CHAPTER 6
STRUCTURAL ASPECTS OF THE DEPOSIT

The study area manganese mineralization exhibits a strong structure control besides lithological control and the mineralization lies on a limb of regional fold. The structural features exhibited by the rock units of the Bharweli area are divided into local structures and major structures. The features observed on large scale and found in majority of the rock types are discussed under major structures, while those found on small scales in the individual rock units are treated as local structures.

6.1 LOCAL STRUCTURE OF THE AREA
The local structures of the area include bedding, schistosity, minor folds, faults and joints.

6.1.1 Bedding
The intercalations of quartzites in phyllites and the pronounced banding in quartzites indicate the original compositional layering and form the traces of bedding planes. The general strike of bedding varies from ENE-WSW in the western part near Barbaspur to NNE-SSW in the northern part of Balaghat Mines. The dip of the beds near the south section is about 70-75° towards SW but tends to become vertical in the some area (Fig.6.1 a). Very prominent bedding plane is also shown by sericite schist (Fig.6.1 b)

Fig. 6.1 a: Field Photograph showing bedding in phyllite.
Fig. 6.1 b: Field photograph of sericite schist showing well developed bedding.
6.1.2. Folds

The bedding planes of the area show various types of folds and associated schistosity planes. The schistosity planes cut across the bedding planes in the hinge area of some of the folds, but are co-folded with the bedding in the hinge area of some other types of folds. The former belong to the early (first generation) structures and the latter belong to the late (second generation structures). The late structures are more pervasive than the early structures of the area.

Various types of fold geometry observed in the study area include:

a) Recumbent folds.

b) Symmetrical folds.

c) Inclined isoclinal folds.

d) Overturned folds.

e) Drag folds.

f) Asymmetrical folds.

6.1.2.1 Recumbent folds: Recumbent folds are most important structures of the area (Figs. 6.2 a, b), and control the manganese-ore deposit’s characteristics. The Balaghat manganese deposit can be divided into two sections on the basis of these recumbent folds. The north section, which is affected by folding (between chainage 3500 to 900) has low dip amount and greater width of the ore body, whereas the south section is free from any folding and shows steep dip with less width. In the north section of the deposit the plunge of the fold is about $15^\circ$ towards SSW direction. The influence of the fold over an area of about 1000 m in strike direction and about 300 m in dip direction is observed.

6.1.2.2 Inclined isoclinal folds: Some excellent isoclinal folds are shown by the phyllites. The fold is inclined isoclinal type. The axial plane inclination is around $30^\circ$ to $40^\circ$ towards west (Figs. 6.2 e and f).

6.1.2.3 Overturned folds: In the northern part of the ore body where the ore horizon widens, the overturned folding of beds displays flattening of dips and changes to eastern dip (Fig. 6.2 i and j).

6.1.2.4 Drag folds: Drag folds are in second stage of folding. The axis of these folds where folded in the shape of drag folds. They are minor in nature, causing tilting of the axis of former fold (Fig. 6.2 k).

6.1.2.5 Symmetrical folds: Symmetrical fold is shown by phyllite, sericite schist and manganese ore. The fold is along strike direction of the formation (Fig. 6.2 c, d, g and h).
6.1.2.6 Asymmetrical folds: The phyllites usually exhibit local minor folds. They are generally asymmetrical folds with their axis running E-W and plunging towards west. Some broad open asymmetrical folds are found in quartzite, phyllite (Fig. 6.2 l). Other minor folds are also observed in phyllite (Fig. 6.2 m). The shapes of asymmetrical folds vary from s-shaped to z-shaped geometry (Fig. 6.2 n).

Fig. 6.2 a: Field photograph of phyllite showing minor recumbent fold.
Fig. 6.2 b: Underground mine photograph of the manganese ore showing minor recumbent fold.
Fig. 6.2 c: Field photograph showing symmetrical folds in phyllite.
Fig. 6.2 d: Underground photograph showing symmetrical folds in manganese ore.
Fig. 6.2 e: Field photograph of phyllite showing inclined isoclinal fold.
Fig. 6.2 f: Field photograph of phyllite showing inclined isoclinal fold.
Fig. 6.2 g: Sample photograph of phyllite showing crenulation cleavage.
Fig. 6.2 h: Photograph of hand specimen showing crenulation cleavage in phyllite
Fig. 6.2 i: Underground mine photograph of manganese ore showing overturned fold.
Fig. 6.2 j: Underground mine photograph of manganese ore showing overturned fold.
6.1.3 Foliation

Almost all the rock types exhibit primary schistose foliations with layers of micaceous minerals inter-foliated with quartz-rich bands (Fig. 6.3 a-b). This in most cases is seen to be parallel to the bedding, forming bedding plane foliation.

