CHAPTER - II
STRUCTURE AND STRATIGRAPHY OF THE SHEAR ZONE ROCKS

A. GENERAL GEOLOGY

The rocks within the Singhbhum shear zone and adjacent areas represent a part of the pre-cambrian metamorphic terrain of eastern Singhbhum. These rocks consist of a pile of metasediments with large and innumerable intrusive and extrusive materials of different types emplaced during different times. Among these metasedimentary rocks, the less metamorphosed younger ones were deposited around the northern fringes of the Singhbhum granite basement while the highly metamorphosed older sediments (pre-Singhbhum granite in age) present in certain parts were intruded by the Singhbhum granite.

The Singhbhum shear zone includes mostly the less metamorphosed younger sediments and the rocks occurring within this zone are characterised by their extremely sheared nature, their lithological composition and their degree of metamorphism. But as the effect of shearing gradually dies out towards north and south, no definite boundary of the shear zone can be detected in the field. The boundaries of the shear zone shown in the maps are drawn in such a way that the zone includes the intensely sheared rocks. Present studies show that the trace of the northern and southern boundaries of the shear zone drawn on the above basis does not, necessarily, indicate a stratigraphic boundary. In fact, the rocks of different stratigraphic positions are cut across by this shear zone and have been intensely sheared.

The nature of the rocks present along the whole length of the
shear zone from west to east is almost similar, only there are some local changes in the composition of the meta-sedimentary rocks and the proportion of psammitic and pelitic materials varies widely from place to place. Highly metamorphosed rocks of pre-Singhbhum granite age are not encountered in the south-eastern part of the shear zone.

In the opinion of Dunn (1937) and Dunn and Dey (1942) these rocks were deformed by a compression directed from the north giving rise to an anticlinorium with a series of folds, the central part of which formed the axis of a chain of great mountains that extended more or less in an east to west direction, south of Tata-nagar. With progressive compression a great zone of overthrust developed along the southern limb of this great anticlinorium. The rocks to the north which had been completely metamorphosed, were thrust bodily against the less metamorphosed rocks to the south and along the zone of overthrust the rocks were closely and completely sheared.

The feldspathic schist and soda-granite occurrences are restricted within the zone of shearing as shown in the location map (fig. 1) and occur within structurally suitable sites. The extent of feldspathisation can be easily demarcated in the field. In the Tata-nagar area the zone of feldspathisation almost covers the whole of the shear zone. But in the Mosaboni area the feldspathic schist zone occupies the western part of the shear zone. (Plate I). The width of the shear zone is very narrow in the south-eastern part while the width increases towards west and it attains a maximum width of about three miles at the western part.
Within the feldspathic schists and gneisses, bands of unreplaced or partly replaced chlorite-schists, quartz-muscovite-biotite schists, chloritic and hematitic phyllites and thin impersistent patches of banded quartzites are common. Phyllites and quartzites are present only in the western part of the shear zone. In this part a thin slice of the mica-schists occurs at the northern part of the shear zone while another slice of chloritic and hematitic phyllites occurs at the southern part of the shear zone. An impersistent horizon of conglomerate lies between feldspathic schists and phyllites. Both the slices mentioned above are feldspathised while the rocks lying in the central part of the shear zone are intensely feldspathised. In south-eastern part, the feldspathic schist zone is demarcated by the meta-basic rocks to the west and mica schists (often garnetiferous) to the east. Both the rock units show the effects of feldspathisation and consequently the feldspathic schist zone includes a part of these rock units. Patches of unreplaced chlorite-biotite-schists are also common here. Coarse porphyroblasts of tourmaline and chloritoid occur abundantly within the feldspathic schists along the eastern flank of this zone. Lamprophyre dykes have been reported from the underground levels of Mosaboni and Badia mines, by Roy (1952) and Biswas et al (1966).

The rocks to the north of the shear zone consist predominantly of garnetiferous chlorite-biotite-schists, hornblende schists, amphibolites and a few ultrabasic rocks interbedded with bands of quartzites, quartz-mica-schists and quartz-kyanite granulites. This is the common rock association throughout the area lying to the north of the shear zone. At some places staurolite and kyanite
occur sporadically in garnetiferous mica-schists. These minerals are distinctly later than the schistosity, because these always cut across or disturb the planes of schistosity. In the south eastern part of the shear zone, a thin band of kyanite quartzite (average 50 yards) runs all along the shear zone, lying just north of it. Detached outcrops of these kyanite-quartzites appear to occur along a continuous horizon. Within these quartzites highly rich concentration of coarse kyanite aggregate is locally present (Fig. 2). Hornblende schists, amphibolite and ultrabasic rocks occur within the mica schists as small lenticular, isolated patches. Sedimentary structures are preserved in the psammitic rocks lying about a mile north-east of the shear zone.

The rocks to the south of the shear zone are of various types. The rock association present in the western part of the shear zone differs from those present in the south-eastern part. Banerji (1962, 1964) has grouped these rocks occurring to the south of Tatanagar into two groups, namely a group of chloritic and hematitic phyllites, slates, quartzites and tuffaceous and gritty rocks to the north and another group of sericitic phyllites, shales, sandstones, arkoses and arkosic conglomerates to the south. The Singhbhum granite, lying further south, shows distinct intrusive relations with the northern group of chloritic and hematitic phyllites at the south-eastern part of the area. But this granite has a long and continuous line of contact with the southern group of sericitic phyllites and the associated rocks. Over a large part of this contact, conglomerates, arkoses and sandstone intervene between the granite and the phyllites and the relation is clearly unconformable (Banerji, 1964). Thus the former group appears to be pre-Singhbhum granite in age while the latter group formed long
after the emplacement of Singhbhum granite and hence these are equivalent to Dhanjori stage.

