CHAPTER V.

STRUCTURAL ANALYSIS OF THE AREA

The Precambrian rocks almost all over the world have a complicated deformational history and show structures of more than one deformational episode. The Delhi belt of metamorphic rocks (Proterozoic?) is one such belt which has undergone polyphase deformation. The area under study involves five folding episodes but the structural map displays only two trends. It has already been pointed out that the scale of the structures is important and the map becomes self-explanatory only when the scale of the structure is comparable to the scale of the map. Even in cases where the map displays all the different structures, it is only in selected areas that structures of a particular episode are prominent and may even be exclusively developed. It is
much less likely that a given area will exhibit structures of different episodes to the same order of importance.

In structural analysis it is customary to divide the area into small domains by a careful scrutiny of the map and to some extent by trial and error where the major structure in that domain is expected to be cylindrical. Although the minor structures may clearly show that the domain is non-cylindrical yet on a larger scale the domain can be statistically cylindrical. Treatment of data in such small domains could yield a general picture of the geometry of the major structure. In areas of polyphase deformation it is advantageous and useful to sort out the data in small domains and treat them independently for an evaluation of the geometry of the structure. Sometimes it is useful to combine two domains and treat the data. However, this method should never be regarded as unique and always potential of yielding results. In an area, as the present one is, this method of analysis has very serious limitations. When S-poles or $\beta$-pole diagrams are constructed, the diagrams display only one or two sets of structures ($F_3$ and $F_5$, in case of area under study). Other structures which are present in a mesoscopic scale hardly become known through these diagrams. So the study of minor structures is imperative for a proper understanding of the deformational history. The S-pole and $\beta$-pole diagrams
can only supplement and support what is actually seen in the rocks and plotted on the map.

Synoptic diagrams which are also traditionally drawn have their own use. Although they tend to conceal some of the less prominent features they do show, however, the prominent regional trends.

Treatment of data:

The treatment of data should be such that there is balance between the quantum of data and the treatment. No amount of elaborate processing of limited data can be of any extra use. At the same time it would be futile to amass data if it is not properly processed. Further, the need of such treatment is also a very important factor related to the purpose.

In the present case the area is divided into six sectors/domains, and in all cases S-pole diagrams are constructed. The term S-pole diagram (Turner and Weiss, 1963) is adopted here in the text. No $\beta$-pole diagrams have been prepared on several counts. The $\beta$-pole diagrams have certain serious limitations. The number of inter-section points that result from a comparatively few S-surfaces is very high. A
hundred $S$-surfaces would yield as many as 2450 intersection points, which is quite unmanageable to contour. It has been thoroughly shown that the $\beta$-intersection does not always point out a fold axis. A $\beta$ maximum could be regarded as a fold axis, only when such an axis is actually seen in the field. Further in the construction of a $\beta$ diagram it is necessary that all the surfaces so treated belong to the same generation. Interpretation of $\beta$-diagrams has to be supported from actual field observations. Spurious $\beta$-concentrations can lead to erroneous conclusions.

**Geometry of Bedding and Cleavage:**

It has already been shown that in the grits and quartzites, the primary planar element bedding is easily recognised. In the amphibolites and pelitic schists where psammitic bands are present, bedding is easily recognisable. A schistosity or cleavage is well developed parallel to bedding surface in almost all the lithological types. This schistosity or cleavage is developed during the first deformation which resulted in isoclinal folding. Since no major first folds are present in the area the relationship between the bedding and cleavage is obscure in the map but in mesoscopic $F_1$ folds one can see the cleavage/schistosity cutting across the hinge zone. So in all the later deformations bedding and this cleavage have
behaved like a single surface.

The area under study has a complete overprinting of structures and so one should expect to see no regularity in the attitudes of S-surfaces, particularly the early ones. However, the map does not show all that randomness in the attitudes; the main reason being that a number of structures are seen only in the mesoscopic scale. The strike direction of the vertical surfaces and the dip directions of the minimum values of the dip are the indicators of fold axial trends, which could be of considerable help in simple map patterns but are of relatively much less value in complex patterns. The area is divided into six domains which are considered to be statistically cylindrical. S-pole diagrams have been drawn for all these domains.

