Polyphase deformation seems to be the rule rather than an exception in orogenic belts all over the world, particularly so in the Precambrian formations. This recognition has come in the light of detailed structural work carried out in different belts. In such complexly deformed belts the study of minor structure (mesoscopic scale, Weiss, 1963) assumes great importance and their study and proper evaluation is an essential part of modern structural investigations (Ramsay, 1960; Clifford et al. 1967; Wilson, 1961). Structural maps showing all relevant data can be largely self explanatory.
The interference patterns that result from the superposed deformation can also become clear from the outcrop pattern in the map (Ramsay, 1962, 1967; Tobisch 1967; White and Jahns, 1950; Reynolds and Holmes, 1954; Naha et al. 1968, 1969). However it must be recognised that such interference patterns become obvious only when the scale of the interfering structures is of the same order. Map pattern in complexly deformed areas could appear deceptively simple when the order of the scale of the structures is highly contrasting or when the area under investigation is limited to a small portion of a large pattern. But in both cases the study of minor structure can be extremely useful in recognising the complex deformation. The present area under investigation is one such with a simple map pattern but the study of minor structures belies this impression. A proper evaluation and appreciation of the geometry of the minor structures in areas of polyphase deformation, although by no means easy, can be of great help in understanding the structural evolution of an area.

In the present study careful attention was paid to the study of minor structures such as mesoscopic folds, their axial surfaces and axes, refolded folds, cleavages, lineations and their inter-relationships. On the basis of these studies the structural history of the area has been worked out.
In all, five deformational episodes have been recognized in this area. A brief account of the broad geometry of these different folds is given here.

**F<sub>1</sub>** folds: The earliest folds recognised in the area are tight to isoclinal with a sharp hinge line or a narrow hinge zone. The axial surfaces of **F<sub>1</sub>** folds commonly trends NNE-SSW to NE-SW and the axes are sub-horizontal (Pl.16.1). They have highly attenuated limbs. These are considered as the earliest, as at no place do they modify or refold any other structure in the entire area.

A very penetrative cleavage is developed during this deformational episode. The relationship of the cleavage and bedding is very clearly seen in the mesoscopic folds where it is parallel to the axial surface of the **F<sub>1</sub>** folds. No major first fold closure is seen in the entire area under study where this relationship could become clear in the map. In all later folds the cleavage/schistosity and bedding are folded together and they are nearly parallel to each other.

These folds are either flattened folds closely resembling similar folds (Class 10 of Ramsay, 1967, p.367) or similar folds themselves. At times the **F<sub>1</sub>** folds closely resemble the later **F<sub>3</sub>** folds that it is difficult to make a
distinction. Because of the superposed nature of the deformation these early folds must have been very much rotated and the initial attitude of these folds is uncertain.

\[\text{F}_2\] folds: In the second phase of folding the rocks have been folded into tight to isoclinal folds, the axial surfaces and axes of which have highly variable attitude. The \[\text{F}_2\] folds are recumbant as well as reclined, depending upon their position with respect to later folds. The axial surface of these folds trends NNE-SSW to ENE-WSW and the axes vary in plunge from horizontal to as high as 75° or so. Undoubtedly, the large variation in the trend of axial surface and plunge (direction and amount) is related and controlled by the later superposed folds. Evidence to this effect is overwhelming. At Srinagar, in a single outcrop one can trace the recumbant folds gradually becoming reclined. In the hinge zone of the \[\text{F}_3\] folds, which is generally broad, the \[\text{F}_2\] folds are recumbent (Pl.17.2) whereas in the limb region they are reclined (Pl.17.1).

\[\text{F}_2\] folds are sparsely seen in the area and wherever present they are on mesoscopic scale only. Some of the best examples of these folds are seen in the conglomerate quartzite formation particularly towards its contact with amphibolite, in the \[\text{F}_3\] folds closure region, north of Srinagar. Plate 20.3
shows the hinge of an $F_1$ fold which is folded by $F_2$ and $F_3$ folds. Plate 17.3 shows the hinge of an $F_2$ fold folded by $F_3$, in which $F_1$ lineation is seen curving round the $F_2$ axis.

A strong steeply plunging lineation representing this folding (Pl.13.3) has been recorded at several places in the quartzites and the amphibolite. Plate 19.3 shows the hinge of an open $F_3$ fold on which $F_2$ lineation is almost at right angles to $F_3$ axis.

The cleavage developed in the $F_1$ deformation is folded along with bedding in these folds. No development of cleavage during this deformation has been observed in the entire area.