6.1.4 Lineation

In the folded limb of phyllite and sericite schist secondary cleavage developed with orientation of sericite flakes showing well developed lineation (Fig. 6.4 a-b).

Fig. 6.2 k: Underground mine photograph showing drag fold, and the relative differential motion (X and Y).
Fig. 6.2 l: Underground mine photograph showing asymmetrical folding in manganese ore.
Fig. 6.2 m: Photograph of hand specimen showing minor folds in phyllite.
Fig. 6.2 n: Field photograph showing S-shaped folds in phyllite.
Fig. 6.3 a: Field photograph of quartzite showing foliation.
Fig. 6.3 b: Field photograph showing foliation in phyllite.

Fig. 6.4 a: Field photograph showing lineation in phyllite.
Fig. 6.4 b: Field photograph showing lineation in sericite schist.

### 6.1.5 Faults

There is not much impact of faults in this entire deposit, though there are some dip-slip faults which displace ore bed less than 3 m in west direction and have got very local effect confining to about 30 m in dip as well as in strike direction. Except this the shape of the deposit is continuous from outcrop up to the deepest proved depth.

No major fault is encountered during the field work, only few minor faults are traced. One fault can be easily demarcated near chainage 8400 in old open pit (Fig. 6.5 a). The throw of the fault is 6 m. From mine history some minor faults were traced during the mining operations in the 4th level. One was at chainage 7400 in ore drive with a throw of 3.5 m. Another was at chainage
5400 with a throw of 6.5 m (Fig. 6.5 b). Few minor faults are also observed along Wainganga river near Gaikhuri village (Fig. 6.5 c), and in the south section of the mine in the phyllite.

Fig. 6.5 a: Map showing fault at chainage 8400 in old open cast mine area.
Fig. 6.5 b: Cross section showing fault at 4\textsuperscript{th} level underground.

Fig. 6.5 c: Field photograph showing minor fault in pegmatite vein intruded in granite.
Fig. 6.5 d: Field photograph showing minor fault in phyllite.
6.1.6 Joints

In the study area, longitudinal bedding joints parallel to the foliation are common. Various sets of joints are developed in the study area; this may be a local structural disturbance. The phyllite (Fig. 6.6 a), sericite schist (Fig. 6.6 b), feldspathic quartzite (Fig. 6.6 c) and ore body are also highly jointed, mostly showing two sets of joints. The major set of joint has a strike of N65°-N245°. In north section of the mine where the ore body is influenced by recumbent fold, four sets of joints along with the random joints are present. The dip of the major set is 18° towards north 130° but the trend of the joint changes according to local dip direction. The south section tends to be less disturbed. Hence two sets of joint were seen along the random joints. The dip of the joint is 60° towards north 145° (Fig. 6.6 d).

Fig. 6.6 a: Field photograph of phyllite showing two set joint.
Fig. 6.6 b: Field photograph of sericite schist showing two set joint.
Fig. 6.6 c: Field photograph showing two sets of joint on feldspathic quartzite in south section.
Fig. 6.6 d: Underground mine photograph manganese ore showing four set of joint breaking in sugar cube form.
6.2 REGIONAL STRUCTURE

The regional trend of formations in the Bharweli area is NNE-SSW with dips to the west at angles varying from $15^\circ$ to $85^\circ$ as observed in the areas of Gaikhuri, Barbaspur east of Manjhara and Balaghat mine. The bedding dips vary from $20^\circ$ to $80^\circ$ due west, all along the rocks of Bharweli area. The bedding and cleavage can be easily seen in the rocks around Bharweli. The major structures in the area include:

1. Bharweli syncline
2. Shears zones / Bharweli fault
3. Wainganga fault
4. Late fractures/veins/intrusions

6.2.1 Bharweli syncline

The rock units around Bharweli define a mappable syncline with NNE-SSW axial trace and plunge towards WSW. The basement gneisses in the east and the cover rocks in the west define this fold. It is an asymmetrical syncline, with the long-limb towards southeast and short-limb towards northwest. Phyllites occur in the core of this syncline and the basement gneiss towards the outer arc (Fig. 6.7, 6.8).