**S-pole diagrams of bedding and cleavage:**

Most of the S-pole diagrams of the different domains of the area under consideration show only incomplete girdles and some are inhomogeneous. Girdles in S-pole diagrams clearly indicate folding. If the average trend of the axial surface is known and plotted in the diagram, the fold can also be specified as upright, overturned, plunging inclined, reclined and so on. Inhomogeneous domains indicate possibility of
overprinting of one structure over the other. In almost all the diagrams no full girdle is seen. It is due to the fact that attitudes from the hinge region of the folds are lacking. The poles of the most prominent girdle in all diagrams indicate the F₃ fold axis. At no place F₂ and F₁ axis are brought out in these diagrams. The spread of the poles also suggests a second girdle, the pole of which indicates the F₅ axis. It is interesting to note that the main girdle in some S-pole diagrams can be drawn in two equally possible alternative (Pl.9 and 10) with reversal of plunge directions. This is consistent with the geometry of mesoscopic F₃ folds detailed earlier. The plunge amount of F₃ folds is highly variable changing from near horizontal to vertical in a matter of few feet. The alternative possible girdle may reflect this feature or may be due to superposition of F₄ folds.

**Sector A:**

The area covered in this sector is about 4.0 sq. miles and is composed of conglomerates, grits and quartzites of Delhi Group. A small area of Banded Gneissic Complex is also covered under this area which however, has been ignored.

The S-pole diagram (Pl.9.1) of bedding and cleavage (S₁ and S₂) of this sector shows 7 per cent and above maxima
towards the northwest and southeast with some amount of spreading. A unique girdle is not evident in this diagram. Two alternative girdles whose poles plunge at 10° in N30 and 10° in N210 can be drawn. A possible explanation has already been made for this feature.

The axes of the mesoscopic $F_3$ folds have also been plotted in this figure which cluster around the girdle pole. A few mesoscopic fold axes however, show a much higher plunge. The girdle pole obviously reflects the $F_3$ for $S_1$ and $S_2$ are included here and secondly $F_2$ structures have not been seen on a major scale. The general splay in the distribution of poles is due to the noncylindrical nature of the sector.

**Sector B:**

The area covered in this sector is relatively small (1.0 sq. mile) and includes quartzites, amphibolite, staurolite garnet mica schist and part of quartz mica schist. The prominent planar elements are bedding and cleavage/schistosity which is parallel to the bedding. $F_3$ lineations are prominent. $F_1$ and $F_2$ lineations are also recognisable in this sector.
Plate 9.2 is the S-pole diagram of bedding and cleavage/schistosity ($S_1$ and $S_2$). The figure shows a maxima in the east southeast of over 25 per cent. No clear girdle can be visualised as in the previous sector, but a probable girdle is drawn, the pole of which ($\beta$) has a subhorizontal plunge in a NNE direction showing the $F_3$ axis.

$F_3$ mesoscopic fold axes and other lineations plotted in the stereogram fall close to the $\beta$-pole of the diagram. Some fold axes show a greater plunge amount and some plot in opposite direction as well. It has already been mentioned that the $F_3$ axes have a highly variable plunge which is seen even in mesoscopic scale.

**Sector C:**

The area covered under this sector is about 4.50 sq. miles and includes quartz mica schist, garnet mica schist, amphibolite and calc schist and quartzite. It is in this sector that the two antiforms in the quartzite with a sandwiched synform in amphibolite are described. The planar elements are bedding and cleavage ($S_1$ and $S_2$). The lineations that are common to this sector are mesoscopic fold axes and wrinkling lineations of the $F_3$ deformation. $F_2$ lineations are also sparingly seen.
The S-pole diagram (Pl.9.3) shows an elongate 9 per cent and above maxima in the southeast and northwest, suggesting a clear girdle. The absence of a complete girdle is probably due to absence of data from the hinge region of the folds. The pole of the girdle has a plunge of 8° in NNE direction which is in good agreement with the lineation data plotted in the stereogram.

**Sector D:**

The area of this sector is about 4.70 sq. miles and includes the same rock types as in sector C. The prominent planar elements are bedding and cleavage/schistosity ($S_1$ and $S_2$).

