CHAPTER V

STRUCTURAL ANALYSIS

5.1. INTRODUCTION

The statistical analysis of the dominant structural elements like foliation ($S_1$), lineation ($L_1$) and joints planes are included in this study. The attitudes of foliations, lineations and joints planes were collected from the area during the field work. A maximum of 200 and minimum of 100 readings on each of the elements were collected from each of the locations.

All projections were made on the lower hemisphere of a Schmidt's equal area net. The poles of planar elements $S_1$ are plotted ($\beta$-diagram) and contoured by free counter method. In contour diagram (π diagram of Sander) the poles of circles in each case is plotted as $\beta S_1$.

In case of linear elements, the measurements in the field and laboratory analyses were carried out following the methods of Turner and Weiss (1963).

The plotting and contouring of joints planes were also carried out similarly to foliation planes (Billings, 1954; Turner and Weiss, 1963).
5.2. STRUCTURE OF THE BASEMENT COMPLEX

5.2.1. Foliation (S<sub>1</sub>)

The statistical representation of poles (β S<sub>1</sub>) to foliation (S<sub>1</sub>) of the rocks of basement complex show a near perfect point maximum, the poles of which are marked as β S<sub>1</sub> in the diagram (Fig. 42). The β S<sub>1</sub> coincides with the maximum defined by the fold of the first phase lineation (L<sub>1</sub>)(Fig. 44). The dip of the foliation which is gentle to moderate is towards NE and often SE. The β S<sub>1</sub> shows a variation in trend N 78° E to S 18° E with a plunge of 25°. This variation of trend is consistent with the planar and linear elements of D<sub>3</sub> (third phase deformation). The presence of F<sub>3</sub> fold is locally observed at Bynthor. The β-axis of the diagram showing low plunge in NE direction compare well with the folds of D<sub>3</sub> and therefore it is supposed that the pattern of orientation shown by the foliation was due to their re-orientation around the third phase folds (F<sub>3</sub>).

The plot of the foliation (S<sub>1</sub>) of the south-eastern part of the basement (Fig. 43) shows marked dissimilarity with that of north-western part (Fig. 42). Two distinct but incomplete girdles are defined, which indicate that the foliations (S<sub>1</sub>) in the complex of the south-eastern part were re-oriented in conjunction with the deformations that affected the overlying Manai Group of rocks.
5.2.2. Lineation (L₁)

The plots of the first phase lineation (L₁) on S show only slight variations of attitudes as revealed by a scattered distribution pattern (Fig. 44). In the field the mineral lineation is parallel to the minor fold axes, the rods and the s₀ \( \Lambda \) s₁ intersections, the plot of these lineations show an identical orientation and plunge to the same direction.

The plot of linear elements show a well defined maximum (Fig. 44) which gently plunges (25° - 30°) towards N 48° E. The centre of the maximum coincide with the S₁ (Fig. 42) of the foliation. The slight scatter of the plots of the lineation (L₁) in the diagram (Fig. 44) indicate influences of later foldings which caused local reorientation of both the first phase foliation (S₁) and lineation (L₁).

5.3. STRUCTURE OF THE MANAI GROUP

5.3.1. Foliation (S₁)

The attitudes of the dominant foliation (S₁) of the Manai Group of rocks are plotted (Figs. 45, 47) to bring out their significance as well as to show their differences to the dominant foliation (S₁) in the basement complex (Figs. 42, 43).
Polar projection of the foliation (s₁) affected by a large fold (f₃) at the Wausau village (Fig. 45) clearly shows the type of re-orientation undergone by the foliation. The spread of the poles to the foliation was caused due to their refolding by a very gently ENE plunging fold. The contoured diagrams constructed from the s₁ foliation in the basal sillimanite conglomerate (Fig. 46) and from the entire area (Fig. 47) also point to a similar type of re-orientation as was caused to the s₁ foliation by the f₃ fold at Wausau.

Both figures 46 and 47 indicate a dominant NE-SW trend with generally SE but often NW dip of the s₁ foliation. The statistical axes of the folds (f₃) that caused the re-orientation of the foliation (s₁) plunge at an average angle of 20° to the ENE.

5.3.2. Lineation (l₁)

A plot of the lineation in the sillimanite bearing conglomerate defines a near perfect maximum (Fig. 48) indicating a gentle to moderate plunge of the lineations to the ENE. However, the plot also shows a tendency of lateral spread which is supposed to have been caused by later refolding of the foliation (s₁) and the associated lineation (l₁).

