CHAPTER 2
GEOLOGY AND STRUCTURE

2.1 GENERAL GEOLOGY OF SAUSAR GROUP

The Sausar Group of metamorphosed sediments and manganese bearing ores were once regarded to be the oldest formations in Central India. The sediment which contains Sausar poly-metamorphic is a part of the larger Central Indian Tectonic Zone (CITZ) (Naqvi and Rogers, 1987). Sausar Group is found to be surrounded within the Tirodi Gneiss along the southern fringe of Satpura Province. The Central Indian Suture (CIS), to the south, indicates its southern boundary. Sausar Group is exposed in the form of a 210 kms long arcuate fold belt having a general ENE-WSW trend with southerly convexity. The rocks of Sausar Group stretch in the East-West direction from Kachidhana in Chhindwara District in the west to Baihar in Balaghat District in the east, over a strike length of about 210 kms long and 25-30 meters wide through Seoni and Balaghat districts of M.P. and Nagpur and Bhandara districts of Maharashtra (Fermor, 1909, 1936; Narayanaswami, et al. 1963; and Khan, et al. 2003). The Sausar Group hosts the largest productive manganese ore deposits of India, contributing about 80% of the total production of the country. Rocks of the same lithology, grade of metamorphism, field relationship and structure, as those of the Sausar meta-sediments, continue further east after an intervening cover of younger rocks, in a same tectonic setting beyond Ratanpur in Bilaspur District. Such group consisting of meta-sedimentary rocks, stratigraphy and structure of the Sausar fold belt has been a contestation among the earlier workers for a long time.

The manganese deposit of the Balaghat district, M.P., found as NNE-SSW to ENE-WSW trending conformable bands in the form of lenses of varying sizes enclosed within the meta-sedimentary sequence of Sausar Group of rocks of Precambrian age as shown in Figure 2.1 (Banerjee, et al. 2007). These manganiferrous rocks are underlain by extremely metamorphosed ore and the Paragneisses which may or may not be a part of the lower Sausar group. The Sausar Group mainly consists of metamorphosed sediments of predominantly greenschist-amphibolite facies with local granulite facies (Yedekar et al. 1990). The peak metamorphic condition of the Sausar supracrustals is estimated at c.7 kb, and at 675 °C (Bhowmik et al. 1999). Both Tirodi Gneiss and Sausar Group show imprints of
polyphase deformation (Mall et al. 2008). Rocks of Sausar Group consists of a
sequence of regionally metamorphosed cross bedded quartzite, pelite, carbonate and
manganese ores deposited on a stable platform (Bandyopadhyay et al. 1995). Granites
or the gneisses and pegmatites all of Precambrian ages are all emplaced in the Sausar
group of rocks. The Sausar group containing manganese deposits which constitute a
belt known as central belt extend over a length of 200 Kms in NE-SW direction and is
wide about 25 meters roughly in N-S direction. The manganese deposits are
importantly available within the politic Mansar Formation as pointed out by Roy,
1966. The Mn rich formations include three types of rocks namely (i) Mn oxide ores,
(ii) Mn silicate-oxide rock and (iii) Mn silicate-carbonate rock (Roy et al. 1986). Both
types of Mn silicate rocks are thinly interbanded with oxide ores and are finely
interlaminated themselves. The generalised simplified sequence of the central belt
Sausar Group as done by earlier workers is organized in Table 2.1.

The Mn-ore belt of Balaghat is mainly constituted of intensely deformed and
metamorphosed rocks of the Precambrian Sausar rocks, having the Mn-ore deposits.
Older and younger gneisses, migmatites, ortho-gneisses, late and post-tectonic granite
plutons, pegmatites and vein quartz, all of apparent Precambrian age have been partly
mixed up with and emplaced in the Sausar rocks (Narayanasmwami et al. 1963). Mixed
gneisses, amphibolites, hornblende-granulites, hypersthene bearing hybrid gneisses
and charnockitic rocks belonging to an older metamorphic group, happen along the
southern side of the Mn-belt. The Sausar Fold Belt (SSFb) contains two major
lithotectonic ensembles namely the Tirodi Biotite Gneiss (TBG) and the meta-
sedimentary Sausar Group (SSG) (Khan et al. 2003). Two phases of granite intrusions
into Sausar Group of rocks have been observed in the area, the first being syntectonic
(foliated granite) and the second late to post tectonic massive granite. The foliated
granite has been interpreted and called by different geologists particularly
Narayanasmwami and Venkatesh (1971) as Mansar Gneiss or Sitasaongi Gneiss in the
area.
Table 2.1 General stratigraphic sequence of central belt, Sausar Group.

<table>
<thead>
<tr>
<th>Sausar Group</th>
<th>Chhindwara District</th>
<th>Nagpur District</th>
<th>Bhandara District</th>
<th>Balaghat District</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bichua and Junewani Formation</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Chorbaoli Formation</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>Mansar Formation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lohangi and Kadbikhera Formation</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Sitaasongi Formation</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Tirodi Biotite Gneiss Formation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manganese Ore</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beds Absent</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend**

- Bichua and Junewani Formation
- Chorbaoli Formation
- Mansar Formation
- Lohangi and Kadbikhera Formation
- Sitaasongi Formation
- Tirodi Biotite Gneiss Formation
- Manganese Ore
- Beds Absent
Figure 2.1 Generalised geological map of Balaghat district, Madhya Pradesh (Banerjee, et. al. 2007)

Bose has accounted the earliest treatise of the rocks of Balaghat Manganese belt by investigating it in 1888-89 and by including mica phyllites, sericite schists, ‘sandstone-quartzites and jaspery quartzites’ associated with manganese ores within this “Chilpi Ghat Series” (Fermor, 1909). Fermor (1909) coined for the first time petrographical term “gondite” in Indian Geology for the metamorphosed manganiferous rocks having characteristics of Mn bearing silicates. According to him, gondite is necessarily composed of quartz and spessartite, but commonly contains other Mn-silicates. He drew the conclusion that the Mn-ore deposits were syngenetic in origin, laid down as sediments and subsequently metamorphosed; a portion of the ore formed directly by recrystallization of the purest oxide sediments to primary braunite, while others were products of subsequent alteration and recrystallization from Mn-silicates. He gave his opinion that the alteration from Mn silicates to oxides was by a process of deep-seated hypogene oxidation in Precambrian times and that the deposits should extend to as great a depth as the host rocks. According to him, the porous superficial ores were products of supergene alteration.

Detailed geochronologic studies are lacking within this belt; but, Roy et al. (2006) based on Rb-Sr and Sm-Nd geochronological studies, claim that the principal phase of metamorphism (amphibolite-grade) occurred between 800 and 900 Ma as
well as said that the Sausar Belt was bounded on the north and south by granulite belts of different ages. The southern granulite belt hosts a charnockite that yielded a Sm-Nd isochron age of 2672 ± 54 Ma. A magic granulite within the southern belt of Sausar Group yielded Sm-Nd age of 1403 ± 99 Ma. The northern granulite yielded Sm-Nd age of 1112 ± 77 Ma. The granulites in the north and south also yielded Rb-Sr isochron ages in the range of 800-900 Ma. On regional scale, the Sausar Group of rocks of central India represent the geology which has been dated by Rb-Sr methods on the Tirodi Gneiss as 1525± 70 Ma and mineral isochron age of 860 Ma (Sarkar, et al., 1986, Naqvi and Rogers, 1987). In addition, U-Th-Pb methods on pegmatites (Holmes, 1955) and K-Ar methods on micas (Sarkar, et al. 1981) yield close ages in the range of 1000 to 850 Ma. The age of basement Tirodi Gneiss is 2325- 2494 Ma based on Sm-Nd age; (Ahmad et al. 2009). The contact between Tirodi Gneiss and the Sausar Group is marked by the presence of an unconformity composed of polymictic conglomerate (Mohanty, 1993). The age of Sausar sedimentation is as ~2.2 to 2.4 Ga (Mohanty, 2003, 2012).

