscovite and biotite flakes (Fig. 4.10). At places within the conglomerate, a second schistosity defined by muscovite flakes has developed locally at an angle of ~20° to the earlier schistosity surface; this is of the nature of a S-C fabric within the matrix of the conglomerate (Fig. 4.11). The main schistosity surface within the matrix of the conglomerate shows later kinks. In the mica schist, within a hinge region of a Dᵢ fold defined by compositional layering (S₀), Sᵢ is seen to develop at high angles to the compositional bands (Fig. 4.12).

Within the central band of the metamorphosed acid volcanics, the schistosity is defined by streaks of biotite and muscovite; often they show an anastomosing pattern and curve round quartz-feldspar aggregates (Fig. 4.13).

Within the amphibolites schistosity is not well developed and is defined by the parallelism of hornblende prisms (Figs. 4.8 and 4.9) with the gneissic banding.
The schistosity is in general parallel to the formational contacts and the gneissic bands in the rocks (Plate 1). In an area 3 km south east of Birantiya village, the D1 planar fabric is seen to cut across the banding (Fig. 4.6) within the calc silicate gneisses and is axial planar near the hinges of the dextral minor folds of D1 origin.

It is therefore postulated that the schistosity is coeval with the axial planar secondary banding in the calc-silicate gneiss and the gneissic banding in the amphibolite. It is a D1 related structure and is the result of the recrystallisation associated with D1 deformation episode.

4.1.3 Axial planes of minor folds and crenulation cleavage

Minor folds are mostly observed within calc-silicate rocks (Figs. 3.8 and 4.6) and at a few instances within the marbles and quartzites. Within the calc silicate gneisses, these folds have folded the gneissic banding, and they could be classified into two categories, D1 and D2. Both the sets of folds (often undifferentiable) have axial planes with NNE-SSW strike with a nearly vertical dip, but with a small difference in their fold axis orientations. At places pressure solution planes have developed parallel to the D1 and D2 axial planar fabric (Fig. 4.14).

4.2 Linear structural elements (Plate 2)

4.2.1 Minor fold axes

The D1 fold axes generally have steep plunge with direction varying from ENE to ESE. These folds are mostly seen on horizontal surfaces, which are nearly the profile sections of these folds. The D2 folds are usually gentler in plunge than the D1 folds, plunging towards NE to ENE.

Within a small exposure of quartzite mylonite occurring west of the Nandna Marble a fold shows sheath like geometry related to the D1 deformation (Figs. 4.15 and 4.16).

There are transverse, broad warps on the schistosity and bedding/banding surfaces. These warps represent the D3 folds. The axes of these folds are variable, mostly steep due east.
4.2.2 Pebble elongation lineation

Pebble elongation lineation is conspicuously developed in the Barr conglomerate throughout its entire strike length. The pitch of the long axes of the pebbles (X direction of the finite strain ellipse) on the schistosity surface is almost down dip. The pebble elongation lineation is parallel to the D1 fold axes. In response to the stretching along the lineation, an extensional joint has developed perpendicular to this lineation within the pebbles (Fig. 4.17).

4.2.3 Mineral lineation

Mineral lineation is observed in the amphibolite and calc-silicate gneiss and is defined by the parallel alignment of amphibole needles on the schistosity surface. This mineral lineation has developed during the D1 deformation episode and is in general steeply plunging. Within the quartzofeldspathic schist, stretched quartz grains define a steeply plunging lineation.

4.2.4 Intersection lineation.

Within the banded amphibolite and the calc-silicate gneiss, trace of the compositional banding on the schistosity produces a striping lineation.

4.2.5 Pucker axis lineation

Subhorizontal puckers of small scale are developed on the schistosity plane within the mica schist, south of Barr. The puckers are mostly asymmetric in nature (Fig. 4.18).

4.3 Deformation Sequence

The different structural elements along with the folds observed on the outcrop scale aid to unravel the deformation history of the rocks of the area. Three deformational episodes are recognised, namely D1, D2 and D3. The characteristics of the planar fabric especially the gneissic banding and
the schistosity and their relation to the macroscopic fold forms serve the basis of such a conclusion.