6.2.2 Shear zone / Bharweli Fault

The rocks of Bharweli area have a tectonic contact with the Tirodi Gneiss. The contact of rocks shows shearing which may be due to the low angle reverse faulting developed at the time of the development of Central Indian Sutures (CIS). The CIS is running further south of the study area and this shear zone-cum-Bharweli fault is associated with the CIS. The outcrops of the rocks are exposed only along the river valley and in the hilly area which is partly covered with dense forest. Except for the Balaghat mines, limited outcrops are available for the study of this shear zone.

6.2.3 Wainganga Fault

The Wainganga River is flowing along a fault with straight trace on outcrop, running in NS direction. This is a vertical fault, with the eastern (Dhansua, Bharweli, Manjhara) block relatively up with respect to the western (Dhapera, Mohgaon, Kanki, Garra, Umertola, Jagpur, Piparia) block (Fig. 6.8).
Fig. 6.7: Map showing regional structure of the study area (after GSI)
Fig. 6.8: Geological Cross Section along XY (after GSI)
6.2.4 Late generation fractures / veins / intrusions

The rocks of the Bharweli area show late fractures and have been intruded by mafic dykes, pegmatite veins, fine grained granitic intrusives and quartz veins.

The quartz veins show ptygmic folds in the granite gneiss/migmatites along the Wainganga River near the Railway Bridge, west of Balaghat Town (Fig. 4.1 d). The quartz veins in biotite schist and gneiss also show ptygmic folds at Jagpur Ghat and Shankar Ghat (Fig. 6.3 a). The pegmatitic veins intrude the biotite schist, gneiss and granitic gneiss, and show well-developed ptygmic folds (Fig. 6.9 b). The fracturing and intrusion took place during the late kinematic stage of the early deformation in the area and the ptygmic folds developed during the second deformation. The quartz veins at places show the rodding structure, formed by deformation during the later phases.

Fig. 6.9 a: Field photograph showing quartz veins in granite at Gaikhuri.

Fig. 6.9 b: Field photograph showing intrusion of pegmatite in granite at Gaikhuri.

6.3 STRUCTURAL CONTROL

6.3.1 Interpretation from underground mapping

The underground structural geometry was determined from the mapping of various subsurface development features like levels, drives, crosscuts, and stopes. Three-dimensional underground geometry was reduced to a projection on a single horizontal plane for preparing the map. Unlike surface maps, the underground maps or level plans show various geological features, and behavior of the ore body and its interrelations at the level of mapping. Preparation of level plan
was aimed to locate the ore bodies and understand the effect of structural features on them. The composite map formed by combining drive and crosscut maps, wall maps, composite plan and sections. Such a plane is generally considered at breast and waist level and mapping is done at either side of those levels as per the requirements. The mapping was done by brunton and tape. The underground mapping was carried out mainly in the developed levels where the ore body, footwall contact and hanging wall contact were exposed.

The ore body at Balaghat mine consists of mainly braunite with bands of jasperoid quartzite, and manganiferous quartzite, combinedly known as Banded Manganese Formation (BMnF) (Fig.6.10 a). The hanging wall rock is incompetent and consists of phyllites and sericite schists of the Mansar Formation and foot wall rock consists of feldspathic quartzite and quartz-schists of Sitasaongi Formation. Both the hanging wall and foot wall are closely jointed.

The ore bed is thick in the middle portion but thins out in the extremities to disappear ultimately. The maximum thickness in the middle portion is about 20 m and the minimum is about a meter, giving an average thickness of about 10 m (Fig. 6.10 b). In the northern extremities ore body is dipping at very flat angle of about $10^\circ$ whereas in the southern extremities it is dipping steeply (about $80^\circ$) (Fig. 6.10 c). Middle portion is involved in at least two cycles of folding (Fig. 6.10 c).

The general strike direction of the deposit is N25°E – S25°W, but changes from chainage 2300 and moves towards northwest direction (Fig. 6.10 d). The chainage is shifting toward south section as the depth is increasing. The dip of the deposit is towards west with amount of 45° to 85° except in northern section where structural complications have resulted in much flatter westerly dips and at places even reversed dips. Swelling and pinching is common in ore body (Fig. 6.10 e and f). The curved geometry of the ore body is increasing with the depth.