The main compositions of the Tirodi suite are biotite-muscovite and biotite gneisses, epidote and biotite quartzites, calc-silicate gneisses, quartz-biotite granulites and feldspathic biotite-muscovite schists. Garnet and sillimanite found in area were metamorphosed to higher grades. The gneisses are coarse to medium grained, banded, commonly porphyroblastic which were regarded as paragneisses by Narayanaswami and Venkatesh (1971). The Sausar Group consists primarily of metamorphosed sandy, shaly and calcareous sediments and manganese ores which is the main Mn-producing suite in India. Calcareous formations (Lohangi and Bichua) are better developed in the north and the west, and argillaceous formations (Mansar and Chorbaoli) in the south and the east of the Mn belt (Naqvi and Rogers, 1987). The Sausar Group comprising of quartzite, pelite and carbonate associations consist stratiform manganese deposits, the largest manganese resources in India (Dasgupta et al. 1984; Bhowmik et al. 1997). Narayanaswami et al. (1963) grouped phyllites and manganese deposits of Bharweli-Ukwa belt under the Mansar Formation of Sausar Group. Pascoe (1950) described these phyllites as the Balaghat branch of Dharwar outerop, generally referred to as the Chilpi Group. These phyllites of Balaghat area unconformably rest over the migmatites with partially melted enclaves of Sausar meta-sediments with development of polymictic conglomerate. There is no physical continuity of these
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rocks either with Mansar Schist of Sausar Group or with phyllite of Chilpi Group. As a matter of fact, these low grade rocks of Balaghat area represent a separate stratigraphic sequence younger to the Sausar Group but equivalent to Chilpi Group and have been deposited in a separate basin. This was designated as the Bharweli Group (Jain et al. 1990). Pal and Bhowmik (1998) have discounted the idea of a separate younger Bharweli Group and have identified them as part of Sausar Group. The Bhandara-Balaghat granulite (BBG) belts comprise a medium to coarse grained two-pyroxene granulite body that is of gabbroic composition and preserves relic igneous fabric. The southernmost unit of SSG is the Bhandara-Balaghat granulite (BBG) domain, which is bounded by CIS. It consists of a suite of high grade metamorphic rocks that include mafic granulite, charnockite, enderbite, gneisses, meta-ultrabasites, iron formation granulite, cordierite granulite and kyanite quartzite.

Manganese formations comprising metamorphosed impure manganiferous sediments (gondite), stratiform manganese oxides and supergene Mn-oxide ore bodies, in intimate association with gondite, are noticed between Chorbaoli and Mansar Formation, between Mansar and Lohangi formations and within Mansar Formation. However, the major ore producing manganese deposits are restricted to the top of the Lohangi Formation. The Sausar meta-sediments seem to have reached the upper amphibolite facies metamorphism. The general trend of this belt is NE-SW in the east, E-W in the middle and NNW-SSE in the west. Along with increase in the grade of metamorphism the fold geometry becomes increasingly more tight and complex from south to north. The major folds are broadly E-W trending and low plunging.

2.2 LITHOSTRATIGRAPHY

Bose (in Fermor, 1909) who mapped the Eastern Balaghat district in 1888-89 was the first to classify the rock of central provinces. He divided the old rocks of Balaghat region into three series, namely the Chilpi Ghat series, the Baihar gneiss (metamorphic and crystalline series) and the Chauria gneiss (intrusive granites). Burton (1912 and 1915) who mapped the Seoni and Balaghat districts proposed the name, “Sonawani series” for the phyllites, schists and calc-silicate rocks of this area, which according to him were unconformable below the Chilpi Ghat series of King (1889) further east. Fermor at that time differentiated two distinct horizons of Mn-ore-

(1) at the base of the Chilpi Ghat series, and (2) at the base of Sonawani series. After
completing the mapping of intensely folded and metamorphosed rocks of the Sausar area, Fermor proposed the name “Sausar series” in 1925 for the rocks of the Sausar tehsil and gave a detailed succession for the first time (Pascoe, 1926). He also gave his observation that Sonawani series of Balaghat district was equivalent to “at least another portion of the Sausar series”. West (Fermor, 1931) slightly modified the classification given by Fermor.

Fermor gave a modification of the Sausar series in 1932 by introducing the Junewani stage in between Chorbaoli and Ramtek stages. He also instituted the Khadbikhera stage below the Utekat stage. The structural and metamorphic study of the “Deolapar nappe” published in the year 1936 completed the first phase of the mapping of the Madhya Pradesh Mn belt started by Fermor in 1911. West (1936) also gave a modification of the Sausar series proposed by Fermor (1909). West (1936) introduced the Sitapar stage above the Bichua stage.

Table - 2.2 Stratigraphic succession of Sausar Series (after West, 1936)

<p>| | | |</p>
<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>S</td>
<td>Sitapar Stage</td>
<td>Hornblende Schists</td>
</tr>
<tr>
<td>A</td>
<td>Bichua Stage</td>
<td>Pure Facies: While dolomitic marble with</td>
</tr>
<tr>
<td>U</td>
<td></td>
<td>serpentine, tremolite and diopside.</td>
</tr>
<tr>
<td>S</td>
<td></td>
<td>Impure Facies: Diopside-actinolite schist,</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td>and schists with wollastonite, grossularite,</td>
</tr>
<tr>
<td>R</td>
<td></td>
<td>tremolite and anthophyllite</td>
</tr>
<tr>
<td></td>
<td>Junewani Stage:</td>
<td>Muscovite - biotite schists with autoclastic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>conglomerates</td>
</tr>
<tr>
<td>S</td>
<td>Chorbaoli Stage</td>
<td>Quartzite and muscovite - quartz schists</td>
</tr>
<tr>
<td>E</td>
<td>(= Ramtek Stage)</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Mansar Stage:</td>
<td>Muscovite - biotite - sillimanite schists with lenticular beds of</td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>manganese ore.</td>
</tr>
<tr>
<td>E</td>
<td>Lohangi Stage:</td>
<td>Pink calcitic marbles and calciphyres</td>
</tr>
<tr>
<td>S</td>
<td>Utekatata Stage:</td>
<td>Banded calc-granulites.</td>
</tr>
<tr>
<td>K</td>
<td>Kadbikhera Stage:</td>
<td>Magnetite - biotite granulites</td>
</tr>
</tbody>
</table>

Shukla (1952) mapped the geology of Balaghat district and suggested the following order of rock succession in this area is as follows:
Table 2.3 Geological Succession of Balaghat District after (Shukla 1952)

<table>
<thead>
<tr>
<th>Series</th>
<th>Formation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Alluvium</td>
</tr>
<tr>
<td></td>
<td>Laterite</td>
</tr>
<tr>
<td></td>
<td>Aplitic granite, pegmatite and quartz-veins</td>
</tr>
<tr>
<td>Chilpi Ghat Series</td>
<td>Quartz-Mica-Schist, With Bands Of Biotite-Kyanite-Staurolite-Schist, Sericite-Schist</td>
</tr>
<tr>
<td></td>
<td>Phyllites and slates, with manganese ore near the base</td>
</tr>
<tr>
<td></td>
<td>----------------------Thrust Plane----------------------</td>
</tr>
<tr>
<td></td>
<td>Granitic gneisses with metamorphosed basic intrusives</td>
</tr>
<tr>
<td></td>
<td>----------? ? ? ?----------</td>
</tr>
<tr>
<td>B</td>
<td>Quartz-Mica-Schist, Crystalline limestone</td>
</tr>
<tr>
<td></td>
<td>Quartz-Mica-Schist, Conglomerate</td>
</tr>
<tr>
<td></td>
<td>Impersistent</td>
</tr>
</tbody>
</table>

Straczek et al. (1956) also gave modification of the stratigraphy of Sausar series suggested by Fermor (1908a, and 1909) and West (1936). He recognized widespread occurrence of Biotite Gneiss of all varieties and proposed the term formation instead of stage. He introduced new formation Sitasaongi and placed it above the formation Tirodi Gneiss by omitting the Utekata and Sitapar stages proposed by earlier workers. He showed disconformity between the Sitasaongi and Tirodi Biotite. He recognized three sub stages viz.