The northern group of chloritic and hematitic phyllites and the associated rocks have a fairly wide outcrop in the southeastern part of Tatanagar area but gradually thin out in the western part, north-west of Ukam Pahar. The southern group of sericitic phyllites and the associated rocks have a fairly wide outcrop in the western part of the area. South of Tatanagar, a large group of basic rocks is emplaced within these phyllites (not shown in the map) and these rocks consist of fine to coarse grained metadolerites and epidiorites which are essentially chloritised actinolite-tremolite-schists and gneisses with altered plagioclase and rare relics of augite (Chowdhury, 1960, p. 64). The pattern of outcrop of these basic rocks indicates that these have been folded along with the surrounding phyllites (Banerjee, 1962).

In the south-eastern part of the shear zone, the rocks lying to the south-west are essentially quartzites and metabasic rocks (Dhanjori lava) belonging to the Dhanjori stages. The Dhanjori quartzites are composed predominantly of quartz with minor amount of micaceous minerals arranged parallel to the shear planes. The quartz grains show undulose extinction and marginal granulation (Fig. 4). Phyllitic rocks of pre-Singhbhum granite age are not common in this part. There is an imperistent band of conglomerates consisting of elongated pebbles of quartzite within a micaceous matrix, which separates these rocks from those of the shear zone (Biswas et al, 1966). The basic lava occurring near the shear zone are rich in sheared quartz (rarely epidote) amygdules. These amygdules are
of different sizes and are generally of elongated ellipsoid shape with commonly circular cross-section. At places, these basic rocks are highly sheared and a crude schistosity has developed in these rocks. In such rocks, the amygdules show a flat elliptical cross-section. Under the microscope, these quartz amygdules are recrystallised aggregates of fine grains and normally these amygdules are found to be surrounded by small grains of pyroxene, amphibole and epidote.

B. METAMORPHISM:

Detailed work for delineating the spatial variation of metamorphic intensity was beyond the scope of the present investigation. During the present work a progressive rise in metamorphic grade across the shear zone from south to north was observed within the parts of the shear zone studied. According to Dunn and Dey (1942) the high grade metamorphic rocks lie in the central part of the geanticline towards north and north-east of the shear zone and there is a "noticeable and expected relation of metamorphism to folding". Naha (1965) worked in an area, north-east of Mosaboni, and showed a progressive increase of metamorphism from north-east to south-west and established a rough concordance of stratigraphy, structure and metamorphic zones. His metamorphic isograd is roughly parallel to the folded quartzite horizons.

Observations made by the present author in the area adjacent to Mosaboni indicates that the rocks lying to the south-west of the shear zone are in the chlorite zone while towards the north-eastern part of the shear zone the grade of metamorphism increases
from chlorite to biotite zone and finally to garnet zone which extends up to Subarnarekha river and beyond. Thus there is a steady increase of metamorphic grades from south-west of the shear zone to the north-east. Similar is the case in the western part of the shear zone where the individual metamorphic grades are more well developed as the width of the shear zone is comparatively greater here. The rocks to the south of the shear zone near Tatanagar are characterised by such index minerals as chlorite and sericite. Biotite is the characteristic index mineral within the shear zone while garnet (occasionally kyanite and staurolite) characterises the metamorphic grade of the rocks to the north of the shear zone.

The kyanite quartzite horizon marks the northern limit of the shear zone. In the south-eastern part of the shear zone, these quartzites lie well within the garnetiferous schists. The kyanite (staurolite) isograd shown by Naha (1965) in areas common with that of the present author, lies about one mile and a half north-east of the kyanite quartzite horizon.

It appears from the above account that the metamorphic grades increase in general from south to north within the shear zone and adjacent areas. In the south-eastern part of the shear zone, there is a steady increase of metamorphic grade from chlorite to garnet zone (including the thin band of kyanite quartzites) from the south-west of the shear zone towards north-east. Further north-east the metamorphic grades decrease (according to Naha) and thus a metamorphic 'high' is located here. This has probably some relation with the structural framework of the area under discussion. But the concordance of metamorphic grades with the
stratigraphy as suggested by Naha, cannot be established from the above observations.

Shearing took place later than the regional metamorphism because the shear zone cuts across the metamorphic zonal boundaries. The shear zone rocks generally indicate a biotite isograd but in the western part, slices of the chlorite and garnet zones have been caught up within the shear zone at its southern and northern parts respectively (Banerji, 1964). All along the shear zone, the rocks show evidence of intense shearing and mylonitisation. Retrogression of high grade schists are common. Biotite schists are often found to grade to chlorite schists. In some parts, relic garnet porphyroblasts are found even within chlorite-schists and these are partly or wholly replaced by chlorite, epidote and chloritoid.

C. STRUCTURE

The rocks of the shear zone and adjacent areas show a complex structural pattern as is expected in an area which has suffered deformation in different phases (Sarkar and Saha, 1962; Naha, 1965) followed by intense shearing and migmatisation (Banerji, 1962). In the present work an attempt has been made to describe the different structural elements present within the feldspathic schist zone and the rocks just adjacent to it and to find out their mutual relations. This would help in the proper understanding of the mode of emplacement and genesis of the feldspathic rocks.

The structural features of the rocks to the north and south of the shear zone are essentially similar to those within it.
(Banerji, 1962, 1964) excepting the features that are imprinted upon the latter due to shearing. Banerjee (1962) investigated in detail the structural features of the shear zone and adjacent rocks south of Tatanagar. Structural features of the areas lying further west around Gamahria and Sini have been described by Chowdhury (1963) and Mitra (1965) respectively. The present author has studied the structural features that are present within the feldspathic schists and granites occurring along the whole length of the shear zone, lying more stress on the Mosaboni and adjacent areas.