The plot of the lineations (l₁) occurring in the schistose rocks of the area do not define a single maximum, but they fall in three distinct maxima, defining a near
perfect girdle (Fig. 49). This lateral spread of the plot of the lineations was supposed to have been caused by their re-orientation by later deformation.

5.4. ANALYSIS AND INTERPRETATION OF JOINTS

All the structural elements of the area are affected by the joints (Pl. III B) and thus they represent a tectonic event post-dating them. Several sets of joints, some of local but most of regional development, occur in the area. The nature and orientation of joints in the basement complex differ from those in the Manai Group. The pink gneiss in the basement complex and the quartzites in the Manai Group are comparatively more well-jointed than other rocks of the area.

The contoured diagrams (Figs. 50, 51) reveal the presence of four sets of joints in the gneissic complex and in relation to the regional foliation ($S_1$), these can be termed as cross-joints, longitudinal joints and diagonal joints. Horizontal sheetings are also sporadically present in the gneissic complex at the north-west part of the area (Fig. 50).

The contoured diagram of joints in the Manai Group (Fig. 51) reveals of preponderance of the cross and longitudinal joints in the rocks. Horizontal sheets are also frequent. The diagram does not show clearly the trend of the diagonal joints, but the spread of the plot of the joints indicate
their presence making small angle to the cross-joints.

The most important sets of joints in both the Group of rocks are the cross-joints which are perpendicular to the foliations ($S_1$ and $S_2$) in the rocks. They are well-developed both in the quartzofeldspathic gneisses (basement) and in the quartzites (Manai Group). Except cross-joints and to a certain extent the longitudinal joints, other joints are less numerous in the schistose rocks.

Relation of the joints to the dominant foliation both in the gneissic complex and in the Manai Group is thus broadly identical. However, the diagonal joints are not as well developed in the latter as they are in the former. The orientations of the joints in both the Groups are also nearly the same. It is therefore supposed that the joints in them developed under the same or identical tectonic fields.

The joints are the latest set of structures to be developed in both the groups of rocks. Thus, their development should have post-dated the latest phase of deformation that affected in upper Manai Group of rocks.

5.5. DISCUSSION

The present area revealed eight phases of deformation, four of these phase belong to the basement complex and the remaining four phases to the Manai Group.
The four phases of deformation, together with medium to high grade of metamorphism (chapter IX) in the basement complex, have made it difficult in determining the original structural forms of the rocks. However, the lithological layerings \((S_0)\) in the quartzofeldspathic gneiss are identified as the earliest structure in the basement rocks, representing the relics of the original bedded structure in a sedimentary pile.

The deformation of the lithological layerings \((S_0)\) during the first phase \((D_1)\) resulted in the formation of isoclinal folds \((F_1)\), which were associated with the development of axial planar foliation \((S_1)\) and lineation \((L_1)\). Thus, the isoclinal folds \((F_1)\) and the associated foliation \((S_1)\) and lineation \((L_1)\) are essentially syntectonic (Turner and Weiss, 1968).

The plots of planar \((S_1)\) and linear elements \((L_1)\), if the slight spreads of the folds caused due to later deformation are disregarded, show consistently uniform distribution of the poles of \(L_1\) (Fig. 44) throughout the whole basement complex.

The similarity of the structural elements shown by the rock units of the basement complex indicate that the lithological layerings and the boundaries of the rock units were originally parallel or nearly so. It is supposed that some of the rocks are of sedimentary derivation, the confor-
mity of the bands of amphibolites and other metasedimentary rocks with the layerings \( (S_0) \) in the quartzofeldspathic gneiss and continuity of structural elements in them indicate that they were originally horizontal or nearly so and parallel or sub-parallel to the original stratification planes. The presence of axial plane foliation \( (S_1) \) to isoclinal folds and dominant lineation \( (L_1) \) indicate that the amphibolites were emplaced not later than the early stages of deformation during which these structural elements \( (S_1, L_1, \text{ and } F_1) \) were developed.

The main stress axis during this phase of deformation \( (D_1) \) trends NW-SE. Slight variation to NNE-SSW is indicated by a variety of small-scale folds. This view was corroborated by the statistical analysis of planar and linear structures (Figs. 42, 44) with their concentration of poles consistent with NW-SE stress field.

The first phase of intense deformation \( (D_1) \) was followed by another phase of deformation \( (D_2) \) which was apparently of a mild intensity, finding expression in the form of small-scale folds \( (F_2) \). These folds folded both lithological layerings \( (S_0) \) and dominant foliation \( (S_1) \) in the quartzofeldspathic gneiss. Associated planar and linear structures (strain-slip cleavages, \( S_2 \)) and linear elements \( (L_2) \) were developed locally.
The main stress field components during this $D_2$ deformation might have acted from NW-SE. This is evident from the trend of planar and linear structures from $D_2$ deformation.