$F_3$ folds: In the third phase of folding, the early folded structures are folded into close to tight, nearly upright, broad hinged folds (Pl. 18.1, 18.2). The axial surfaces of these folds ($F_3$) trend NNE-SSW to N-S and the axes have highly variable plunge amount but the plunge direction always lies in the axial surface, i.e. the axial surface is generally planar while the plunge is not constant. These folds are the most common and obvious in all rock types in the area. Perhaps this is the folding which to some extent is reflected in Heron's map (1953) and most of the references in his Memoir are probably to these folds.
The $F_3$ folds are typical parallel or concentric folds modified by varying degrees of flattening. The folds not only die out in a vertical direction, a common feature of parallel folds, but also die out in strike direction. Excellent examples of $F_3$ folds on mesoscopic and outcrop scale displaying plunge variation (Pl. 18.3, 19.1) from almost horizontal to vertical can be seen at several places. The inconsistency in plunge can be best explained by flattening involving inhomogeneous flow (Ramsay, 1962; Brown et al., 1972), which seems to be a characteristic feature of this folding episode. However, it is uncertain whether the regional variation of the same is related to this process or is a reflection of the superposition of later folds.

Excellent evidence of deformation of first and second folds by the $F_3$ is seen in the area. Plate 16.3 and 20.1 show a refolded fold in which an $F_1$ fold is folded by an open $F_3$ folds and the axes of the two folds are nearly parallel. The relationship between the first three structures is clearly displayed in a specimen (Pl. 17.3) where the second fold is refolded by the third fold. On the hinge of the second fold a distinct lineation is seen curving round the hinge which represents an $F_1$ structure.
A strong lineation is developed parallel to the axes of these \( F_3 \) folds throughout the area. In the quartzites, grits and amphibolite a poorly developed fracture cleavage, parallel to the axial surface of these folds can be seen (Pl. 21.3). This cleavage is, however, restricted to a few outcrops only.

\( F_4 \) folds: The \( F_4 \) folds are generally open to gentle folds. They are usually associated with kinks in the amphibolite and mica schist (Pl. 18.1). The axial surface of these folds is moderately dipping and has a \( NNW \) trend. The \( F_4 \) axes have variable trend and plunge amounts because of the superposition of these folds on differently oriented surfaces as well due to later almost \( E-W \) gentle warps. At a few places these folds affect the \( F_3 \) axes which take sinuous turn generally between north-south and east-west, otherwise the \( F_3 \) axes plunge \( NNE \) and \( SSW \) resulting in the formation of dome and basin structure, which is seen in mesoscopic as well as on a major scale in the area (Pl. 18a.3, 21.1). This deformation \( (F_4) \) is well displayed in the geological map. A weak cleavage parallel to the axial surface of these folds is developed in the mica schist and at a few places in the amphibolites and quartzites.

\( F_5 \) Folds: Some very open flexures with vertical to sub-vertical axial surfaces and steeply plunging axes belong to
this phase of deformation. Since this is superposed on diversely oriented surfaces the plunge direction and amount is highly variable. These structures, being the last, have in different degrees affected all other earlier structures.

The folds $F_1$ to $F_5$, all owe their origin to flexure-slip. Only the $F_1$ folds have some resemblance with similar folds Class 1C, otherwise the rest of the folds are typical class 1A or 1B of Ramsay (1967, p.367). The orthogonal thickness '$t'$ is generally of the same order in all regions of the fold, however in some cases certain amount of flattening has modified it to some extent. Disharmonic folds, reversal of curvature in the hinge area, a general compliance of the competency law and congruous drag folds all indicate their origin to flexural slip. Sen (1972) also regards the folds as of flexural slip origin in Rajgarh area.

At this stage it would seem worthwhile to make a comparison of the structures and their chronology with those of other areas, although very little work has been accomplished on Delhi rocks. The work of Gangopadhyay and Sen (1968) and Bhattacharya (1970) is on areas which are almost 150 miles from the area under study and is of very preliminary nature. Detailed accounts have yet to come in print. There are only two published accounts which deal with the structure of the
Delhi rocks and are within reasonable limits to make a comparison. Rajgarh (Sen, 1972) and Sheopura (Mitra, 1970) are 13 and 60 miles respectively from Srinagar.

Sen's description of the geometry of the folds shows that the folds do not have any style. He also mentions that if $F_{II}$ and $f_1$ and $f_2$ of $F_{III}$ cannot always be identified (ibid, p.190). His map shows only $f_1$ and $f_2$ axial traces. The sketches and descriptions are also not lucid enough to make a comparison. His fig. 1-d illustrates the relationship between $F_{II}$ and $f_2$ of $F_{III}$ which is identical with the $F_2$ and $F_3$ relationship of Srinagar area. A broad general comparison indicating the equivalence of structures is given in Table 1.