The compositional banding seen in the rocks of the area is composite in nature. The banding is partly primary and partly secondary formed by metamorphic differentiation during an extended period of deformation – metamorphism. The compositional layering is folded along with the development of axial planar fabric.

4.3.1 D\textsubscript{1} episode of deformation

The first deformation episode, D\textsubscript{1}, is defined by folds that are tight in geometry. The minor folds associated with the D\textsubscript{1} episode are almost always dextral on plan. These folds have a secondary compositional banding parallel to their axial plane. The folds are generally tight to isoclinal in geometry. They are almost always steeply plunging with a sub-vertical axial plane trending NNE – SSW (Figs. 3.18, 4.3, 4.4, 4.6 and 4.19).

Along with the gneissic banding the schistosity is also a product of the D\textsubscript{1} deformation. Within the calc-silicate gneiss also the schistosity is seen to cut across the compositional layering supposedly of primary nature (Fig. 4.6). The sheath fold developed within the quartzite east of the Nandna marble is also formed during late stages of D\textsubscript{1}.

4.3.2 D\textsubscript{2} episode of deformation

The D\textsubscript{2} folds are folds that have folded an earlier schistosity / gneissosity and there is no development of axial planar cleavage associated with it (Figs. 4.14, 4.20, 4.21 and 4.22). The folds are at places seen as kinks seen on the outcrop scale. The general plunge of the fold axis of the D\textsubscript{2} folds is gentler than the axis of the D\textsubscript{1} folds.

Keeping in mind the geometry of the D\textsubscript{1} and D\textsubscript{2} fold forms, the constancy of the orientation of the axial plane and the small angular difference in the plunges of the respective fold axes, it can be postulated that the D\textsubscript{2} folds are developed at a later part of the deformation that produced the D\textsubscript{1} folds. D\textsubscript{1} and D\textsubscript{2} together constitute a prolonged phase of progressive deformation, which is a general shear type of deformation.
The combined $D_1$ and $D_2$ structures are produced by a combination of east–west compression (normal to the schistosity) and a dextral simple shear on the schistosity surface. In other words it is a transpression type of deformation.

The extreme flattening of the pebbles in the conglomerate, straight banded outcrop pattern of the rocks and the predominance of the tight to isoclinal folds attest to the compression associated with the $D_1$ deformation. The asymmetric deflection of marker bands, asymmetric tails around the porphyroblasts, development of S-C fabric are evidences of the later simple shear deformation. The asymmetric folds with isoclinal to tight geometry defined by compositional banding/schistosity are a result of this progressive deformation. It is postulated that the $D_1$ folds were formed in the early stages and were refolded by $D_2$ producing a Type III interference pattern (Fig 4.23). Progressive shearing has given rise to variable plunges of the fold axes distributed on planar axial surface steeply dipping due ESE. The $D_2$ folds usually have gentler plunges than the $D_1$ folds. $D_2$ crenulation cleavage is observed to cut across the $D_1$ schistosity within the mica schist.

4.3.3 Structures associated with $D_3$

The effects of third phase of deformation $D_3$ are sporadic. These are broad transverse warps, which have folded the regional foliation into broad open folds with E-W trending axial surfaces.

4.3.4 Shear zones:

The entire area is a strong deformation zone suggested by the straight linear outcrop of the lithological bands. The effects of intense shearing are localised along the margins as well as in the zones within of the Barotiya Group.

Along the eastern boundary, the Nandna marble, a finely laminated carbonate mylonite, exhibits strong deformation features in the microscopic scale, like isoclinally folded flakes of mica (Fig 4.24), mylonitised fragments of quartz and/or feldspar clasts (Figs. 4.25 and...
4.26), occurring as tectonic inclusions (Mcintyre, 1951, Ramberg, 1955, Rast, 1956). The mylonitic banding is parallel to the regional foliation of the area (Fig. 4.27). The thin band of quartzite to the west of the Nandna marble is also mylonitised. It contains porphyroclasts of quartz, quartzo-feldspathic aggregates and mica within a fine grained quartzose matrix with a few feldspar grains. The quartz grains in the matrix are stretched to thin elongated ribbons (Fig. 4.28). At places larger porphyroclasts of quartz show deformation lamellae (Figs. 4.29 and 4.30) and subgrain formation (Figs. 4.31 and 4.32). Strong S-C fabric is seen within this rock. Porphyroclasts of mica are kinked (Fig. 4.33) or deformed to mica fishes (Fig. 4.34) within the shear zones.