Mainly two stages of folding have been noted with thrust form SSE-NNW direction (Fig. 6.10 g and h) which has not only changed the dip of the ore but also responsible for the thickening and thinning of ore bed at various places along the dip and strike.

- Formation of recumbent fold in the north section which is plunging at about $15^0$ towards SSW and has an area of influence of about 1000 m in the strike direction and about 300 m in the dip direction (Fig. 6.10 i).
- During the second stage, axes of the early folds were folded to curvilinear geometry. They are minor in nature.
Fig. 6.10 a: Geological map of the Banded Manganese Formation between 15 crosscut to 13 crosscut at the 10th underground level (200m depth).
Fig. 6.10 b: Underground map showing flat dips between 25 crosscut to 27 crosscut at the 10th level.
Fig. 6.10 c: Underground map showing steep dips between 48 crosscut to 49.50 crosscut at the 10th level.
Fig. 6.10 d: Underground map showing general strike of the ore body at the 6th level.
Fig. 6.10 e: Underground map showing pinch-and-swell behavior of the ore body at the 7th level.
Fig. 6.10 f: Map showing pinching and swelling behavior of the ore body at the 8th level.
Fig. 6.10 g: Map showing folds in the north part at the 9th level.
Fig. 6.10 h: Map showing folds in the north part at the 10th level.
Fig. 6.10 i: Map showing one limb of the recumbent fold at the 11th level.
6.3.2 Interpretation from mapping of winze

A winze is an opening from an upper level to lower level along the dip of the ore body (Figs. 6.11 a to c). This serves the purposes of airway, and also for material transport. The winze also exposes the ore body on the dip direction between the two levels. The floor of the winze is usually the footwall contact of the ore body and the winze is designed in such a way that exposes the ore for the maximum part of its inclined length. Here also short holes are drilled in the floor and roof of the winzes to know the thickness of the ore body. A raise is opposite of a winze and is an opening from the bottom level to the upper level along the dip of the ore body. This also serves the purpose of ventilation, ladder way and for transportation of material. Winze gives us the cross sectional view of ore body in the field. After completion of winze, the mapping started from either upper level or lower level by the help of ladder. Before mapping the visibility of all the bands of the ore body is confirmed; else the winze is washed by water.

The attitudes of the ore body are noted and are transferred to the section, which is already prepared during borehole cross section In the north section the dip of the deposit is very flat and is about 10° to 30° towards west (Figs 6.11 a to c); in the south section the ore body is steep dipping (about 80°) towards west (Figs.6.11 d and e); whereas the middle portion has at least two cycles of folds along the dip as well as along the strike (Fig 6.11 f).

6.3.3 Interpretation of the longitudinal vertical section

Longitudinal section is not very much helpful to find out the structural control on the Balaghat manganese deposit. The ore body of Balaghat manganese ore deposit is massive, continuous, highly folded and jointed. The mining is complete up to the 8th level. Mining at the 9th, 10th and 11th level is under operation, and the 12th level is under development. The ore body is thick in the central part and thins out in both extremities. So due to economic point of view the mining is only confined between chainage 500 and 6300. In the mining area the ore body is massive and uniform with post-metamorphic structures. The ore body is folded and plunges towards SSW (Fig. 6.12).
Fig. 6.11 a: Cross section of winze 7 from 9th to 10th level showing very sallow dip.

Fig. 6.11 b: Cross section of winze 13 from 9th to 10th level showing very sallow dip.

Fig. 6.11 c: Cross section of winze 31 from 9th to 10th level showing very sallow dip.
Fig. 6.11 d: Cross section of winze 43.5 from 9th to 10th level showing steep dip in the south part of the deposit.

Fig. 6.11 e: Cross section of winze 52.5 from 9th to 10th level showing steep dip in the south part of the deposit.

Fig. 6.11 f: Cross section of winze 35 from 9th to 10th level showing recumbent fold in the north part of the deposit.
Fig. 6.12: Longitudinal vertical section showing existing and future levels of the Balaghat mine, structurally deposit is massive, continuous, extremely folded and jointed.
6.3.4 Interpretation of borehole cross sections

The structure of ore body can be understood from the cross section of boreholes and update of information of the ore body already exposed during mining (presently 1st level to 11th level). To understand the behavior of the ore body the structural control cross section at an interval of 30 m has also been prepared.