1. Lohangi Substage
2. Utekata Substage.
3. Kadbikhara Substage

Narayanaswami et al. (1963) proposed that phyllites and sericitic schists of the Chilpi Ghat series can be correlated with the muscovite schists of the Mansar and Sitasaongi Formations of the Sausar Group. They grouped Kadbikhera, Utekata and Lohangi stages into a single Lohangi stage by giving the status of sub-stages to the individual ones and also added a new Sitasaongi stage at the base of the succession. The Tirodi Biotite Gneiss (TBG) regarded as the lower most unit of the Sausar series by Straczek et al. (1956) was reinterpreted as basement Gneisses by Narayanaswami et al. (1963). The stratigraphic succession proposed by Narayanaswami et al. (ibid) is presented in the Table-2.4.
Different workers have given the stratigraphic sequence of Sausar belt such as West (1936), Strackzec et al. (1956), Shukla and Anandalwar (1959), Narayanaswami et al. (1963), Rao (1979), Bandopadhyay et al. (1995) and Khan et al. (2003). Because of lateral facies changes in the area, the sequence and the names of the formations differ slightly from place to place (Roy, 1973). Stratigraphic succession of the Sausar Group of Bastar Craton (Bandopadhyay et al. 1995), modified from Narayanaswami et al. (1963) is given in the Table 2.5. Contributions of West (1936), Straczec and Krishnaswami (1956), Shukla and Anandalwar (1973) and Bandopadhyay et al. (1995) are very much appreciable.

Tripathi et al. (1981) studied the rocks of Bharwell-Ukwa area distinctly exposed in Baihar area and compared the Baihar gneiss of Bose (1889) with the Junewani Formation of the Sausar Group and assumed the Chilpi Group to be stratigraphically older and correlatable with the Sausar Group. Rao (1981) indicated the low-grade rocks of Bharwell-Ukwa Baihar belt, forming the Chilpi Group, to be equivalent to the Mansar Formation of the Sausar Group. Dasgupta et al. (1984) considered the schistose rocks of Bharwell-Ukwa area as “Sausar meta-sediments”, having sheared contacts with the older Chilpi Group and younger gneisses of Baihar.

Jain et al. (1990, 1991 and 1995) mapped a major shear zone from Hatta and Baihar in Balaghat district in the east. This shear zone is termed as the “Central India Shear” (CIS) zone. The rocks of Chilpi Ghat Group are separated from the manganese belt by a gneissic country through which this major ductile mylonite zone (CIS) passes (Jain et al. 1991). The manganese bearing rocks of Bharwell-Ukwa area were considered to be younger than the Sausar Group and are exposed to the north of this Central Indian Shear (cf. Jain et al. 1991). The rocks to the south of CIS were mapped as the Khairagarh Group, Nandgaon Volcanics, Dongargarh Granitoid, and Malanjkhand Granitoid.

Bandopadhyay et al. (1995) discussed about the development and relative tectono-stratigraphic positions of the four important Proterozoic supracrustal fold belts viz., Mahakoshal Group, Kotri- Dongargarh Super Group, Sakoli Group and Sausar Group, the last three together being named as “trinity” in the west central part of Bastar Craton. They said that the Proterozoic basins believed to have formed by local extension of the existing Archaean continental crust, contained a tripartite package of volcanic, volcano-sedimentary and sedimentary successions.
## Table-2.4. Stratigraphic succession of the Sausar Group (after Narayanaswami et al. 1963)

<table>
<thead>
<tr>
<th>Formation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bichua Formation</td>
<td>Dolomitic marble, calc gneiss and calc schist including diopside, actinolite schist and schists with wollastonite, grossularite, tremolite and anthophyllite; the marble is often serpentine-bearing and occurs throughout the area except in the south and east.</td>
</tr>
<tr>
<td>Junewani Formation</td>
<td>Muscovite-biotite schist and quartz biotite granulite; at places a fine grained biotite gneiss, commonly garnetiferrous; in the sillimanite zone contains sillimanite, commonly as quartz-sillimanite knots (tabloids); in the middle grade zone contains staurolite and kyanite; at places apparently grades and interfingers with rocks of Bichua Formation. Distribution widespread but often lenticular.</td>
</tr>
<tr>
<td>Chorbaoli Formation</td>
<td>Quartzite, quartz-schist, quartz-muscovite schist and feldspathic muscovite schist, occasionally garnetiferrous, grading to strongly feldspathised muscovite gneiss, contains kyanite in the middle grade areas, and sillimanite and quartz-sillimanite tabloids in the sillimanite zone; at places contains stretched pebbles of quartzite and autoclastic breccia. Distribution widespread except in central portion of the belt.</td>
</tr>
</tbody>
</table>
| Mansar Formation   | Manganese-ore and Gondite Horizon-I  
Muscovite schist, muscovite-biotite schist, sericite schist and phyllites; commonly garnetiferrous, contains sillimanite in sillimanite zone and staurolite in middle-grade zone; becomes muscovite-gneiss in local areas of feldspathization; also low grade sericite schist and phyllite containing ottrelite; the most widespread formation in the sequence. Manganese-ore and Gondite Horizon-II (within Mansar Schist) |
| Lohangi Formation  | Manganese-ore and Gondite Horizon-III  
(1) Lohangi Sub-stage: Pink and white calcitic marble partly dolomite at places and associated calciphyres.  
(2) Utekata Sub-stage: Calc-granulite and gneiss, containing diopside actinolite, epidote, plagioclase and garnet; often microcline bearing banded calc-granulite or gneiss: locally grades into epidote-quartzite. Occurs throughout the area but is generally thin and discontinuous; at places gradational and intermixed with marble.  
(3) Kadbhikera Sub-stage: Quartz-biotite granulite, commonly with epidote and magnetite, intercalated quartz biotite schist, locally developed in the western part of the belt, only apparently gradational with the Utekata calc-granulite; generally thin and lenticular.  
The Lohangi Formation laterally pinches out to the south and east and is exposed the underlying Sitasaongi Formation. |
| Sitasaongi Formation| Quartz-muscovite schist and feldspathic muscovite schist with intercalated quartzite; becomes muscovite gneiss, where feldspathised locally. Occasionally garnetiferrous and kyanite-bearing; thickest development in Bhandara District apparently extends to the east as schistose sericite and feldspathic grit |

| ?-----------------| Discontinuity-------------------?----------------- |
| Tirodi Biotite Gneiss |  |

37
Table 2.5 Stratigraphic succession of Sausar Group (Bandopadhyay et al. 1995, modified from Narayanawami et al. 1963)

<table>
<thead>
<tr>
<th>FORMATION</th>
<th>LITHOLOGY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bichua Formation</td>
<td>Dolomite, Marble, Calc-silicate gneiss schist.</td>
</tr>
<tr>
<td>Junewani Formation</td>
<td>Metapelite (Mica Schist), Quartzite, granulite, biotite-Gneiss (Reworked basement).</td>
</tr>
<tr>
<td>Chorbaoli Formation</td>
<td>Quartzite, feldspathic Schists, Gneisses, Autoclastic Quartz, Conglomerate</td>
</tr>
<tr>
<td>Mansar Formation</td>
<td>Metapelite (mica-schists and gneisses), graphitic Schists, Phyllite quartzite, major manganese deposits and gondite.</td>
</tr>
<tr>
<td>Lohangi Formation</td>
<td>Calc-Silicate Schists and gneisses, marble, Manganese deposits.</td>
</tr>
<tr>
<td>Sitasaongi Formation</td>
<td>Quartz mica Schists, Feldspathic Schists, mica gneiss, Quartzite, Conglomerate.</td>
</tr>
</tbody>
</table>

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Tirodi Gneiss

Biotite gneiss, Amphibolite, Calc-Silicate Gneiss (Tirodi Gneiss), Granulites, Mica Feldspathic Schists.