Besides the mylonitic character, the Nandna marble as well as the quartzite are fractured and show signatures of cataclasis. A network of fractures transect the rocks (Fig. 4.27) resulting in the formation of angular blocks typical of cataclasis (Figs. 4.28 and 4.35). The mylonitic banding is seen to be disrupted by these fractures. This implies that a brittle deformation has post dated the mylonitisation. Often the fractures are close spaced and form a fracture zone in the rock (Fig. 4.35). Within these fracture zones the rock has been transformed into a very fine grained material of the same composition like a gouge (Fig. 4.36). Slip and drags are also seen along these fracture surfaces indicating movement along them (Fig. 4.37). At places thin veins of pseudotachylite have formed and has been injected either parallel (Figs. 2.11 and 4.38) or at angles to the mylonitic foliation. It is suggested that the brittle structures were formed during the exhumation of the mylonites.

Along the western boundary, within the Barr conglomerate, indications of shear and its sense are provided by asymmetric deflection of schistosity, pebble geometry (Fig. 4.39), development of S-C fabric within the matrix of the conglomerate (Fig 4.12), asymmetric tails against pebbles, sheared and fractures pebbles, asymmetric kinking of schistosity and dextral folding of flattened pebbles. All these show a dextral sense of horizontal shear. Within the matrix rich portions of the Barr conglomerate at a place about 2 km north of the Ram Dev Temple, quartzo-feldspathic veins are seen emplaced parallel to axial planes of asymmetric dextral
minor folds (Fig. 4.40). These veins are thus emplaced along a direction which is perpendicular to the direction of compression. This is in contrast to the general view that the veins form along extensional fractures perpendicular to the least principal stress direction. Similar features have been reported by Hand and Dirks (1992), Druguet and Hutton (1998), and Rosenberg and Handy (2001). The possible mechanisms for vein emplacement along axial surfaces have been summarized by Vernon and Paterson (2001). Following them, it is suggested that the veins of the Fig. 4.40 may have formed by filling up of tensional cracks parallel to axial surfaces, due to temporary relaxation during folding. This process is similar to the "retrodeformation" suggested by Means (1987). He suggested that stress relaxation in the waning stages of deformation may cause the elastic or plastic strain rates to differ along $\sigma_1$ and $\sigma_3$ directions. On a very local scale, shortening can result perpendicular to the regional $\sigma_3$. Depending on the behaviour of the minerals undergoing deformation, sites of low stress may form parallel to the axial surfaces, and thus a local $\sigma_3$ direction may eventually be at high angles to the regional $\sigma_3$ direction.

In the region bounded by the two strongly deformed boundary zones (i.e. the Barr conglomerate and the Nandna marble), effects of shearing is more pronounced within bands of metamorphosed acid volcanics than the other rocks of the area. Within the metamorphosed acid volcanics, tails around the porphyroclasts of feldspar and quartz - feldspar aggregates; kinks in muscovite; mica fishes are evidences of shearing in the rock (Figs. 3.29, 3.30 and 4.41). Even in a microscopic scale the shear bands develop with the formation of S- C fabric in the rock (Figs. 4.42 and 4.43). Within the calc silicate gneisses, shearing along the spaced cleavage developed during D2, often rotates an earlier foliation in the rock (Fig. 4.44). In all the rocks these rocks the sense of shear is dextral and subhorizontal.

It is therefore suggested that the sense of shear is of a sub horizontal dextral simple shear type of movement. It is suggested that an
east–west compression is combined with this subhorizontal dextral simple shear (Fig. 4.45).

4.4 Orientation Analyses of the planar and linear structures in the Barotiya Group

The summary orientation data of the planar and linear structures are shown in Figures 4.46 and 4.47. Equal area projection of the 195 poles to compositional banding within the biotitic marble, calc-silicate gneiss and amphibolite (S₀) shows a cluster about a modal orientation of 35° / 84° E (Vide Table 4.1 for the cone of confidence at a confidence interval of 95%) (Fig. 4.48). As discussed earlier the compositional bands are partly primary and partly secondary produced by metamorphic differentiation. Some poles deviating from this cluster are from the short limbs of a few dextral folds, whose long limbs are parallel to the regional attitude of banding.