The third phase deformation ($D_3$) is characterised by the presence of large open folds ($F_3$) with the resultant development of axial planar fracture cleavages ($S_3$). Intersection of $S_3$ (fracture cleavage) with folded foliation ($S_4$) resulted in the development of an intersection lineation ($L_3$).

During the closing stages of $D_3$ deformation, a number of pegmatitic bodies developed in the area, were displaced by some minor faults trending N-S. Development of the faults are taken to mark the last phase of deformation ($D_4$) that affected the rocks of the basement complex.

The rocks of the Manai Group were also deformed by four different phases of deformation. The trend of metamorphism of the metasedimentary rocks is also similar to that shown by the rocks of the basement complex. The bedding planes and lithological layerings are the earliest structures ($s_0$) in the rocks of the Manai Group. The primary linear structure ($l_0$) is shown by the elongated pebbles in the conglomerate.

Subsequent to the consolidation of the rocks of the Manai Group they were deformed ($d_1$) when the dominant foliation ($s_1$) and lineation ($l_1$) and related isoclinal and
other type of folds ($f_j$) were formed. Because of the isoclinal nature of most of the folds, in most of the cases, the foliation ($s_1$) is parallel or nearly parallel to the lithological layerings ($s_0$) in the rocks. The angular relation between $s_0$ and $s_1$ is discernible only at the apex regions of the folds.

The main stress axis during this phase ($d_1$) of deformation was supposed to have been oriented in a NW-SE direction, which resulted in acquiring by the dominant foliation an NE-SW trend. This view was corroborated by the statistical analysis of planar and linear structures (Figs. 47, 49) with their concentration of points consistent with NW-SE stress field.

The $d_1$ deformation was followed by $d_2$ deformation. During this phase of deformation, shearing in the grey actinolite schist occurred and might have produced the shear-zones trending NE-SW in it. In these shear-zones, the dominant foliation ($s_1$), produced during the earlier phase of deformation, is destroyed and drawn parallel to the locally developed strain-slip cleavage. Intersection of the dominant foliation and the strain-slip cleavage produced $l_2$ (intersection lineation $s_1 (= s_0) \wedge s_2$). Recrystallization of mica along the cleavages ($s_2$) is locally widespread but very weak.

During the third phase deformation ($d_3$) the rocks became non-plastic as shown by the presence of open folds.
(f₃). No planar structures can be recognised that are consistent mesoscopically with this deformation. The only lineation produced were cringles (l₃) elongated parallel to the f₃ fold axes (Fig. 37).

Development of minor faults marked the last phase of deformation (d₄) that affected the structural elements developed during d₁, d₃ and d₃ deformations.

Jointing in the rocks of the whole area followed the last phase of deformation.
FIGURE 42. Equal area stereogram of $S_1$ foliation from north-eastern part of the basement complex, 210 points, contours 1, 3, 5, 7, 13 and 19%.

FIGURE 43. Equal area stereogram of $S_1$ foliation from south-eastern part of the basement complex. 200 points, contours 1, 2, 4, 6, 10 and 14%.
FIGURE 44. Equal area stereogram of linear elements 
(L₁) from the basement complex. 160 points, 
contours 1, 3, 6, 8, 12 and 15%.

FIGURE 45. Equal area stereogram of poles to s₁ 
foliation folded by large-scale folds 
(f₃) from Mawsaw village.
FIGURE 46. Equal area stereogram of $s_1$ foliation in sillimanite conglomerate from south of Nongbri village. 120 points, contours 1, 3, 6, 8, 12 and 15%.

FIGURE 47. Equal area stereogram of $s_1$ foliation of Manai Group of rocks. 180 points, contours 1, 2, 5, 7, 9 and 12%.
FIGURE 48. Equal area stereogram of linear elements (l₁) in sillimanite conglomerate from south of Nongbri village. 110 points, contours 1, 2, 4, 6 and 10%.

FIGURE 49. Equal area stereogram of linear elements (l₁) of Manai Group of rocks. 130 points, contours 1, 3, 6, 9 and 15%.
FIGURE 50. Equal area stereogram of poles to joints:  
I longitudinal joints, II cross-joints, III & IV diagonal joints. 350 joints from the  
Basement Complex. Contours 1, 3, 5, 7, 9 and 15%.

FIGURE 51. Equal area stereogram of poles to joints:  
I longitudinal joints, II cross-joints.  
300 joints from the Manai Group of rocks.  
Contours 1, 4, 6, 8, 10 and 12%. 