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Older Metamorphics

Charnockite, Orthogneisses and Granite Biotite Gneisses, hornblende Gneisses, Amphibolites and calcgranulites

Banerji et al. (1997) proposed a two-tier classification of the Sausar rocks based on STM carried out by them from Operation MP, Jabalpur.

Table 2.6 Stratigraphic succession of Sausar (after Banerji et al. 1997)

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Metasediments</td>
<td></td>
</tr>
<tr>
<td>Base not seen.</td>
<td></td>
</tr>
</tbody>
</table>

Khan et al.'s work (2002) reveals that the Tirodi Biotite Gneiss (TBG) constitutes basement for Supracrustal Sausar Group (SSG). The contact between TBG and SSG is tectonised. The lower (Lohangi Formation) and upper (Bichua Formation) part of the SSG is mostly presence of calcareous facies sediments,
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whereas middle part (Mansar and Chorbaoli Formation) is predominantly pelitic and psammopelitic with subordinate psammites.

The following lithostratigraphic succession of Sausar Group and associated Gneiss- migmatites is suggested by Khan et al. (2003).

**Table 2.7 Lithostratigraphic succession of Sausar Group** (Khan et al. 2003)

<table>
<thead>
<tr>
<th>Stratigraphic Name</th>
<th>Rock Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recent Deposits</td>
<td>Alluvium &amp; Soil.</td>
</tr>
<tr>
<td>Quaternary</td>
<td>Laterite</td>
</tr>
<tr>
<td>Intrusives</td>
<td>Massive Potassic granite, pegmatite and quartz veins. Foliated potassic granite.</td>
</tr>
<tr>
<td>Bichua Formation</td>
<td>White dolomitic marble + red and yellow chert.</td>
</tr>
<tr>
<td>Chorbaoli Formaton</td>
<td>Coarse grained, garnetiferous quartz-mica schist with local development of magnetite and staurolite. Micaceous and cherty, ferruginous quartzite with local development of magnetite and garnet.</td>
</tr>
<tr>
<td>Mansar Formation</td>
<td>Fine grained garnetiferous mica schist and quartz-mica schist with thin chert and quartzite and thick horizon of Mn ore and gondite.</td>
</tr>
<tr>
<td>Lohangi Formation</td>
<td>Calc silicate rocks, calc-gneiss with subordinate pink calcitic marble and minor Mn ore horizons.</td>
</tr>
<tr>
<td>Sitasaangi Formation</td>
<td>Meta gneiss and micaceous quartzite.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pre Sausar Basement (Archaean)</th>
<th>Tirodi Biotite Gneiss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Multicomponent gneiss e.g. biotite gneiss, migmatite gneiss etc. with amphibolite enclaves.</td>
</tr>
</tbody>
</table>

Tirodi Biotite Gneiss (TBG) is a basket term which has a variety of gneissic rocks for instance biotite-plagioclase gneiss, felsic-migmatitic gneiss, tonalitic gneiss, cordierite gneiss etc. as has been observed in the western continuity of the area during STM work carried out by Op. Mah. (Khan et al. 2003). In this present study area, mostly biotite gneiss-migmatite has been observed. They have given the opinion that the TBG constituted the basement for SSG on the basis of the following observations.

1. The TBG is characterised by a distinctly different lithological package of diverse gneisses with small enclaves of metabasic rocks and mafic granulites.

2. In Bharweli- Ukwa region in MP, the TBG is overlain by basal conglomerate horizon belonging to Sausar supracrustals. However, contact relationship between
TBG and SSG in most of the places has been obliterated due to later deformation and metamorphism during Sausar Orogeny.

3. The tectono-thermal history of the TBG is polycyclic which suggests that the deformational and metamorphic events of TBG have been later overprinted by the structures and thermal history of the Sausar Orogeny.

4. Recent petrological work (Pal and Bhowmik, 1998) has indicated that TBG records the effects of an older granulite facies metamorphic event, which are totally absent in Sausar Group of rocks. The SSG has reached only up to mid-upper amphibolite facies condition of metamorphism. Thus presence of the older tectono-thermal event in TBG indicates its pre Sausar age.

2.3 STRUCTURE OF THE SAUSAR GROUP:

West (1928 and 1938) (General reports, G.S.I.) who joined the central provinces party in 1928, started mapping the Deolapar area and made detailed studies of the structure of the Sausar rocks, the metamorphism of the calc-gneisses and granulites, the origin of sillimanite “tabloids” in the Chorbaoli and Junewani schists and the rhythmic sedimentation in the microcline-bearing banded calc-granulites and proposed the “Deolapar nappe” for the complicated structure of this area in the year 1930.

Fermor (1906) found the rocks of the Sausar tehsil intensely folded into isoclinal synclinoria and anticlinoria, and recumbent folds of an Alpine type and differentiated for the first time in India, the “pitch” of folds by the slickenside grooving in the gneisses, quartzites and Mn-ore.

Huin et al. (1998); Khan et al. (1998, 1999) and Bhowmik et al. (1999) have observed three generations of structure from the Sausar Group showing successive overprinting relations and have confirmed that the first generation structure in the Sausar Group overprints early mylonitic fabric in the Tirodi gneiss-migmatite. The Sausar Group noticed three phases of deformation and four phases of metamorphism, where metamorphism of this group of rocks was roughly synchronous with the various stages of deformation. The first phase of deformation produced isoclinal folds, axial plane schistosity and mineral lineation. The second phase of deformation generated super folds and crenulations cleavage. Siddiquie (2004) also reported this from the East Gharbham quarry, Vizianagram District, A.P., while the third
deformational phase formed open folds with steeply dipping axial planes (Sarkar et al. 1977). The structural studies indicate that the Sausar Group and the immediately subjacent Tirodi Biotite Gneisses (TBG) have suffered polyphase deformation by intense thrusting and folding (Chattopadhyay et al. 2001; Khan et al. 2003). A very early phase of thrusting involving crystalline basement (TBG) rocks along with SSG is observed and at least four-phases of folding (F₁-F₄) have been demarcated by these workers. The thrust slices and the associated thrust related F₁ recumbent reclined folds were refolded by subsequent upright folding episode (F₂). It is also observed that these thrust sheets specially concentrate along the northern margin of SSFB and intensity of thrusting rapidly decreases southward, from hinterland to foreland, a feature characteristic of many fold thrust belts (Chattopadhyay et al. 2001). Bhowmik et al. (1999) drawn the conclusion that the granulites formed the basement for deposition of Sausar supracrustals and were tectonically imbricated with the latter during the Sausar orogeny correlated with the 1000 Ma Grenvillian event. Two main tracts of granulites have been identified within the gneisses- the northern Ramakona Belt (RKG) and the southern Bhandara Balaghat Belt (BBG) (Bhowmik et al. 1999; Ramachandra and Roy, 2001). Both the Sausar Supracrustals (SSG) and Tirodi Biotite Gneisses (TBG) are intruded by later felsic magmatic plutons. Full of debates and contradictions on the basement vis-a-vis status of TGB and also on the lithostratigraphic succession of the Sausar Group have been going on among the geologists. Structural and metamorphic evolution of Sausar Supracrustals and the tectono-thermal history of the adjacent high-grade gneisses and granulites have been studied and documented by recent workers (Bhowmik et al. 1999; Bhowmik & Roy, 2003; Chattopadhyay et al. 2001, 2003 a & b and Khan et al. 2002, 2003).