Equal area projection of the 737 poles to schistosity (S₁) measured within the quartzite, acid volcanics, conglomerate and mica schist of the area show a cluster, the mean orientation of the schistosity being 28° / 83° E (Vide Table 4.1 for the cone of confidence at a confidence interval of 95%). The small angle between the strikes of the modal orientations of S₀ and S₁ is statistically significant and is consistent with the dextral asymmetry of the minor folds and the dextral sense of shear.

Equal area projection of 52 pebble long axis lineations within the conglomerate show a cluster with a mean orientation plunging 85° towards 101° (Fig. 4.50) (Vide Table 4.1 for the cone of confidence at a confidence interval of 95%). It is postulated that these pebble long axis correspond to the maximum extension direction associated with the D₁ compression.

Equal area projection of 247 mineral lineations within the amphibolite, show a cluster around a mean lineation having orientation of 71° towards 57° (Fig. 4.51) (Vide Table 4.1 for the cone of confidence at a confidence interval of 95%).

Equal area projections of the 80 undifferentiated D₁/D₂ minor fold axes along with the intersection lineation and striping lineation within the
calc-silicate rocks and biotitic marble show a distribution along a great circle oriented 84° towards 110° (Fig. 4.52) (Vide Table 4.1 for the cone of confidence around the great circle pole at a confidence interval of 95%). The great circle approximately coincides with the modal schistosity. The distribution of fold axes on a plane is consistent with the simple shear component of the deformation regime. The D$_2$ structures are mostly gently plunging while the steep plunging ones belong to the D$_1$ generation.

4.5 Discussion on the geometry of the structures

A conspicuous feature of the area is the straight outcrop pattern of the rocks associated with a consistent attitude of the pervasive regional foliation (schistosity or gneissosity) steeply dipping due ESE. This is in contrast to the outcrop pattern in the adjacent Sendra Group to the east (Gangopadhyay and Mukhopadhyay, 1984). Biswal (1993) also formulated a three stage deformational scheme for the rocks of the area, but he did not comment either on the shearing or on the extreme flattening of the rocks of the area.

In conclusion, it may be stated that the present study clearly reveals that the rocks of the area have been deformed by at least three phases of deformation. We interpret from the study of the structural elements that a progressive deformation comprising D$_1$ and D$_2$ is responsible for the formation and later folding of the structural elements seen within the area. The D$_1$ produced the banding within the gneisses and the schistosity in the schists. These along with the primary layering in the rock were folded during D$_2$, the later stage of the said progressive deformation. This deformation is of transpressive type with an east – west compression combined with a horizontal dextral shear. However we cannot rule out the possibility that the main gneissic banding is produced by still earlier deformation phase whose other imprints remain elusive. The last phase D$_3$, is much later and produced broad warps of the earlier structures. The straight outcrop pattern of the formational contacts is ascribed to the strong component of simple shear in the deformation.
The rocks of the Sendra Group have also undergone three phases of deformation (Gangopadhyay and Mukhopadhyay, 1984) (Fig 1.12). The first phase of deformation is represented by tight to isoclinal minor folds with moderate to steep plunge of fold axes due north. The second deformation produced the macroscopically recognizable folds. These have variable plunge of axes on a predominantly NNE – SSW trending axial plane. The major structure as recognized by them is a southerly plunging second generation (D2) antiform. D1 is associated with production of gneissic banding and isoclinal folds within the calc silicate gneisses. The D2 has produced another set of compositional banding within the calc silicate gneisses (parallel to the axial plane of the D2 fold described earlier), cross cutting the earlier bands. The third deformation episode is represented by broad warps. The folds and the regional schistosity have been disturbed by the emplacement of granite plutons in the area.

Comparing the nature of the deformation phases and the structures that resulted, it appears that the D2 of the Sendra complex is comparable to the combined D1 – D2 of the Barotiya Sequence.
Table 4.1 Eigenvalues of the distribution patterns in projection diagrams and angular measures of the cone of confidence at 95% confidence level.