Along the entire shear zone, different types of interesting structural features are present. These include major folds, minor folds, major and minor cross-folds, faults and joints. Structural elements associated with the folds of different generations are also present. These help to deduce the structural history of the area. Before going into the details of individual structural elements, the different types of folds are described.

a. Major folds:

In the western part of the shear zone south of Tatanagar, a series of major antiformal and synformal folds occur within the shear zone and to its south (Banerji, 1962, 1964). These folds have "........... subhorizontal axes trending approximately ESW-WNW and extend from the eastern to the western border of the area in an arcuate sweep convex to the NE'. These folds are overturned to the south-west with gentle dipping northern limbs and steeply dipping southern limbs. But in the south-eastern part of the shear zone around Mosaboni no major folds as such could be recognized. Only
the effects of a regional fold movement is preserved here as a prominent axial plane schistosity. About two miles north-east of Mosaboni, major synformal folds within quartzites have been reported by Naha (1965).

b. Minor folds:

Different types of minor folds from mesoscopic to microscopic scale are present within the rocks of the shear zone. The axes of these folds make different types of lineation on S-planes. The minor folds of different generations have folded the bedding planes (S₁), the schistosity planes (S₂) and the strain slip cleavages (S₃) around axes which are either subhorizontal or down dip. Individual fold patterns of the minor folds will be discussed later under the heading linear structures.

c. Cross-folds:

The major folds described above have been affected by cross-folds in different scales. Cross folding activity is best exemplified in the areas south of Tatanagar where the zones of culmination and depressions along the major fold axes have been shown by Banerji (1962, 1964). Besides the major set of cross-folds, a minor set of cross-folds is observed in this area which have affected the S-planes. In the south-eastern part of the shear zone minor cross-folds can be readily observed in the field but the major cross-folds are not as conspicuous as the minor cross-folds. Narayanswami (1959) described the major cross-fold axes that are present in Singhbhum and adjacent areas and showed one cross-fold axis through Pathargora (22°32': 86°27') along north-south direction. Another such cross-fold axis probably runs roughly along north-south direction near Gohala. These folds have affected
the rocks of the shear zone and adjacent to it. Such later folds are likely to have formed during the waning phase of shearing.

In the underground levels of the Mosaboni mine, cross-folds of different scales are present. These folds have a sub-vertical axial plane slightly oblique to the direction of dip of the schistosity planes. These folds appear to have folded the S3 planes along with the lode zone (Dey, 1965).

**Structural elements:**

The different structural elements that are present in the area under discussion can be classified into two groups namely (I) sedimentary structures and (II) tectonic structures.

I. Sedimentary structures - The most important sedimentary structures present in this area, are stratification, cross-stratification and penecontemporaneous deformation structures. These are well preserved within the psammitic rocks specially within the quartzites lying along the Subarnarekha river bed, north-east of Mosaboni. Stratification planes have been obliterated by later shearing within the shear zone rocks, only rarely are these preserved within the kyanite-quartzites adjacent to the shear zone.

The stratification planes (S1) are recognised within these rocks by the presence of colour and compositional banding and range from stratification laminae, measurable in mm, to thin beds about a metre thick. These often show rhythmic bedding with alternate quartzose and micaceous layers. Stratification planes are also observed within the Dhanjori quartzites lying to the
south-east of the shear zone.

Cross-stratification and contemporaneous deformation structures like convolute bedding and folded cross stratification have been observed in only a few exposures along Subarnarekha and Sankh nala bed, north-east of the shear zone (Fig.5, 6). Due to the paucity of exposures showing these sedimentary structures, deduction of the direction of younging and the paleocurrent directions was not possible. Naha (1965) deduced the direction of younging (towards north-east) and the regional paleocurrent directions (from S and SSW to N and NNE) from the study of the cross-stratifications preserved within quartzites lying further north-east of the present area.

The presence of slump structures, rhythmic deposition of argillaceous and arenaceous laminae, intimate association of laminations and convolute bedding etc. in the areas north of the shear zone are suggestive of an active geosynclinal environment in that part (Naha, 1959).

II. Tectonic structures:

All the secondary planar and linear structures that are observed on the surface as well as in the underground mine levels are described here. It will not be out of place to mention here, that it is not possible either to detect or to measure all the structural elements from the underground because of unclean rock surface and poor lighting.

1. Planar structures:

(a) Schistosity- The most prevalent planar structure is the
schistosity ($S_2$) defined by the parallel arrangement of flaky minerals namely biotite, chlorite, muscovite etc. The attitude of this schistosity is parallel to the axial plane of folds on $S_1$. This relation is established by Naha (1965) in the areas northeast of Mosaboni and according to him this relation can be observed on all scale, from micro-sections with $S_2$ parallel to the axial plane of folds on $S_1$, to regional maps with strike of $S_2$ running parallel to the trace of the axial planes of plunging folds marked by the quartzite beds.

(b) Strain slip cleavage (Umfalting cleavage)- Observations made in the field around Mosaboni indicate that with the increasing deformation the schistosity planes were folded at first into symmetrical pucker of mesoscopic scale (Fig. 7, 8.) with a subvertical axial plane trending NWW-SSE and subsequently an $S$-plane ($S_3$) developed parallel to the axial planes of these pucker. This is of the nature of a strain slip cleavage (Fig. 9). With increasing deformation they became more closely spaced and ultimately obliterate all earlier structures. Thus, traverses across the strike of the regional schistosity in this area, starting from the Subarnarekha river bed in the north-east up to the western margin of the feldspathic schist zone clearly expose, both in hand specimens and in micro-slides, the gradual development of $S_3$ and its transposition on $S_2$. Within the feldspathic schists, both $S_2$ and $S_3$ planes are defined by mica flakes. These two secondary planes, in sections cut perpendicular to the schistosity, make acute angle with one another. This renders an anastomosing feature on such sections. The strike of $S_2$ and $S_3$ planes
are almost parallel while \( S_3 \) dips more gently towards east, within the rocks of the feldspatic schist zone.

Along these later developed \( S \)-planes (\( S_3 \)), intense shearing took place producing extensive mylonitisation and the mylonitic bands are oriented parallel to \( S_3 \)-planes. In the pelitic and basic rocks extreme sericitization and chloritisation have developed along these planes.