The granulites found in Balaghat Mn-belt are marked by the development of mylonitic structure including S-C fabric in different rocks and comprises multiple shear zones having polycyclic histories. Earlier workers have observed that there are at least two prominent ENE-WSW trending ductile shear zones within Sausar belt. There are two prominent ductile shear zones, which border the granulite belt, one in the north and other in the south. The northern shear zone has steep northerly dip, though at places, reversal in the attitude has been noted. The stretching lineation on this steeply dipping mylonite plane is invariably steep. The lineation data, in conjunction with shear bands suggest predominant dip-slip component with northern
Sausar belt going down with reference to the granulate belt. On the contrary, the steep northerly dipping shear zone on the south of the granulate belt exhibits a reverse sense of movement wherein the granulate belt has been thrust over the Amagaon gneisses. At least one set of small folds is developed on this foliation plane. The general direction of fold axes is approximately N 60°-70° E. The foliation direction is generally N 60°-70° E with dip angles ranging from 60° to 80° towards north. The minor fold-lineations observed also follow in this general direction.

The southern part of the Mn belt constitutes a zone of isoclinal fold with steep dips (50°-80°) to the south, in the central part, the folds are mostly recumbent type with (30°-60°) dip towards south. Increase in deformation to the north has led to the development of thrust sheets (nappes). The folds as well as faults are arranged in an enechelon pattern, progressively shifting towards north. The structure is further complicated by refolding or cross folding of the earlier folds. Moreover, there is emplacement of granite plutons and ortho-gneisses along the axes of cross folds. The axis of the cross folds plunge at low angle (10°-15°) to the west or SW.

The planar features included bedding plane (S₀), axial plane cleavages of folds of different generations (like S₁, S₂ etc). Planar features of gneiss (gneissosity) and syntectonic granite (foliation) were also observed. The linear structural features like fold axes (F₁, F₂, F₃ etc) and mineral and intersection lineation of different generations (e.g. L₁, L₂ etc) were also studied and observed.

The regional structure's trend in the Sausar series follows the general trend of the manganese belt which is very complex. The rocks have been affected by several major periods of folding and faulting which are broadly organized as below:

1. **Folding**: On westerly trending axes, which culminate in the developed of isoclinals folds.

2. **Faulting**: On the axes of the isoclinals folds and refolding of the folds on strongly transverse to parallel axes, with the result those axial planes of earlier isoclinals fold are themselves refolded into isoclinal refold. Large scale recumbent folding and the development of a western trending Nappe structure with major thrusting and faulting followed by continued folding on westerly axes, which resulted in the folding of the thrust plane.
3. **Transverse Faulting:** There is evidence also of a pre-thrust period of faulting as indicated by the fact that in the western part of the belt, there is transverse fault of pre-thrust age.

Replacement ortho gneisses occurred during metamorphism. These syntectonic plutons are mainly concordant but locally are discordant. Unfoliated discordant granite stacks, pegmatite and quartz veinlets date during the period of recumbent folding and thrusting. The major structure and emplacement of the youngest granites probably occurred in the Pre-Cambrian time.

2.4 **ASSOCIATED ROCKS WITHIN THE GEOLOGICAL FORMATION OF STUDY AREA**

1. **Tirodi Biotite Gneiss**

TBG are found as basement rocks in the study area. They are medium to coarse grained, hard compact gneisses with well-defined bands of dark and light coloured minerals (Figure 2.2) and mostly weathered on the surface. The rock seems to be Para gneiss and apparently is a part of the Sausar Group. The gneiss maintains the same special position relative to the overlying units through a belt of 120 Kms long and 25 Kms wide. The rocks are found with subordinate interrelated amphibolite, hornblende gneiss, calc-silicate gneiss, quartz, biotite, granulite and feldspathic biotite, muscovite schist commonly garnetiferrous.

2. **Sitasaongi Formation**

Rocks found below the Manganese ore bed consisting of conglomerates, pebbly grits and quartzites with minor amounts of quartz-sericite or muscovite-schist, often feldspathised, these groups of rocks is named as Sitasaongi formation. The most prominent members are the conglomerate and pebbly grits (Figure 2.3 a). These rocks are in contact with the granitic gneisses to the south and manganese horizon to the north and have varying thickness. The feldspathised schistose are pebbly grits grade into sericitic gneisses at some places. These are light pink to greyish white coloured rocks. Sitasaongi schist is medium grained, hard, compact rock. Foliation is not well developed and they are partially weathered. The quartzites are feldspathic in nature, very coarse grained and thinly banded (Figure 2.3 b).
3. **Lohangi Formation**

Lohangi formation consists of pink calcite marble and associated Calc-silicate, Calc-granulites and gneisses. Epidote quartzite occurs throughout the area but it is generally thin and discontinuous. The outcrop of conglomerate and grit makes a sharp loop on the north side of the ridge and shows granite in the core of the loop. The lenticular bands of marble are found overlying the conglomerates and grits of Sitasaongi formation at this loop. It is pink in colour, medium to fine-grained and consisting of perfectly developed crystals of pink calcite.

![Figure 2.2](image)

**Figure 2.2** Hand specimen showing alternate light and dark coloured bands in Gniess from Tirodi mine, Balaghat district, (M.P.)

![Figure 2.3](image)

**Figure 2.3** Photo showing a) field photograph of boulders in gritty conglomerate and b) hand specimen photo of Feldspathic quartzite showing banding from Bharweli, Balaghat district, (M.P.)
Figure 2.4 Field photograph showing a) Jasperoid and manganiferous band (BMnF) and b) manganese ore found between sericite schist and Feldspathic Quartzite from Bharweli, Balaghat district, (M.P.)

Figure 2.4 Hand specimen showing c) Phyllite and d) Sericite schist from Bharweli, Balaghat district, (M.P.)

4. Mansar Formation

The Mansar formation is a thin sequence of muscovite schist, muscovite-biotite schist, sericite schist and phyllites, commonly garnetiferrous. These rocks contain much sillimanite in the rich grade zone of metamorphism staurolite in the middle grade zone and sericite schist occurs in the low to high grade zone indicating that the original sediments from which the rocks were derived were highly argillaceous. Rocks are medium to fine grained, soft, sometimes garnetiferrous, quartz-sericite-schists and phyllites overlying the manganese bed observed from Ukwa to Waraseoni.

The characteristic of the formation of manganese ore is deposited as admixture of pure and impure sediments. The pure sediments having high quality of Mn ore, whereas the impure sediments contain jasperoid quartzite and manganiferous quartzite, together known as Banded Manganese Formation (BMnF). This phenomenon continues over the entire manganese belt (Figure 2.4a). The manganese
ore is found between the sericite schists of the Mansar Formation and feldspathic quartzite of Sitasaongi Formation (Figure 2.4b).

Phyllites appear to have undergone at least two phases of deformation, schistosity being a crenulation cleavage that has more or less completely transposed the earlier schistosity. At places, some of these phyllites show compositional layering of sericite, chlorite and quartzose layers, with quartz showing neither recrystallization nor any directional orientation and appears to be bedded. The phyllite constitutes the major rock type in this area, consisting of sericite, chlorite and at times with fine biotite (Figure 2.4c).

The sericite schist is found in the Bharweli area trending ENE-WSW. The sericite schist is fine to medium grained (Figure 2.4d). It is greenish to dark greyish black in colour. Sericite schist grades into medium grained mica schist towards the northern part of the Bharweli. The mica schist is fine to medium grained and is grey to brownish grey in colour. The sericite schist is fine grained and contains quartz, flakes of sericite and muscovite. The dimensionally oriented flakes of sericite, quartz and occasionally muscovite define the schistosity.

5. **Chorbaoli Formation**

Rock found in this formation is a medium to coarse grained quartz-muscovite-schists with variations to a fine grained quartz-schist or to a quartzite. This Formation comprises of quartz-muscovite-schist, quartz-schist, quartz-tourmaline-schist and muscovite-schist. The schists are commonly garnetiferrous and locally are feldspathic. They contain kyanite in the middle grade metamorphic zone and sillimanite concentration in high-grade zone. These rocks at places contain bodies of quartzite conglomerate and auto clastic breccias.