The entire deposit can be divided into two blocks on the basis of the amount of dip. In the south section the ore body shows steep dip (60°-85°) (Fig. 6.13 a) and in the north section the ore body has very shallow dip (10°- 30°), with flattening of dip at depth forming a synclinal structure (Fig. 6.13 b).

From chainage 800 to 2300 a recumbent fold can be easily demarcated in the cross section. In chainage 800 it is between 2nd and 3rd level (Fig. 6.13 c) and at chainage 1700 to 2300 it is between 4th and 6th level (Figs. 6.13 d and e). The axial plane of the fold strikes east – west and the fold plunges towards SSW. A recumbent isoclinal fold is also observed at chainage 8400, between 4th and 7th level (Fig. 6.13 f). The axial plane of this fold is also east-west. Between 15th and 16th level some minor faults are observed; the throw of the fault is around 10 m (Fig. 6.13 g). The pinch-and-swell is the common characteristics of the ore body (Fig. 6.13 h).

**Fig. 6.13 a:** Cross section at chainage 6100 along borehole no 15 and 35 showing steep dip.

**Fig. 6.13 b:** Cross section at chainage 5400 along borehole no 57 showing flattening of dip at depth forming a synclinal structure.
Fig. 6.13 c: Cross section at chainage 800 along borehole no 25 showing trace of recumbent fold.
Fig. 6.13 d: Cross section at chainage 1300 along borehole no 68 and 69 trace of recumbent fold.
Fig. 6.13 e: Cross section at chainage 1700 along borehole no 29 trace of recumbent fold.
Fig. 6.13 f: Cross section at chainage 2300 along borehole no 50 trace of recumbent isoclinal fold.
Fig. 6.13 g: Cross section at chainage 8400 along borehole no 22 showing small scale fault at 16.5th level.

Fig. 6.13 h: Cross section at chainage 4500 along borehole no 63 and 66 showing pinch-and-swell structure.

6.4 DISCUSSION

Structural elements are greatly emphasized to formulate the proper/scientific mining methods and their safety, exploration strategies and borehole planning. These also lead to discovery of new deposits or extension of ore bodies in existing deposit. These structures that control ore deposition can be primary or secondary (superimposed). In certain types of ore deposits, the primary controls are dominant, in others, superimposed features such as faults dominate. The structural control on mineralization in Balaghat manganese deposit is understood after study of field data, underground maps, cross section of winzes, longitudinal section and cross section of different boreholes. At Balaghat the manganese mineralization is mostly affected by folds with subhorizontal axial plane and fold axes in underground sections. These recumbent folds are the main structure which affects the geometry of mineralization. Due to recumbent fold the ore deposit got flattened in the north section of the deposit, giving a very wide ore horizon whereas the south section is free from this folding and has steep dip and narrow width (Fig. 6.14). However, some of the folds with moderate to steep plunging axes with EW axial traces are $F_2$ folds.
Fig. 6.14: Underground map of various levels showing different phases of deformation in Balaghat manganese deposit.

Deformation and metamorphism take place in three stages in this area. Deformation and metamorphism ($D_1$-$M_1$): The first folding generated isoclinal folds with axial planar schistosity.
These folds on the ore band have NNE-SSW trend (recumbent fold). Deformation and metamorphism (D$_2$-M$_2$): Tectonic deformation of second generation developed folds on schistosity and reoriented early folds (Fig. 6.14). These folds were mostly upright with NNE-SSW trend (i.e. drag folds and asymmetrical folds). Deformation and metamorphism (D$_3$-M$_3$): These folds with NS to NWW-SSE axial planes caused swing of regional trend.

Other folds like isoclinal, asymmetrical, and symmetrical drags are affecting the mineralization locally, giving pinch-and-swell structure which is very common characteristic of the ore body of Balaghat manganese deposit.

Joints are also very common structures in Balaghat manganese deposit. The effect of joint on the deposit is marked by low wall-strength of the ore body. Due to low strength more supports are required during mining operation in closely jointed strata and the fine generation becomes high in ROM. Faults are not very prominent structure in this area; only few dip-slip faults can be recognized locally. Very small scale faults are found at deeper levels.