In the underground levels of Mosaboni mine both \( S_2 \) and \( S_3 \) are present, \( S_3 \) being gentler than \( S_2 \). This conforms to the observations made in the corresponding parts of the feldspatic schists zone of the surface.

2. Linear structures:

The following types of linear structures are common in the area studied:

(a) Intersection of \( S_1 \) and \( S_2 \) - This type of lineation is often preserved within quartzose mica-schists occurring near Subarnarekha, and kyanite-sericite quartzites lying just north of the shear zone. It occurs as fine sub-horizontal lines on schistosity planes wherever the attitudes of \( S_1 \) and \( S_2 \) differ in amount of dip.

(b) Minor fold axes - A number of types of minor folds are observed within the different rocks of this area and the axes of these folds form different types of lineation. These minor folds along with the trend of their axes are described here.

(i) Minor folds of \( S_1 \) - These folds are present within quartz-
mica schists near Subarnarekha as close folds (rarely open) with a well developed axial plane cleavage. Intersection of this cleavage with the bedding is parallel to the main fold axis of $S_1$. Mineral lineation is oblique to the fold axis.

(ii) Minor folds of $S_2$: Under this heading subhorizontal puckers, small scale chevron folds and down-dip puckers are discussed separately.

Sub-horizontal puckers- Small scale puckers measurable in mm., with a sub-horizontal axis are present within quartz-rich mica schists exposed on Subarnarekha and Sankh nala(Fig. ). This type of puckers can be detected from a distance as fine sub-horizontal lines on the schistosity planes (Fig. 11.). The intensity and wave length of these folds increase gradually towards west.

Small scale chevron folds- These are rather common in occurrence within the pelitic schists lying in between the shear zone and the Subarnarekha river. The folds are asymmetric chevron type with amplitudes varying upto 1-2 inches. The axes of these folds are very sharp and strike almost parallel to the strike of the schistosity planes with a little amount of plunge on either side. Along the crests and troughs of these folds a widely spaced cleavage has formed parallel to their axial planes. Slippage has taken place along these cleavage planes during shearing. These planes have been described earlier as $S_3$ planes and these occur in much close intervals within the rocks of the shear zone lying further west.

Down-dip pucker- Another set of fine down-dip pucker lineation has developed within the mica-schists occurring near the shear
zone. The axes of these puckers are slightly oblique to the direction of dip. The wave lengths and the amplitudes of these folds gradually increase and within the shear zone rocks, the wave lengths of these puckers ranges even upto 2/3 inches. Due to interference of these two sets of puckers, one sub-horizontal and the other downdip, 'interference domes and basins' of different sizes have formed in the shear zone rocks.

(iii) Minor folds of S₃ - The strain-slip cleavage (S₃) and the mylonitic bands within the feldspathic schists are intricately folded. These folds are of different types, namely, asymmetric dextral and sinistral (s- and s-) folds, -and isoclinal f_olds and conjugate folds. All these folds are disharmonic in nature and show wide variation of their attitudes(Figs.13-15). Hence the measurement of the attitudes of these folds are not feasible. Such folds are more common in the south-eastern part of the shear zone.
In the following pages, a short description of these folds are given:

Asymmetric S- and Z-folds - These are common in feldspathic schists and migmatites of the shear zone. The amplitudes of these folds are in general 2-3 cms. only. They are often of a reclined type.

Isoclinal folds - Only a few mesoscopic isoclinal folds have been detected within the rocks of the feldspathic schist zone. These are exposed in a nala, south of village Merhia(22°32';86°28') with compressed synforms and antiforms. The closure of these folds are acute and sharp. The wave length of such folds measured near
exp T31(Fig. 18.) is about 3'ft. and their amplitudes are more than three times than those of the wave lengths. Small scale drag occurs on the two limbs of such folds showing typical s-and z-pattern. They may be same as asymmetric folds described above which are locally tightened.

Conjugate folds - Small scale conjugate folds are observed in the feldspathic schists lying north of Mosaboni along road cutting (Figs.16, 17). These folds consist of paired reverse folds with axial planes inclined towards one another. These conjugate folds are usually about 4-6 inches across. The geometric pattern of these folds are similar to those described by Johnson (1956) from the Moine Thrust zone.

(c) Mineral lineation— This type of lineation is quite common within mica-schists, feldspathic schists and quartzites. The lineation is defined by fine needle-like flakes of muscovite, chlorite and biotite on the S-planes. The attitudes of these lineations are essentially down dip in nature showing variations of 10°-15° on both sides. These lineations are found to be folded by subhorizontal pucker.

(d) Pressure shadows on garnet— This is also a type of mineral lineation exposed within garnetiferous mica schists, lying north of the shear zone (Fig. 12). The 'garnet tails' on the S2-planes are aligned parallel to the mineral lineation. This lineation generally makes a small angle (about 30°) with the down dip pucker on Sg. Tails of garnet are composed of fine mica flakes.
(e) **Striations and grooves** - This type of lineation is present in the quartzites and mylonitic micaceous quartzites occurring within and adjacent to the shear zone. These rocks show long continuous striations and grooves on the S-planes. This lineation is essentially parallel to the direction of dip of the S₃-planes. Along these striations and grooves fine flakes of micaceous minerals have formed.

(f) **Strephed pebbles** - The conglomerate horizons lying just south of the shear zone show elongated pebbles of different sizes, stretched parallel to the direction of dip.

3. **Faults:**

There are several strikewise discontinuities of the feldspathic schist zone due to 'post thrust' faulting. These are described below:-

(a) **Turamdih fault** - One such fault is present near Turamdih (22°43'; 86°12'). The fault plane strikes NNE-SSW showing a lateral displacement of about 150 yards. Banerji (1962) described it as a line of 'fracture faulting' of the nature of a dip fault.