**Large scale interference patterns:**

No large scale interference pattern is reflected by the outcrop pattern in the geological map. However, the structural map clearly shows the dome basin pattern (Type 1 of Ramsay, 1962). This pattern is common and can be seen on all scales, from a hand specimen to a large outcrop scale.

It has already been shown in the earlier pages that the $F_3$ folds are close to tight and have steeply inclined NNE-SSW trending axial surfaces and these are the only large scale structures. The quartzite hills west of Srinagar, east
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<td>Mitra 1970</td>
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<tr>
<td>F₁ Isoclinal, reclined, dead folds with acute rounded hinge on a mesoscopic scale.</td>
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<tr>
<td>F₂ Only major structures, open, asymmetrical low amplitude folds with a NE-SW axes</td>
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<td>F₃ NW-SE trending broad warps on a mesoscopic scale.</td>
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of Barla and Budhol and west of Nareli are all large scale \( F_3 \) folds. The \( F_4 \) folds are open to close folds with NNW trending axial surfaces and are superposed on all early structures.

The interference of these \( F_3 \) and \( F_4 \) folds resulted in dome and basin structure (Type 1 of Ramsay, 1962). The theoretical aspects of the formation of dome and basin by a single phase of folding (de Sitter, 1956; Wunderlich, 1963; Nicholson, 1963) and by two phases of folding (Weiss, 1959; O'Driscoll, 1962; Ramsay, 1962; Tobisch, 1966) have been discussed by several authors. Ramsay (1962, p.473) has suggested certain criteria by which these two different types of structures can be identified. If we apply the same criteria it becomes clear that the dome and basin pattern in the present area has resulted from two phase deformation. The presence of two sets of axial surfaces and sometimes even development of a cleavage although limited to the closure region of the folds and variation in plunge direction by more than 90° are indicative of a two phase deformation in the development of dome and basin patterns.

The shape and form of the domes and basins have been explained (Ramsay, 1962; Carey, 1962; Tobisch, 1966) as due to difference in the wavelength and amplitude of the
interfering structures and/or flattening. In Srinagar the domes are elongated in the $F_3$ direction which is related to the high amplitude of $F_3$ as compared to $F_4$ folds. It may also be noted that the axial surfaces of the two structures are oblique to each other.

The conglomerates, exposed west and south of Srinagar and the quartzites west of Nareli display dome and basin structure, which is clear from the bedding/cleavage pattern only. No large scale closures are seen in the area. West of Srinagar in the conglomerates some very good examples of dome and basin structure can be seen which are obvious from the structural map (Pl.3). South of Srinagar a large basin is seen which shows the development of centripetal drainage.

Dome and basin structures, both on small and large scale are also developed in the quartzites near the 5th milestone. The circular hill south of the Ajmer-Srinagar road is a basin in the quartzite.

The dome and basin type of interference pattern is well developed and preserved in the more resistant formations. In the amphibolites and mica schists they have not been noticed.
Interference patterns on a small scale:

Interference patterns of all the three types described by Ramsay (1962) are seen on a small scale (from that of a hard specimen to at best a small outcrop) are seen in the amphibolites and the quartzites. Five successive episodes of deformation have been recognised in this area and a short account of the geometry of the folds generated in these episodes is already described. In such repeatedly deformed rocks interference patterns should naturally be present.

**Type 1:** The interference of $F_3$ and $F_4$ folds results in the dome basin pattern and this has already been described in some details.

**Type 2:** Typical mushroom and lobate forms of interference patterns (Ramsay, 1962) are seen in these rocks (Pl. 22.3, 23.2). In this type of interference pattern the early folds are refolded by later folds such that the axial surfaces of the first folds become folded with the limbs of the first folds. The hinges of the early folds are bowed up or down and the limbs become refolded into common antiforms and synforms. The geometry of the early folds is highly variable and is also dependant on the tightness (or inter limb angle) of the later folds. In the hinge zone and the limb region
of the later folds the early folds have a different geometry.

In the present area $F_2$ folds are tight and sometimes isoclinal recumbent to recline with their axes approximately in the NW-SE directions. These folds have been superposed by $F_3$ folds which are upright and whose axes are NNE-SSW. The relationship between $F_2$ and $F_3$ folds closely conforms with the conditions necessary for the production of Type 2 interference patterns. Generally small scale mushroom pattern and lobate forms have been noticed and some excellent examples on an outcrop scale of this interference can be seen in the contact zone of the conglomerate with the amphibolite (Pl.23.1).