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<th>Type</th>
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<th>Eigen Values</th>
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<td></td>
<td></td>
<td>( \lambda 1 )</td>
<td>( \lambda 2 )</td>
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<td>18.538</td>
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<tr>
<td>Mineral lineation</td>
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<td>Point Concentration</td>
<td>226.993</td>
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</tr>
<tr>
<td>D1 and D2 axes + intersection lineation</td>
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<td>?</td>
<td>64.88</td>
<td>13.36</td>
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</tbody>
</table>
PLATE 1. Plot of representative foliation data measured in the rocks of the area.

- schistosity
- cleavage
- planar parting
- mica foliation

Legend:
- Black line: Boundary of the area
- Arrow: Direction of strike
- Label: Orientation of foliation

Scale: 1 cm = 1 km

Orientation: North (N)
PLATE 2: Plot of representative lineation data measured in the rocks of the area.
Fig. 4.1  Tightly dextrally folded and disrupted pelitic layers within the Nandna marble, 5 km south of Jhala Ki Chauki, near Kashiya. Diameter of the coin is 2.3 cm.

Fig. 4.2  Mylonitic banding of Fig. 3.8 as seen under crossed polars. Layering is developed by the alternation of coarser and finer grained bands. Porphyroclasts of various shapes made up of strained quartz, large grains of muscovite and a few of biotite. There are some carbonate veins, which cross cut the lamination at high angles, indicating extension along the banding.
Fig. 4.3 Isoclinally folded quartzose layers within the calc-silicate gneisses 3 km south of Birantiya on plan. These are the first generation D₁ folds having an overall dextral geometry. Note that the folds are rootless and disrupted along their long limbs. Diameter of the coin is 2.3 cm.

Fig. 4.4 Plan view of Isoclinally folded (D₁) quartzose layers within the calc-silicate gneisses near Birantiya. These first generation D₁ folds of dextral geometry and have been disrupted by a later fabric which is parallel to the D₁ axial plane.
Fig. 4.5  Schistosity defined by tremolite prisms parallel to gneissic banding in calc-silicate gneiss under crossed polars. Large round grains of older hornblende seen.

Fig. 4.6  Dextral D, fold in calc-silicate gneiss seen near the 428m peak with a prominent axial planar cleavage on plan. The trend of the cleavage is 10° - 190° and the trend of the compositional bands (S.) in the limb region is 30° - 210°. The length of the chisel is 12 inches.
Fig. 4.7  Darker amphibole-biotite rich layers and lighter quartz-feldspar-epidote layers in banded amphibolite seen on a vertical section facing south near Birantiya village. Elliptical pods of lighter material seen to be appressed between the gneissic banding. Length of the bar is 1 feet.
Fig. 4.8 and 4.9. Crude banding in the banded amphibolite with hornblende rich and quartz-feldspar rich bands. Alignment of hornblende prisms is parallel to banding. Quartz-feldspar form a fine grained granoblastic mosaic. Elongated quartz grains are also aligned parallel to the gneissosity. Fig. 4.8 is under plane polarised light, while Fig. 4.9 is under crossed polars.
Fig. 4.10  Schistosity defined by the parallel alignment of biotite and muscovite flakes in the matrix of Barr Conglomerate, under crossed polars.

Fig. 4.11  Main schistosity and oblique sigmoidal S-planes in matrix of Barr Conglomerate seen on plan south of Barr along the Highway. Main schistosity acting as C-plane and angular relation with S-planes indicate dextral sense of shear.
Fig. 4.12  Thin section drawn from a hinge region of D, fold in the mica schists. Biotite rich domains alternate with quartz rich domains indicating a primary layering in the rock ($S_0$). Note that the biotite flakes are aligned parallel to form the schistosity ($S_1$) in the rock. The mica flakes within the layerings are also aligned parallel to the $S$, fabric Photograph under plane polarized light.

Fig. 4.13  Biotitic laminae and streaks enclosing lenticular quartzofeldspathic domains forming an anastomosing pattern. Coarser grains of quartz and feldspar embedded in a finer grained matrix of the same composition. Photograph under plane polarized light.
Fig. 4.14  Pressure Solution seams (which are parallel to axial planes of a D₂ fold) cutting across the compositional layering as seen on plan within a carbonate rich part of calc-silicate gneiss.