(b) **Pathargora fault**: In the south-eastern part of the shear zone the feldspathic schists and associated rock units are shifted by an oblique fault which extends almost north-south for about two miles and a half producing two truncated tongue-like occurrences of feldspathic schists and granites on the two sides. The fault plane is nowhere exposed in the surface but the presence of this fault has been established by detailed field mapping. According to Dey (1965), the bore-hole data indicate a N-S trending fault plane
with 46° dip. Due to the absence of any vertical bed within either of the faulted halves and the absence of exposed parts of the fault plane (to observe the direction of slickensides, if any), it is not possible to determine whether it is a wrench fault or not. But the presence of a 'post-thrust wrench fault' along Gohala (described below) a few miles south of Pathargora and the parallelism of the Pathargora fault with it suggest the possibility of the Pathargora fault being a wrench fault.

(c) Gohala fault - About seven miles south of Pathargora, the feldspathic schists and other rock units of Dhanjori and Chaibasa stages have been shifted again towards east by Gohala fault by about two miles and a half. It is a north-south trending steep eastward dipping fault with a net slip of 2 miles. According to Sarkar and Saha (1962) the Gohala fault is "......most likely the southward continuation of the Mischintapur fault", which according to Sarkar and Mukherjee (1958) is a dextral type of wrench fault.

4. Joints:

Joints have developed extensively in the granitic rocks of the shear zone and in the adjacent quartzites and basic rocks. Within the schistose rocks, these are not so prominent. Strike joints, dip joints and a set of cross-joints are frequently encountered within the rocks of the shear zone. Their attitudes vary from one end of the shear zone to the other, tallying approximately with the trend of the shear zone. No detailed study of these joints was carried out.
To make a systematic and statistical analysis of the major structural elements, the area under investigation has been divided into eight parts. The poles of the secondary S-planes and lineations have been plotted on equal area nets for each part. The $\Pi$-S diagrams have been contoured with the help of 'Dimitrijevic' net. Maps showing the different sectors and their corresponding $\Pi$-pole diagrams are enclosed (Plates, III & IV).

It is evident from the structural maps that the structural data were collected only from the rocks of the feldspathic schist zone, excepting the south-eastern part of the shear zone. In this part, the sectors include both the feldspathic schists and adjacent rocks. The $\Pi$-S diagrams were prepared with the data measured essentially from the $S_3$-planes. These planes have developed well within the feldspathic schist zone. But in some parts adjacent to this zone, it is too difficult to differentiate the $S_1$, $S_2$ and $S_3$ planes in the field, as the attitudes of all these S-planes are parallel to one another. In such cases, the corresponding poles may indicate the poles of any of the three S-planes.

**Sector I** (Area west of Gohala-fault)- The schistosity in this part shows more or less NWW trend with moderate dip towards east. The attitudes of the schistosity planes were measured from the exposures lying within, north and south of the shear zone and these are plotted in a single diagram. The distribution of 77 $\Pi$-poles shows a single maxima with moderate spread. The modal schistosity plane as calculated from the diagram strikes along 329° and dips 47° towards east.
Sector IIA, IIB and IIC (Area between Pathargora and Gohala fault)-
The schistosity in this part shows more or less north-north-west

trend with moderate dip(35-45°) towards east. The attitudes of the

schistosity planes within the rocks lying to the south of the shear

zone have been plotted in the diagram of Sector IIA. Similarly

diagrams for sector IIB and IIC have also been prepared taking data

from the rocks lying within and north of the shear zone respective­

ly. Each of the three \( \Pi -S \) diagrams show a single maxima with

similar nature of the spread of the \( \Pi \)-poles. Thus it appears that

the rocks lying north and south of the shear zone show statistically

similar structural features like those present within the shear

zone.

Sector III (Area West of Pathargora fault)- The distributions of

\( \Pi \)-poles in the diagram prepared from the data collected from

this sector show similar type of distribution with a single maxima

as is observed in the \( \Pi -S \) diagrams described earlier. Modal

foliation plane strikes 341° and dips 48° towards east.

Sector IV (Area between Keruadungri and Hitku)- This is the eastern

most sector of the western patch of feldspathic schists. From the

plots of schistosity it is evident that the strike of the schistosity

markedly changes from NW to NE. The distribution of \( \Pi \)-poles shows

a single maxima with comparatively small spread. The modal folia­
tion plane as determined from the diagram strikes along 294° and

dips 50° towards north.

Sector V (Area between Dhadkidih and Kharkajrivett)- From the \( \Pi -S \) dia­

gram of this sector it becomes apparent that the strike of the
schistosity within this area turns from ESE to east conforming with the turning of the shear zone itself. Plots of 50 $\pi$-poles of this area show a single maxima with a very small spread.

**Sector VI (Area around Kolabira)** - The $\pi$-S diagram corresponding to this area shows a single maxima. The higher contours exhibit a small spread of the $\pi$-poles in the southern part of the diagram.

**Sector VII (Area around Sini)** - In this sector the strike of the schistosity is east-west and the modal schistosity plane determined from the $\pi$-diagram strikes along $274^\circ$ and dips $56^\circ$ towards north. Plots of $\pi$-poles show a single maxima lying near the south-pole of the diagram.

Study of these $\pi$-pole diagrams indicates (i) that the rocks lying to the north and south of the shear zone show essentially similar structural features as are present in the rocks lying within the shear zone (cf. $\pi$-S diagram of Sector IIA, IIB & IIC) (ii) that the strike of the schistosity gradually changes from $NNW$ in south-eastern part of the shear zone to $N$ and ultimately to west in the western part. This observation nicely tallies with the curving of the shear zone from south-east to west, (iii) that the 'post thrust faults' have not abruptly changed the general attitude of the schistosity in the faulted halves and (iv) that the mineral lineation and slickensides plotted in these diagrams are slightly oblique to the dip direction.