**Type 3**: In this type of interference pattern the early folds are refolded such that their axial surfaces and limbs are folded by the later folds. The hinges of the early folds are however unaffected and they are subparallel to the later fold hinges. Continuously converging and diverging outcrops characterise this type of interference. In the present area the superposition of $F_3$ over $F_1$ results in typical type 3 patterns (Pl.24.1). Co-axial structures with $F_3$ and $F_1$ hinges parallel to each other are very common (Pl.20.1,20.2). In several $F_3$ hinge zones the $F_1$ structures have been observed. The early attitude of the $F_1$ folds is uncertain.
Regional structure of the area:

Heron (1953) attempted to give a broad picture of the general structure of the Delhi rocks and also drew a number of sections to make clear his interpretation. It is unfortunate that his description and sections do not tally when examined closely. Many of these sections seem to be artificial and modelled to suit his interpretation. One such section is drawn between Ajmer and Srinagar.

His identification of different quartzites into Alwar and Ajabgarh appears largely arbitrary, having no relation with the structure. The fault he has marked at the base of the eastern side of the hill, west of Nareli, is also based on evidence of a very doubtful nature. These points have already been touched upon in Chapter II.

All the descriptions of Heron (1953) refer essentially to NNE-SSW trending folds which are now recognised as $F_3$ folds in this area. The regional trend of the Delhi rocks in this area and elsewhere as well is largely determined by these folds. In the following pages the major structure of the area in terms of $F_3$ folds is discussed.

With the limits of the area under study no impressive closures are seen which could have made the structure self
evident. The structural mapping carried out in the area at least brings out $F_3$ and $F_4$ structures. The regional NNE-SSW trend of the Delhi rocks is largely controlled by the $F_3$ folds. These are essentially parallel folds which show some flattening and so the folds become tight with near vertical beds in the core. The $F_3$ axial surface traces are not only inferred from the cleavage, bedding attitudes but also by studying the location of 'S', 'Z' and 'M' shaped folds of $F_3$ deformation.

On the eastern side of the boundary in the map, are exposed Pre-Delhi schists which dip at moderately high angles towards west. These are overlain by basal Delhis, which also dip towards west near its contact with underlying Pre-Delhi schists. The repetition of beds due to folding is very clearly seen in the geological map (Pl.3). The ridge with 2531 and 2219 peak is nearly parallel to the axis of the major antiform which forms a closure north of Srinagar. To the east of it is a synform.

It has already been discussed in previous pages that due to the interference of $F_3$ and $F_4$ structures, dome and basin structure has developed in these rocks, particularly in the area west and south of Srinagar.
The undulating country between Srinagar conglomerates/quartzites and the double ridge (2070') is occupied by different mica schists and amphibolites which have a uniform westerly dip and no major $F_3$ folds have been observed in them.

The double ridge of quartzite (2070') with amphibolite, calc schist on either side and in the valley portion, is made up of two synforms in the quartzite and a sandwiched antiformal valley. This is based on the recognition of the amphibolite, calc schist band as one and the same and on structural evidence such as cleavage/bedding attitude and location of 'S','Z' and 'M' shaped minor folds.

Heron (1953, p.210) considered the broad Nareli valley between the hills east of Barla and west of Nareli to be a anticline. The present study also confirms that Nareli valley is an antiform occupied by garnet mica schist, the outcrop width of which has increased due to subsidiary folds in it. Inspite of a large area concealed under quartz, pegmatite vein debris and soil, the cleavage pattern clearly brings out the antiformal structure.

The quartzite in the hills west of Nareli dips towards west near its contact with the underlying garnet mica schist
or limestone/marble. The quartzite displays a synform towards the east and an antiform towards the west, which are clearly brought out in the structural map. The axes of these larger structures run almost NNE through the crest of the hill. The beds are nearly vertical in the core of the folds and steeply dipping in the limbs, indicating that they are fairly tight folds. The quartzite does not show any specific closures but the main hills represent folds of third episode \( F_3 \) over which are superposed folds of fourth episode \( F_4 \) which results in the formation of dome and basin structure. The large circular hill (Sulia Dangar, 2396') south of the Ajmer-Srinagar road is a basin in the quartzite, which due to differential weathering of quartzite and mica schist, forms a hill feature.

The fault which Heron (1953) considered to be passing through the eastern foot of the hills west of Nareli, is very much doubtful, as no field evidence to this affect is seen in the area. The main point brought in support of a fault by Heron is that the strike of the quartzites shows an abrupt swing from the general NNE trend. The present study clearly shows that the northwesterly swing is due to superposition of \( F_4 \) folds over \( F_3 \) (Pl.4). No major faults have been seen in the area. Two small faults causing minor displacement are seen in the northern portion of the area.

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