Fig. 4.15  Exposure of a sheath fold with a steeply plunging axis within the thinly bedded quartzite immediately west of Nandna marble.
Fig. 4.16 Plot of bedding surfaces (A) and the fold axis (B) within the thinly bedded quartzite describing the sheath fold of (4.15).
Fig. 4.17 and 4.18  Quartzite pebbles oriented in a downdip manner giving rise to a lineation on the schistosity surface in Barr Conglomerate (4.17). Elongation of pebble parallel to lineation. Subhorizontal tensile fractures, nearly perpendicular to lineation seen. In some instances where the matrix is more micaceous, the matrix that envelops the pebbles show development of small subhorizontal puckers (4.18). Diameter of the coin is 2.3 cm.
Fig. 4.19  Dextral $D_1$ fold seen on plan. A weakly developed axial planar cleavage, at an angle to compositional banding on short limb, subparallel to banding on long limb is seen. Length of the hammer is 14 inches.

Fig. 4.20  $D_1$ fold sinistral on plan seen within the calc silicate gneiss near the 428 m peak. The composite $S_1$-$S_2$ is folded without the development of any axial planar fabric, unlike the $D_1$ folds.
Fig. 4.21 Open D, fold seen on plan within the calc-silicate gneiss near the 428m peak. No axial planar fabric develops in the rock. Minor M and W shaped folds seen along the hinge region.

Fig. 4.22 D, dextral kink bending the foliation within the matrix and flattened pebble in Barr conglomerate near Ramdev Temple. Towards right the kink passes into a series of en echelon cracks almost parallel to the axial plane of the kink folds.
Fig. 4.23  Field sketch of a Type III interference pattern exposed on a plan, seen within the calc silicate gneisses south of Birantiya. Note that the compositional bands are folded by \( D_1 \) and \( D_2 \), with a weak banding along it. Length of the Bar 1 feet.

Fig. 4.24  Extremely fine grained mylonitised matrix of Nandna marble, under plane polarized light. Folded biotite porphyroclast is seen within the marble along with some deformed quartzose porphyroclasts. Smaller clasts of bitotite and quartzofeldspathic fragments are also present.
Figs. 4.25 and 4.26  Porphyroclasts of aggregates of quartz+feldspar+carbonates (in 4.25) and quartz (in 4.26) in the mylonitized matrix of Nandna marble. The quartz grains show strong intracrystalline deformation and dynamic recrystallization. In 4.26 thin ribbons of quartz are sigmoidally bent and at an angles to the foliation in the rock, indicating dynamic recrystallisation along incremental extensional directions in relation to the shearing event. Photograph under crossed polarized light.
Fig. 4.27  Mylonitic banding within fine grained Nandna Marble cut across by later fractures. Photograph under crossed polarized light.

Fig. 4.28  Quartzose - mylonite adjacent to the Nandna Marble. The rock contains angular clasts of mylonite set in a ferruginous matrix. The mylonitic fragments show a fine grained quartzose matrix with porphyroclasts of quartz, feldspar and mica. Note the anastomosing fractures, which indicates a brittle deformation post-dates the ductile deformation that produced the mylonite. Photograph under crossed polarized light.
Fig. 4.29 Quartz-mylonite adjacent to the Nandna marble. A quartz porphyroclast shows deformation lamellae. A fabric oblique to the mylonitic banding (s-bands) defined by dynamically recrystallised quartz grain shows sigmoidal shape. Photograph under crossed polarized light.