**Structural synthesis**

There is no major fold on the schistosity planes of the area
under investigation as seen from $\mathcal{N}$-diagrams. But a set of conspicuous axial plane schistosity ($S_2$) with a unidirectional dip towards north and north-east, in general, is present in the whole area. The intersection of these schistosity planes with the bedding is horizontal. This suggests that the rocks of this area have been affected by folding movement on a regional scale with subhorizontal axes of folding. Thus, the effect of the first deformation in this area is clearly seen from the extensive development of the $S_2$-planes and a set of minor folds with subhorizontal axis. The mineral lineation is related to this deformation and may represent the direction of stretching.

The second deformation folded the $S_2$ planes and along the axial plane of these folds $S_3$ planes developed. These occur in close spacing within the shear zone rocks where the deformation is intense. During this deformation two sets of puckers were formed on $S_2$-planes, namely, a subhorizontal set of puckers and another set of puckers with a downdip axis. Along the $S_3$-planes, intense shearing took place producing extensive mylonitisation. The effects of shearing are well marked by the downdip lineation and striation and direction of shearing can be easily inferred from the lineation directions. The magnitude of the displacement along the $S_3$-planes could not be determined. But the field evidences suggest that a small scale thrusting (probably of a few tens of feet in magnitude) took place as a result of which the hanging wall side was upthrown. There is no unequivocal proof of major movements along a thrust, plane as suggested by Dunn and Dey (1942).

With the accession of feldspathic materials during the closing
phase of shear movements the $S_3$ planes along with the mylonitic bands (Fig. 20; 21) were again folded disharmonically producing asymmetrical $S$- and $Z$-folds, isoclinal folds, conjugate folds and folds of various other forms (Figs. 22-24). These folds are the effect of the third deformation within the shear zone. Such folds on $S_3$ have developed only locally, specially in the southeastern part of the shear zone around Mosaboni.

The end of these tectonic activities was marked by the faulting of the shear zone across its strike direction which have displaced the rocks of the shear zone and adjacent areas. The faulting activity is distinctly later than the third deformation and hence it is has been correlated with a fourth deformation. Thus, these post-shear faults mark the end of the orogenic movement which started with the first deformation.

All the four deformations, described above, took place during a single orogenic period. The time gap between these deformations may have been very small and even there may have been some amount of overlap. The effects of the first deformation has been obliterated from the rocks of the shear zone by the later deformations. Only in one exposure of kyanite-sericite-quartzite, north-west of village Surda, a small refolded fold was observed (Fig. 25). Here the bedding ($S_1$), appears to have formed a recline fold during the first deformation and this was again folded along a subvertical axial plane. Thus in this particular exposure the effects of two successive deformations are preserved.

**Comparison with adjacent areas:**

Naha (1965) described in detail the structural history of the area lying a few miles from Mosaboni just to the north-east of the
shear zone. According to him the horizontally bedded rocks were flexurefolded with simultaneous development of axial plane schistosity at the early stage of deformation. Thrusting took place at a later stage, resulting in slip on $S_2$-surfaces with the development of a 'lineation' along the direction of tectonic transport in the thrust zone. These two stages of deformation correspond to first and second foldings described by the present author. Naha (1965) further suggested that all the tectonic structures were produced during a single period of deformation. But there is no unequivocal evidence in favour of a single period of deformation. In fact, there are evidences (described in structural synthesis) which clearly suggest more than one period of deformation.

Banerji (1962, '64) described a series of major antiformal and synformal folds in a part of the shear zone, south of Tatanagar. With the progressive increase of the intensity of deformation, according to him, these folds were more and more compressed and were ultimately affected by shearing. As a consequence slip occurred along the existing $S$-surfaces and there was concomitant compression at right angles to it giving rise to minor folds, pockers, linear trends and a widely spaced fracture cleavage ($S_3$). This was followed by a minor set of closely spaced cross-folding movements. Formation of major synforms and antiforms, mentioned above corresponds to the first deformation described by the present author while the shearing and associated activities corresponds to the second deformation.
In the south-eastern part of the shear zone no such antiformal and synformal folds belonging to the first deformation can be deduced as there is no repetition of lithological units. Moreover, the width of the shear zone in this part is very narrow, hence had there been any such folds these would have been tightly compressed and escaped detection.

**Table-1**

Comparison of the structural history of the area with the adjacent areas:

<table>
<thead>
<tr>
<th></th>
<th>Present author</th>
<th>Banerji (1964)</th>
<th>Naha (1965)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fourth</strong> deformation</td>
<td>Post shearing fault</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Third deformation</strong></td>
<td>Migmatisation and folding of $S_3$-planes and mylonitic bands (locally)</td>
<td>A closely spaced minor cross fold activity.</td>
<td></td>
</tr>
<tr>
<td><strong>Second deformation</strong></td>
<td>Intense shearing along $S_3$-planes producing slifcensides ($a'$)Folding of $S_2$ with the appearance of $S_3$- and pucker lineations.</td>
<td>Intense shearing with slip along $S_1$-surfaces giving rise to a down dip pucker and a set of widely spaced fracture cleavage ($S_3$)</td>
<td>Formation of a subhorizontal pucker at the final stage of penetrative movement. Thrusting with slip on $S_2$-surfaces with development of a' lineation.</td>
</tr>
<tr>
<td><strong>First deformation</strong></td>
<td>Folding of $S_1$ on subhorizontal axis and appearance of axial plane schistosity with mineral lineation.</td>
<td>Folding of sedimentary beds into major synforms and anti- forms with the axial plane schistosity. Widely spaced major cross-folds.</td>
<td>Folding of $S_1$ and appearance of $S_2$ as Early the axial forms with Phase plane schistosity.</td>
</tr>
</tbody>
</table>

* It is regarded as a continuation of early phase.  
** All the four deformations are regarded as the different phases of a single orogenic movement and probably have some amount of overlap.
In this part of the shear zone, the effects of major cross-folding (pre-shearing in age) is not as evident as that present in the western part. Here, undulations and curving of lithological boundaries and the attitude of fine puckers on the schistosity planes parallel or oblique to the direction of dip, suggest the presence of cross-folding activity. The effects of post-shearing cross-folds which took place at the closing phase of second deformation are more prominent here. Such cross-folds of both major and minor scale were observed in the field. These correspond to the third phase of deformation. In table 1, comparison with the adjacent areas is shown.