6. **Junewani Formation**

Junewani Formation comprises of medium to fine grained muscovite-biotite-schist and quartz-biotite-schist and at places there are fine-grained biotite-gneisses. It contains sillimanite in the high-grade metamorphic zone and kyanite and staurolite in the middle grade zone. Narrow synclinal bands of quartz-biotite-schist grading into biotite-gneiss are also observed at one place.
7. Bichua Formation

The rocks of Bichua Formation occur throughout the area except in the eastern end of the belt, where it has not been encountered. The Formation contains dolomitic marble and associated gneiss, granulites and tonalite schist. Calc-granulite band is seen at one place in the study area.

2.5. METAMORPHISM OF SAUSAR GROUP

The Sausar Group of rocks forming the central part of the SMB is represented by an older metamorphic group including the Tirodi gneiss-migmatites and supracrustals, and a sequence of intensely deformed younger plat formal facies supracrustals intruded by granitic rocks (Narayanaswami et al. 1963). Regional/dynamo-thermal metamorphism in Sausar Fold Belt ranges from low to high grade. Earlier worker (Narayanaswami et al. 1963) pointed out that there is a gradual increase in the grade of metamorphism from east to west as well as from south to north. The easternmost part (parts of Balaghat and Bhandara districts) indicates low grade of metamorphism (chlorite-biotite zone).

Rocks within the Sausar Belt recorded a protracted history of convergent margin activities from ca. 1400 Ma to ca. 800 Ma (Roy et al. 2006). The Sausar meta-sedimentary rocks are metamorphosed to upper amphibolite to granulite facies and have undergone migmatization. The metamorphic grade of Sausar Group increases from low green schist facies in the southeast to upper amphibolite facies in the northwest. Detailed metamorphic studies revealed that peak metamorphism of Sausar Group occurred as 6.5-8.5Kb/550°C, followed by decompression and cooling, indicating collisional tectonic setting (Pal and Bhowmik, 1998). Sarkar et al. (1990a) considered the Sausar Groups as Palaeoproterozoic based on radiometric data of Ghosh et al. (1996) and Sarkar et al. (1985). Although exact timing of deposition, deformation and metamorphism of Sausar Group is not uniform, reliable radiometric age-data of granites and pre-Sausar granulites broadly regard the age of Sausar Orogeny at 1000 Ma (Lippolt and Hautmann, 1994). The granulites of the Sausar Group show a clockwise P-T field, though granulite metamorphism in RKG belt is believed to be of pre-Sausar age (Bhowmik & Roy, 2003; Bhowmik et al. 2005). Presently the granulite outcrops and associated high-grade gneisses are tectonically juxtaposed and interleaved with Sausar Supracrustals and the high-grade gneissic
foliation at places is overprinted by amphibolite facies (=Sausar felsic; Bhowmik et al. 1999).

Recent geochronological data also show that terminal cooling (post peak) of these granites took place at about 1100 Ma, preceding main Sausar metamorphic event (850-900Ma) (Roy et al. 2006). Roy et al. (2006) developed a tectonic model for the region whereby the Dharwar and Bastar Cratons were juxtaposed with the Bundelkhand Craton during the younger Sausar orogenic cycle as part of the larger assembly of Rodinia. On the contrary, Stein et al., (2004) claim that the juxtaposition between the northern and southern Indian cratonic nuclei along the Central Indian Tectonic Zone (CITZ) occurred during the earliest Paleoproterozoic based on Re-Os ages from within the Sausar Belt (Malanjkhand granitoid batholith). They report a Re-Os age of 2490 ± 2 Ma for the granitoid that is nearly identical to U-Pb zircon ages of 2478 ± 9 Ma and 2477 ± 10 Ma for the same unit (Panigrahi et al. 2002). Cu-Mo-Ag mineralization ages associated with the intrusions ranged from 2446-2475 Ma (Stein et al. 2004). Stein et al. (2004) expressed that the region underwent significant 1100-1000 Ma reworking, but the main assembly of cratons took place during the latest Archaean to earliest Paleoproterozoic (2.5 Ga) along the Sausar Belt.

Throughout the length of the area, from west of Balaghat to Samnapur near Ukwa, granites and gneisses are found to the south of the belt of Sausar (Chilpi) Phyllites. The gneiss near the contact with the Sausar Group is more granitoid in various patches and may, in part, be intrusive and moreover, in the south, they are more foliated and schistose and appear to be of composite nature. At some places, they appear to be a gradation between the two types. Older intrusive dykes and sills are also found in the gneissic area which has been metamorphosed to hornblende-
schists and epidiorites etc. Some of these basic intrusive have also been invaded and intruded by veins and stringers of later granitic and aplitic materials. The admixture between composite gneisses, older basic intrusive and later granites etc. are very complex and at some places there is much gradation between these. This complex group of gneisses and associated basic metamorphic rocks is regarded to belong to an older metamorphic group. The older foliated or composite gneisses to the south are muscovite-biotite-gneiss with schists and aplitic bands and are usually perfectly banded. The foliated gneiss often shows remnants of the original schistose materials.
as bands and lenses; these are usually sericitic schists or muscovite-biotite schists, but occasional bands of quartzites are also found within these gneisses.

2.6 REGIONAL GEOLOGY OF STUDY AREA
2.6.1. REGIONAL GEOLOGY OF BHARWELI BLOCK

The Bharweli manganese mine is located in the Mansar Formation of Sausar Group. The strike length of ore body is 2.8 kms having a general strike direction NE-SW and dip varies from 25° to 85° W. The width of the ore body is 1.0 metre in thickness at both ends whereas it increases to as high as 30 m in the central portion and an average thickness is 10 metres. As the ore bed dips N.W. and is found nearly at the top of the ridges. The western slope of the ridge is made up of sericite, phyllites and schists which overlie the ore body (Figure 2.4 c-d). These indicate westerly dips direction of 60°-70° at the southern end, becoming flatter towards the north. The ore bed is intercalated with a number of thin lenticular beds of black and jasperoid quartzite and is separated from the underlying gritty series by a variable thickness of pinkish and grey quartzite and quartzose phyllites (Figure 2.4 a-d). The thickness of this quartzose band in the main portion of the deposit is about 70 m, exposed at abandoned open cast mine of Bharweli mining area. The geological succession of the Sausar Group which is found in the Bharweli mine is given in the Figure 2.5 (Sarkar et al. 2011).
**Figure 2.5** Stratigraphic column showing lithostratigraphic units of the Bharweli manganese ore deposit (after Sarkar et al. 2011)

The conglomerates along with pebbly grits and quartzites with minor amounts of quartzite-sericite muscovite schist often feldspathised of Sitasaongi Formation underlies the quartzites below the ore bed (Figure 2.3 a-b). These form the eastern slope of the Bharweli ridge and also cover the low ground for some distance to the east. The thickness of this zone is about 300 m near the underground mine, but narrows down gradually towards the north. Rocks of the Mansar stage may be divided based on lithology and area distribution into two broad regional groups. The Mansar rocks in the northern part comprise of mainly medium-grained muscovite-schist and muscovite-gneisses and are exposed as a durably plunging anticline or dome. It forms the type faces of normal Mansar stage rocks. In contrast to this, there is a few kms wide zone of medium to fine grained, soft, sometimes garnetiferous, quartz-sericite-schists and phyllites overlying the manganese bed from Ukwa to Waraseoni discussed
in the earlier literature as 'Chilpis'. Conglomerate and the pebbly grits are the most prominent outcrops. These rocks form the bottommost member of the Mansar Formation as seen in the area and are in contact with the granitic gneisses to the south and manganese horizon to the north and have varying thickness. The whole of this gritty formation as well as the gneisses at its contact show effects of intense crushing and mylonitisation and represents a thrust zone. The feldspathised schistose pebbly grits grade into sericitic gneisses at places in the present study area.