The S-pole diagram (Pl.9.4) shows a 8 per cent and above maxima in the southeast and northwest and is nearly a replica of the plot of sector C except that in this figure girdles in two alternative ways can be drawn giving plunge in the opposite direction for which a possible explanation has already been given in previous pages. Further there is an indication of the $F_5$ deformation in the figure. The contours of lower values indicate a peripheral girdle whose poles have high plunges in west-northwest and southwest direction.
The $F_3$ mesoscopic axes and other lineation plotted in the stereogram are in fair agreement with the $\beta$-pole of the stereogram.

**Sector B:**

The area covered in this sector includes the Nareli valley area of scanty outcrops (11.50 sq. miles). The rock types in this sector are garnet mica schist, impure limestone and quartzite. The prominent planar elements are bedding and cleavage/schistosity ($S_1$ and $S_2$) as in other sectors. The lineations are mainly of $F_3$ deformation, however, a few $F_1$ and $F_2$ lineations have also been observed in quartzites.

The $S$-pole diagram (Pl.10.1) of bedding and cleavage shows a 7 per cent maxima in the northwest and southeast. Here again no unique girdle can be drawn. The alternative girdles giving plunge in opposite directions are possible as in case of sector A and D. $F_3$ lineations plotted in the stereogram are fairly consistent with the $\beta$-pole of the diagram. The spread of the poles indicates the effect of $F_5$ deformation more impressively than in any other sector in the area. $F_5$ mesoscopic fold axes have very high plunges in direction which are in close agreement with the $\beta$-poles of the diagrams.
Sector F:

The area covered under this sector is about 6.50 sq. miles and includes the same formations as in sector E.

The S-pole diagram (Pl.10.2) shows the maxima of 6 per cent and above and the poles show some spreading. There is no clear girdle indicating the F₃ axes as in some other sectors. This is mainly because of paucity or absence of data from the hinge region of the folds. This is further complicated by F₅ deformation which has rendered the maxima considerably elongate and strongly suggestive of peripheral girdles. The probable girdle and its A-pole representing the F₃ axis is shown in the stereogram. The F₃ axis has a plunge of 10° in approximate NNE direction. The A-poles reflecting F₅ structure has a plunge of 50° in N90 and 10° in N280 directions. The lineation data is not inconsistent with the data of the stereogram.

Geometry of axial surfaces:

The attitude of the axial surfaces of folds is an important as any other data in statistical analysis. It has already been pointed out that the F₁ and F₂ folds are comparatively infrequent. The most common folds belong to F₃ episode. If the axial surface data of folds of different
generation are plotted in S-pole diagrams they could confirm the field observations. The interrelationships between \( F_1 \), \( F_2 \) and \( F_3 \) folds is unequivocally demonstrated in the field. Further, the \( F \) and \( F_2 \) axial surface attitude data are limited and not viable for plotting in S-pole diagrams. The axial surfaces of \( F_3 \) folds, however, have been plotted in a stereogram. They are generally steeply inclined on either side. The spread of poles around the peripheral maxima (Pl.10.4) is suggestive of these surfaces being involved in a later deformation. Peripheral girdle can be drawn the pole of which plunge at high angles to the east and west. The poles indicate that the \( F_5 \) axes which are intersection lines of steeply dipping \( F_5 \) axial surfaces with steeply dipping limbs of \( F_3 \) folds. \( F_4 \) folds are again limited and the effect of this folding on \( F_3 \) is not shown in the stereograms.

**Geometry of fold axis and lineations:**

In the areas of polyphase deformation the fold axes and related linear structures do not have a specific trend. The early linear elements have diversified trends since they are rotated during later deformations. The linear structures of later folding episodes also have some diversified trends since they are superposed on already folded and diversely
oriented S-surfaces. The later axes and related lineations have a rectilinear trend is a mistaken impression. It should be noted that the later structures are coincident with the intersection line of the axial surface of a later fold and the S-surfaces already undergoing deformation (Weiss and McIntyre, 1957; Weiss, 1959; Ramsay, 1960; Johnson, 1969). So in an area of polyphase deformation the linear structures could plunge almost in all directions. Further, it is always not possible to sort them out as to which generation of folding do they belong.

No plots of lineation are attempted here. The $F_3$ lineations in each sector have been plotted in the S-pole diagrams to show their agreement. It must be admitted that on several occasion the lineations could not be related to the folding episodes.