**Relation of mineral formation with deformation.**

A number of thin sections of the shear zone rocks were studied to determine the different phases of deformation by means of textural criteria.

Under the microscope, mica schists lying to the east of the shear zone show porphyroblasts of garnet occasionally with si-trails and rarely with the rolled si-trails. This obviously suggests that the formation of garnet started at the beginning of 1st deformation which produced the schistosity($S_2$) and was completed before the beginning of the second deformation. Gradual development of $S_3$ along the axial planes of the pucker on $S_2$ during the second deformation has been observed within the rocks of the shear zone (described earlier). In the feldspathic schists and granites, porphyroblasts of plagioclase, sometimes as augen, have formed within the
inter-spaces between \(S_2\) and \(S_3\). Disoriented flakes of mica and grains of quartz are very common in these porphyroblasts but these do not form any definite si-trail. Moreover, the growths of the porphyroblasts by pushing aside the foliation planes are also observed in a number of thin sections. In some feldspathic schists, plagioclase porphyroblasts with subhedral outlines are found to cut across both \(S_2\)-and \(S_3\)-planes. The gradual formation of these porphyroblasts is best exemplified by the rocks occurring south of Tatanagar and have recently been described by Banerji and Talapatra(1966).

The first stage in these transformations appears as opening out of the schistosity planes as a result of slight bending of the chlorite, muscovite and biotite shearfs around the quartz-feldspar porphyroblasts which at this stage of the transformation are approximately 1-2 mm. in diameter. The next stage in these transformations commences with an increase in the size of the porphyroblasts when the schistosity planes are further pushed apart and the rocks assume a streaky appearance. With further increase in the size of the porphyroblasts to about 5 mm, the rocks assume an augen texture which is finally transformed into a coarse gneissose to granitoid fabric. Plagioclase porphyroblasts are also found to occur along the axial region of the disharmonic folds on \(S_3\) (along with the mylonitic bands) wherever such folds are present. All these features suggest that the plagioclase porphyroblasts are syn-to post-tectonic with respect to the third deformation.

From the above account of the tectonic structures along the Singhbum shear zone, it can be inferred that the area under consi-
D. STRATIGRAPHY

The pre-cambrian rocks of Singhbhum district present a stratigraphic problem unique of its kind, due to a number of reasons, the most important ones among them are—(i) the complex structure of the area as a result of more than one phase of superposed orogenic movements, (ii) highly metamorphic character of the rocks (iii) absence of widely exposed key horizons that may help regional correlation (iv) lack of adequate age data of the rocks determined on a statistical basis.

Dunn and Dey (1942) published a stratigraphic succession of this area based on their work spread over many years. Since then, a number of geologists have tried to establish a more comprehensive sequence from their work in different parts of Singhbhum. Among them, Sarkar and Saha (1962), Banerji (1964) and Iyenger and Anand Alwar (1965) have worked out the stratigraphic sequence of Singhbhum on a regional basis.

In the opinion of Dunn and Dey (1942) the rocks to the north of the shear zone belong to the Chaibasa stage while those within and to the south of the shear zone belong to the Iron Ore stage. These authors suggest that the Chaibasa stage rocks are stratigraphically the oldest rocks exposed in the area and the Iron Ore stage rocks follow these in normal sequence. They further suggest
that these rocks were quite strongly folded and deeply denuded before the Dhanjori stage rocks were deposited above them and were themselves folded due to a resumption of the fold movements. Finally, thrusting took place and the older Chaibasa stage rocks were successively thrust over the Iron Ore stage and the Dhanjori stage rocks. The Singhbhum granite is intrusive into the Iron Ore stage but its relation to the Dhanjori stage is indefinite. The Dhanjori stage possibly overlies the Singhbhum granite unconformably (Dunn and Dey, 1942; p.239). The soda granites are considered intrusive into the Dhanjori stage and represent a residual soda rich part of Singhbhum granite which was caught up within the shear zone and was highly sheared.

Sarkar and Saha (1959, P.151; 1962, p.123) have given a different stratigraphic succession in Singhbhum summarized as follows:-

Granophyre, soda granite

Singhbhum Orogeny (905-934 m.y)

Dhanjori Series...

\[ \text{Dhanjori Lava} \]
\[ \text{Quartzite-conglomerate} \]

(Overlap)

Singhbhum series...

\[ \text{Dhanbhum stage} \]
\[ \text{Chaibasa stage} \]

Unconformity

Singhbhum granite

Iron Ore Orogeny (2038 m.y)

Gabbro-anorthosite, epidiorite

Iron Ore series...

\[ \text{Upper shales with sandstones and volcanics} \]
\[ \text{B.H.Q.} \]
\[ \text{Lower Shales, lavas, sandstones and conglomerates} \]
In the opinion of these authors the Iron Ore series of rocks which include the rocks to the south of the shear zone are the oldest in the area and have been affected by an older orogeny—the Iron Ore Orogeny, while the Chaibasa stage rocks belong to a younger Singhbhum series which include the rocks to the north of the shear zone and have been affected by an younger orogeny—the Singhbhum Orogeny. The Dhanjori series of rocks are considered to be younger than the Singhbhum series and to have been affected by the Singhbhum Orogeny. These authors suggest that the Iron Ore and Singhbhum Orogenies were differently oriented and that the shear zone marks the boundary between these two orogenies to its north and south respectively. As a consequence of the later Singhbhum Orogeny the NWW trending foliation planes in the Iron Ore series of rocks immediately to the south of the shear zone were rotated approximately parallel to the trend of that orogeny. These authors also suggest that the Singhbhum granite was intruded into the Iron Ore series of rocks at the end of the Iron Ore orogeny while soda-granites and the granophyres were intruded into the Singhbhum and Dhanjori series of rocks at the end of the Singhbhum Orogeny.