Rocks occurring below the manganese ore bed in this area consisting of conglomerates, pebbly grits and quartzites with minor amounts of quartz sericite muscovite schist, often feldspathoids were grouped as Mansar Formation. The Bharweli outcrop in above mentioned zone of conglomerates and pebbly grits is well developed in Bharweli, Malegaon and Langur areas. Thickness of this conglomerate and gritty zone at Bharweli is around 3 metres. The contact between the pebbly grits and the granitic gneisses on the hill slope, north-west of Malegaon, however runs almost North-South. The grit in the Bharweli ridge and in the Malegaon hills is feldspathic, sericitized and contains small rounded to sub rounded pebbles of quartz and fresh pink orthoclase, plagioclase and tourmaline, large microcline and albite. The grits usually grade downwards usually into coarser conglomerate with larger pebbles of quartzite and granite (Figure 2.6 a). Occasional pebbles of Iron-Ore (Specularite) are also found. At most of the places the conglomerate bed comprises boulders (40-50 cm) of granites, gneisses and slates derived from local lithology. Beautiful crystals of corundum are also seen in the conglomerates at one place (Figure 2.6 a). The crystals of corundum are of almond size and deep violet in colour, concentrated along the NNE flank of canal in Malegaon Magjin, Bharweli mine area. The dominant minerals of the boulders at places are quartz, orthoclase feldspar and Muscovite (Figure 2.6 b). Some ellipsoidal quartzite fragments are also observed as fractured in a particular direction with rounded to sub-rounded quartzites in the conglomerates (Figure 2.6 c). Quartz veins intruded in the conglomerate with folded structure are also seen (Figure 2.6 d).

The ore bed in the Bharweli mine is thinly bedded and contains intercalated with thin layers of grey and red jasperoid quartzite and phyllites which make up of nearly 30% of the thickness of ore bed. Braunite is the principle mineral associated with minor amounts of hollandite (Figure 2.7 a). The psilomelane is compact, massive
and fine grained, while the hollandite found as fine glistering crystals. Braunite is
found as browny black as medium grained. Spessartite or other manganese silicates
are not found associated with the ore due to low degree of metamorphism suffered by
the rocks in the area. The underlying quartzites are massive where the ore is thick, as
in the main portion of the Bharweli mine and is very thin where the ore bed is not of
high grade, containing above 50% Mn and the phosphorous content is low.
Manganese ore associated with jasperoid quartzite and manganiferous quartzite
together known as Banded manganese formation (BMnF) is observed in the
underground mining (Figure 2.7b).

2.6.1.1 REGIONAL STRUCTURE OF BHARWELI

The structures of this area are controlled by lithological control and mineralization
lies on the limb of regional fold. The structures observed in this area are bedding,
schistosity, faults, minor folds and joints. Very steep dips are found only in the north-
south trending part of the zone and perhaps due to drag fold. The ore bed shows a
number of minor folds but sharp drag folds in the mine area. The bed makes a shallow
'S'-fold in the abandoned main open cast mine near the northern boundary of the
Hirapur village and about 640 m. to the north of the ropeway-crossing. Well
developed bedding plane is seen in the sericite schist (Figure 2.8a). The anticlinal
portion of this fold is very sharp and shows a plunge of about 20° towards S 35° W.
The synclinal portion of the drag fold is more shallows and shows a number of minor
corrugations or rolling with plunges of the order of 20° in directions converging
towards the main synclinal axis which plunges towards west. Minor lineation such as
groves in the footwall of the ore bed and crenulations cleavage in the phyllites (Figure
2.8b) also show the same amount and direction of plunge as also reported by
Siddiquie, 2004. The other set of acute drag folds plunge more steeply towards north.
The thickness of the ore bed increases locally as a result of these drag folds
(Siddiquie, 2004). The main S-shaped drag fold mentioned above is also traceable in
the underground workings where the average plunge is nearly 16°. Two sets of joints
are observed on feldspathetic quartzite in abandoned open cast mine (Figure 2.8 c).
Recumbent folds are observed in the manganese ore in the underground mine (Figure
2.8d). No major transverse faults have been noted but the ore beds shows evidence of
minor slips at places.
Figure 2.6 a-d Field photograph of gritty conglomerate showing Corundum schist, granite, gneiss, quartzite, chert, quartz vein, muscovite and orthoclase.

Figure 2.7 Photograph of underground mine showing a) bands of jasperoid manganiferous quartzite with hollandite and braunite and b) Hand specimen showing BMnF of jasperoid quartzite, manganese ore and manganiferous quartzite.
2.6.2 REGIONAL GEOLOGY OF TIRODI BLOCK

The rocks of the Tirodi area represent to a large extent regionally metamorphosed, Pre-Cambrian sediments which have been grouped known as Sausar Group. A schematic diagram showing stratigraphic position of the manganese ore horizon in the Sausar group of central belt as worked out by Roy (1981) is shown in the Table 2.1. The area is characterized by extensive stretches of Tirodi biotite-gneiss (TBG) with mafic-ultramafic enclaves (Subba Rao et al. 1999). The Sitasaongi Formation occurs as a thin zone of quartz mica schist and quartzite between ore horizon and TBG and forms the foot wall of the manganese ore horizons of Mansar Formation. The Lohangi manganiferous member is mostly confined to the stratigraphic position between the Mansar muscovite-schist and TBG, and occurs as
discontinuous beds of calc-silicate rocks and calcitic marble with or without manganese ore. Ore zone is conformable between the overlying muscovite schist (Mansar schist) and underlying Tirodi gneiss and or between the muscovite schist (Mansar schist) and Lohangi Formations.

Stratigraphic sequence of these two ore zones is clearly shown in the table 2.1 under Tirodi-Sitapatore group of Balaghat district. The manganese deposits of Tirodi area are syngenetic, metasedimentary belt, locally called 'reefs'. The reef (ore horizon) extended from Jamrapani in the South East to Paonia in the north for an approximate distance of 6.5 KM and is conformable between the overlying Mansar Schist (muscovite sillimanite schist) and underlying Tirodi gneiss.

At places minor bands of dark green fuchsite mica bearing zone is seen just above the manganese horizon of Mansar Formation. The dolomitic marbles of Bichua Formation are overlying the feldspathic quartz-muscovite schist of Chorbaoli Formation (Vemban and Nagarajaiah, 1974). The Sausar Group rocks are closely associated with TBG and intrusive granitoids (Roy et al. 2006) and have mostly tectonised contact with the basement (part of TBG). Pegmatites are seen intruding all the formations in the area and range in thickness from less than a meter to about six meters. Manganiferous formations are conformably interstratified with the pelitic host rocks and show imprints of identical deformational and metamorphic history (Roy, 1981; Bhattacharya et al. 1984). The metapelites of Tirodi area record typical Barrovian type metamorphism with rich development of almandine variety of garnets, staurolite, kyanite and sillimanite. Garnet-biotite thermometry of the metapelites suggests metamorphic conditions of 650 + 25°C at 6 Kb pressure (Roy et al. 1986). Younger intrusive rock like pegmatites are seen in largest concentration in the ore body, they do not intrude the neighbouring rocks, but follow along their contacts and along the fault and Major joint plane. Fragments of ore are included by these pegmatites and in a few places, the fragments show slight rotation, indicating movement within the pegmatite body, the pegmatites usually carry honey coloured Manganese-garnet. Manganese ore is observed between the muscovite schist and sericite schist shown in Figure 2.9a. Red chrome garnets are observed near the contact of pegmatites in south Tirodi mine, which are intruding the manganese ore and Tirodi gneiss (Figure 2.9b). Orthoclase associated with muscovite schist is also observed.
near the contact of pegmatites (Figure 2.9c). Manganese ore associated with jasperoid quartzite is also observed in the south Tirodi mine (Figure 2.9d).