Fig. 4.30 Core and mantle structure in a quartz porphyroclast showing deformation bands in quartz-mylonite adjacent to the Nandna marble. Photograph under crossed polarized light.
Figs. 4.31 and 4.32  Quartz-mylonite near the Nandna marble. The quartz porphyroclasts are elongated oblique to the banding (4.31). The individual porphyroclasts are dynamically recrystallised into long oblique ribbons (4.32). Note that the ribbons in the porphyroclasts are steeper than the elongation direction of the porphyroclasts themselves due to progressive dynamic recrystallisation (4.31). Photograph under crossed polarized light.
Figs. 4.33 and 4.34  Porphyroclasts of muscovite in the quartz-mylonite west of Nandna marble. The porphyroclasts are kinked (4.33) or deformed to mica fishes (4.34). The lower one has the form of mica fish oblique to the mylonitic banding. The elongation of the muscovite in 4.33 is oblique to the (001) cleavage. Photograph under crossed polarized light.
Fig. 4.35 and 4.36  Brecciated mylonitised Nandna marble. Note the anastomosing network of fractures and angular blocks of quartz and carbonates. Zones of intense fractures are seen in the bottom right corner of 4.35. A very fine grained carbonate gouge fills up the fractures in 4.36. Photograph under crossed polarized light.
Fig. 4.37 Mylonitic foliation shows sigmoidal drag near the fracture, indicating movement along the fracture surface within the mylonised Nandna marble. Photograph under crossed polarised light.
Fig. 4.38 Thin streaks of pseudotachylite within the mylonitised band with clasts of quartz in quartz-mylonite. Photograph under crossed polarized light.

Fig. 4.39 Exposure of a quartzite pebble on plan surface within the Barr conglomerate. Note the characteristic shape of pebble (double hockey stick shape) and asymmetric deflection of foliation in the matrix caused by dextral shear. Length of the pen is 7 inches.
Fig. 4.40  Dextral minor folds with axial planar fabric developed within the matrix of the Barr conglomerate indicating compression perpendicular to the axial plane.

Fig. 4.41  Deformed and metamorphosed acid volcanics. At the bottom right of the photograph, a bent flake of muscovite is seen which is roughly parallel to the schistosity in the rock. Note that thin elongated streaks of quartz are oriented at an angle to this schistosity, as a result of dynamic recrystallisation. Photograph under crossed polarized light.
Fig. 4.42 and 4.43  Shear bands seen in a microscopic scale within the metamorphosed acid volcanics of the area. Note that the alignment of the quartz grains is dextrally oriented with the foliation in the rock. This represents a S-C fabric in a microscopic domain. 4.43 is a blow up of the area marked by the box in 4.42. Photographs under crossed polarized light.
Fig. 4.44 Development of a spaced cleavage ($S_2$) oblique to compositional banding in calc-silicate gneisses, near Megarda ($P$). The acute angle relation corresponds to sinistral sense. An extensional shear plane has developed subparallel to the spaced cleavage indicating dextral movement sense. A schematic reconstruction of the above feature is shown in A, B and C. The $D_2$ has produced a spaced $S_1$ imprinted on $S'$ (or $S_0$) with a sinistral sense of asymmetry (A). On the longer limb shear planes ($S$) developed parallel to $S_1$, the sense of shear being dextral (B). This results in a sinuous shift of the $S_1$ fabric (C), quite similar to the photograph above.
Fig. 4.45 Cartoon showing the gradual development of the structural regime of the area. (I) shows the rocks were first flattened across the strike. Note that the pebble (marked by solid ellipse in this figure) retains the elliptical geometry even after the flattening. Subsequent to this flattening, the rocks were subjected to a prolonged phase of sub-horizontal simple shear (II). This resulted in the asymmetry of the pebble orientation, mostly dextral in nature. Note that there is however no asymmetry in the vertical section.
Fig. 4.46  Trend map of the schistosity ($S_1$, $S_2$) and the gneissosity measured in the study area.
Fig. 4.47 Generalised trend map of the linear structures of the area
Fig. 4.48 Equal area projection of 195 poles to compositional banding within the biotitic marble, calc-silicate gneiss and amphibolite

Fig. 4.49 Equal area projection of the 737 poles to schistosity (SJ) measured within the quartzite, acid volcanics, conglomerate and mica schist of the area
Fig. 4.50 Equal area projection of 52 pebble long axis lineations within the conglomerate.

Fig. 4.51 Equal area projection of 247 mineral lineations within the amphibolite.

Fig. 4.52 Equal area projections of the 80 undifferentiated D1/D2 minor fold axes along with the intersection lineation and striping lineation within the calc-silicate rocks and biotitic marble.