Recently, Iyenger and Anand Alwar (1965) have described the stratigraphy of Singhbhum, Keonjhar and Mayurbhanj area and have suggested a sequence slightly modifying the sequence proposed by Sarkar and Saha (1963,1962). These authors have suggested a eugeosynclinal assemblage containing 'spilitic' rocks, along the northern and eastern margin of Singhbhum granite mass.

Investigations carried out by Banerji and his co-workers along and across the entire Singhbhum shear zone, suggest that there
are three distinct stratigraphic units in the area from north to south. In the areas south of Tatanagar the middle group of rocks lying within the shear zone consists of feldspathic schists and gneisses, chlorite-schists, banded quartzites and a thin and impersistent band of basal conglomerates. These conglomerates when traced eastwards, merge with the quartzitic conglomerates at the base of the main Dhanjori basin and on this ground the middle group of rocks within the shear zone is correlated to the Dhanjori stage. The group of mica schists (with occasionally garnet, kyanite and staurolite) belong to Chaibasa stage. In this area, a group of hematitic phyllites, tuffs, gritty phyllites and banded hematite quartzites occurs south of the Dhanjori group of rocks described earlier. Singhbhum granite shows intrusive relation with these rocks. These rocks have lithologic similarities with the Iron Ore stage rocks with which these should be correlated. South of these rocks occurs another group of sericitic phyllite, shales and sandstones with a thick band of conglomerate at their base, making a distinct zone of unconformity above the Singhbhum granite. These conglomerates contain abundant pebbles of banded hematite quartzites, red jasper, quartzites and other fragments of rocks which are very common within Iron Ore stage. These rocks, therefore, occupy a stratigraphic position above the Iron Ore stage similar to the Dhanjori stage rocks at the middle of the shear zone and should be correlated to these rocks. Thus it appears that the younger Dhanjori stage rocks occur on either side of the older Iron Ore stage rocks south of Tatanagar. Banerji (1964) showed
that the Iron Ore stage and Dhanjori stage rocks are not cofolded but have been deformed in two distinct phases—an earlier pre-Singhbhum granite phase and a later post-Singhbhum granite phase. The Iron Ore stage of rocks were deformed during the earlier phase into major antiformal ridges accompanied by synformal troughs on the two sides. These troughs were filled by the Dhanjori sediments and metavolcanics which were deformed during the later phase. The sediments in the northern trough were affected by shearing, migmatisation and mineralization while those in the southern trough were not so affected. In the south-eastern part, the shear zone runs along the southern part of Chaibasa stage rocks (commonly mica-schists) and these have been feldspathised resulting into feldspathic schists and soda-granites. In this area, an imperistent band of conglomerate is mapped in between Dhanjori and Chaibasa rocks.

From the overall study of the shear zone rocks a stratigraphic sequence is deduced by the present author which is shown in Table-2.

The stratigraphic position of Chaibasa stage rocks in this sequence is controversial. The present studies indicate that the essential structural features of rocks to the south of the shear zone are similar to those within and to the north of it and the available evidences do not warrant the assumption that the rocks to the south were affected by an orogeny differently oriented from that operating in the north as suggested by Sarkar and Saha (1962). Also the effects of shearing in this area—hanging wall side being slightly upthrown—do not suggest any large scale thrusting. On the contrary the marginal region of Dhanjori and Chaibasa rocks indicate a probable normal sequence towards north and north-east. In this area, the occurrence of the conglomerate horizon above the
Dhanjori rocks immediately under-lying the shear zone rocks indicate a stratigraphic break. On the basis of the above evidences, Biswas et al. (1966) have suggested that the rocks to the north of shear zone are likely to be younger than the Dhanjori stage rocks to the south and south-west.

### Table-2

<table>
<thead>
<tr>
<th>Stratigraphic succession of the rocks adjacent to the shear zone.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apatite-magnetite, copper-sulphide and uraniferous veins.</td>
</tr>
<tr>
<td>Basic and ultrabasic intrusives</td>
</tr>
<tr>
<td>Feldspathic schists, Soda-granites (migmatitic)</td>
</tr>
<tr>
<td>Arkasoni granitic rocks</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unconformity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic and ultrabasic intrusives</td>
</tr>
<tr>
<td>Lavas and epidiorites,</td>
</tr>
<tr>
<td>Shales and Phyllites,</td>
</tr>
<tr>
<td>sandstones and quartzites,</td>
</tr>
<tr>
<td>conglomerates and arkoses.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Dhanjori Stage:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mica-schists, hornblende-schists,</td>
</tr>
<tr>
<td>Kyanite quartzite, quartz-granulite etc.,</td>
</tr>
<tr>
<td>Conglomerate (impersistent)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Chaibasa Stage:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singhbhum granite, Diorite</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unconformity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Singhbhum granite, Diorite</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Unconformity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Banded hematite quartzites, chloritic and hematitic phyllites, slates, quartzites, grits, epidiorites etc.</td>
</tr>
</tbody>
</table>
Thus the sequence of rocks in the shear zone may be a normal one younging northwards from the Singhbhum granite border. In the event of such a correlation the Dhanjori basin would have to be considered a synclinal structure since the youngest rocks would occur at its core.

This is only a plausible suggestion, based on some observed facts gathered during this work. The complete solution of this problem must await further detailed structural and stratigraphic studies on a regional scale, along and across the shear zone and further south and north of it aided by age determinations of these rocks on a statistical basis.