Figure 2.9a Hand specimen photo showing manganese ore associated with muscovite schist and sericite schist from Tirodi mine, Balaghat district, M.P.

Figure 2.9b Hand specimen photo showing red chrome garnet associated with quartz from Tirodi mine, Balaghat district, M.P.

Fig. 2.9c Hand specimen photo showing orthoclase and muscovite schist near the contact of pegmatite from Tirodi mine, Balaghat district, M.P.

Fig. 2.9d Hand specimen photo showing manganese ore associated with jasperoid quartzite from south Tirodi mine, Balaghat district, M.P.

The thickness of the ore body varies from 1.5m to 10m, the thickest part of outcropping in South Tirodi section. The manganese ore bands are interlayered with Gondite, the quartz in the gondite has a tendency to become dominant at places on either side of the ore bed. The ore is hard, dark grey and fine to medium-grained, composed mostly of braunite which gives a metallic lustre with streaks and patches of more bluish lustre, which are apparently made of hollandite with hausmannite. At places as North section in northern part of pit no. 6c, psilomelane and cryptomelane type of ore is seen. Rarely, but in some parts mostly like southern part of pit No. 6c of
North section Manganese silicates and rhodonite type ore are seen. Gondite is composed of dark grey quartz with cloudy inclusions of Manganese Silicates and yellowish garnet of all sizes. Locally, the gondite is rich in rhodonite, ranging in size up to 7.5 cm long and 5 cm across.

Mostly Braunite (Primary silicate oxide) ore bands inter layered with gondite and high siliceous ore mainly pyroxene and garnet group of ores are found in the area due to high grade metamorphism of sedimentary manganese deposits. Primary manganese silicate oxide (Braunite) ore is found about 60% of the total deposit and Mn content in these braunite ore is ranging from 42 to 49%. Some dark black fairly weathered soft residual ore about 5% of the total deposit is found, where the ore beds are in contact with decomposed mica schist and also with weak zone like faults and joints plane.

2.6.2.1 REGIONAL STRUCTURE OF TIRODI

The Geological structure of Tirodi area is very complex. The rocks of this area have been intensely folded. Three stages of folding which have taken place in Tirodi area have been described as follows.

1. Folding of the ore bed into isoclinally synclinal folds with the axis of the fold, plunging both in northerly and southerly direction.
2. Tilting of the axial plane of isoclinal folds and the refolding of the same at low to moderate angles with westerly trend developing into a cross fold.
3. Large scale recumbent folding (mostly in the hazard area and North Tirodi section) and development of westerly trending "Nappe" structure.

2.6.3 REGIONAL GEOLOGY OF UKWA BLOCK

The Manganese Ore horizon occurs in the lower part of a sequence of metasedimentary rock of Sausar Group of Precambrian age. The rock of the Sausar Group at Ukwa extends in NW direction in Balaghat district of Madhya Pradesh. The deposit is located almost at the eastern end of the belt and further eastwards the Sausar Group of rocks are covered by Deccan basalt. The formation of ore body and country rock belonging to the Archaean age group are well exposed along the hill. The tabular ore body is outcropping on hill top and occurs to the north of Ukwa village along the southern slope of a narrow ridge trending N60°E with general strike along NE-SW measures along 6 Km in length. The dip of the ore body varies between 20° to 45°.
NW overlying the ore bed are found sericite-schists and phyllites on the top and north slope of the ridge. It is crenulated and coarse-grained approaching mica-schist and contains some grains of black and red iron oxides.

The Ukwa manganese deposit occurs within the Sitasaongi and Mansar formations of the Sausar Group. Manganese ore is interbanded with quartzite (Figure 2.10 d). The ore is either massive or banded and consists of braunite, hollandite, bixbyite, pyrolusite and cryptomelane and is soft to very soft in nature. Braunite is the dominant constituent. Hematite occurs in close association of braunite and bixbyite.

The wall rock contacts are phyllite and sericite schist in hanging wall (Mansar formation) and quartzite, quartzite schist in Footwall side (Sitasaongi formation). Jasperoid quartzite is observed as Footwall side of Sitasaongi formation at Gudma village (Fig. 2.10 a). Sericite schist of hanging wall of Mansar formation is also observed as exposure at Gudma village- open cast mine (Figure 2.10b). The ore bed is intercalated with layers of quartzite, nearly 3 m. thick underlain by a zone of sericite phyllites, which is in turn underlain by a zone of sheared, feldspathic pebbly grit forming the southern slope and the base of the ridge. Manganese ore is found associated with jasperoid quartzite in the underground mining (Figure 2.10c). Intercalations of phyllitic beds are also found in the gritty beds. The whole group is sheared and crushed and autoclastic conglomerates have formed at some places. Near the hanging wall there is weak, friable ore body and interbanded with clay, causes different roof control problems while extraction in addition to the dilution of ore. The width of the ore body varies from 1.1 Mtr to 6 Mtr. The strike of the beds is about N70°E-S70°W in the south-western portion of the deposit veering to nearly N50°E-S50°W in the north-eastern portion with minor variations due to local flexures. There are a number of faults at 150° L. underground causing a displacement of ore body resulting in barren zone between Ch.5300 to Ch.5800 in Ukwa section and between Ch.7800 to Ch.7900 in flat section. A similar geological disturbance has been noticed in 1850° L.a. Ch.12500 also resulting barren zone between Ch.12000 to Ch.12500. Several strike & dip folds have been also noticed in the ore body by the present author. The variation in dip of the ore body has been divided into four sections as Gudma, Ukwa, Flat and Samnapur sections in its areal extent.
The ore bed consists of manganiferous quartzite intercalated with thin layers of Mn ore (Figure 2.10 d). East of the Gudma, the ore bed gradually increases in thickness to about 3.5 m. this thickness is maintained over a length of about 1.2 kms and this section forms the main central section of the Ukwa mine. The dip of the bed in this section is about 45°. In this section, further northeast, the ore bed included the intercalated quartzite varying in thickness from 2.4 to 3.6 m. The general depth is shallow and the beds show gentle warping. This makes the ore bed suitable for open cast mining.

Figure 2.10a Hand specimen photo showing Jasperoid quartzite at footwall side of Sitasaongi formation at Gudma village (open cast mine).
Figure 2.10b Hand specimen photo showing Sericite schist at hanging wall side of Mansar formation at Gudma village (open cast mine).
Figure 2.10c Hand specimen photo showing Manganese ore associated with Jasperoid quartzite from underground mine.
Figure 2.10d Field photo showing Manganese ore associated with manganiferous quartzite at Gudma village (open cast mine).
2.6.3.2 REGIONAL STRUCTURE OF UKWA

The ore body is more or less straight but at one place, it dips at 20° to 45° towards north-west into the ridge. The ore bed in the north-eastern portion of the deposits show a series of rolling drag folds plunging towards west and the top of ore bed shows a wavy surface in some of the developed sections of mine. The folds are asymmetrical with the axial plane dipping north and the axes plunge west at 5° to 10°. The minor crenulations show a plunge of nearly 30° towards N15°E (Fig. 2.11 b). Apart from these rolling folds, there are also a number of sharp drag folds in the ore bed at places resulting in slips. Sericite-schists on the hanging wall side show two sets of joint planes in the direction of N20°E and N80°E dipping at 75° and 85° towards east and south respectively. Manganese ore showing two sets of joints are observed at open cast mine, Gudma village (Fig. 2.11 a). There are also strike joints, at one place, a set of curved joints striking north-south and showing concavity. Prominent bedding at manganese ore are also observed at open cast mine, Gudma village (Fig. 2.11 c).

Figure 2.11 a. Photograph of manganese ore showing two sets of joints at Gudma village (open cast mine).
Figure 2.11 b. Photograph of phyllite showing crenulation features at Gudma village (open cast mine).
Figure 2.11 c. Photograph of manganese ore showing well developed bedding at Gudma village (open cast mine).