CHAPTER 3
BALAGHAT MANGANESE ORES

3.1 GENERAL STATEMENT

The manganese ore bodies of the study areas occur conformably with the meta-sedimentary sequence of the Sausar Group (Fernor, 1909; Pascoe, 1950; Straczek et al. 1956; Narayanaswami et al. 1963; Vemban and Nagarajaiah, 1974). The Sausar Group hosts the largest productive manganese ore deposits of India, contributing about 80% of the total production of the country. 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). The meta-sedimentary manganese ore deposits of large size are hosted by the gneiss and quartzites in the Balaghat district of M.P. The important mines with better exposure of the ore bodies and host rocks include Bharweli, Tirodi and Ukwa mines. The manganese deposits are importantly available within the politic Mansar Formation as pointed out by Roy, 1966. 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 (Narayanaswami et al. 1963).

The primary manganese ores are syngenetic with the enclosing gneiss as typical meta-sedimentary mineral assemblages of braunite, bixbyte, vredenburgite, jacobsite and hausmannite with minor rhodochrosite, spessartite and rhodonite in some low grade ore samples. The secondary ores dominantly as manganese oxides are irregular supergene and replacement bodies generally associated with zones of strong structural disturbance and consist of pyrolusite, psilomelane and cryptomelane with minor quartz, magnetite and other accessory minerals (Siddiquie et al. 2015b&c).

The primary ore minerals correspond to the regional metamorphism of the earlier manganese rich sedimentary protolith leading to the formation of manganese silicates and manganese carbonates. Secondary ores are the result of oxidation and supergene enrichment of the primary manganese ores as evident in the contrasting mineral assemblages of the two ore groups (Siddiquie et al. 2015b&c).

The Manganese 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 Mn-ore belt of Balaghat is mainly constituted of intensely deformed and metamorphosed rocks of the Precambrian Sausar rocks, having the Mn-ore deposits.

Mn-silicate and Mn-oxide ores are co-folded and co-faulted with the meta-sedimentary rocks especially gneiss and quartzite. Huge bodies of Mn-silicate and Mn-oxides are presently being mined out actively from many underground and open cast mines of the Balaghat district, M.P. The primary manganese silicate ores in the form of bands and horizons are associated with the oldest geological succession as in the region and are very complex due to intricate folding and faulting due to the poly-phase deformation of the region. Balaghat manganese ore deposits are dominantly large bodies of bedded ore bodies are represented by the typical metamorphic ore minerals with associated supergene ore minerals (Roy, 1964b and Siddiquie et al. 2015b&c).

The present manganese ores deposits are dominantly meta-sedimentary, metamorphosed ores of economically medium to average grade, with some high grade pockets, veins and lenses mined out heavily in the present study area. The Manganese ore samples have diverse manganese mineral assemblages of Mn-silicates, Mn-carbonates and Mn-oxides recording sedimentation, multi grades of metamorphism and supergene enrichment.

### 3.2 BHARWELI BLOCK

The Bharweli group of mines is located at 8 km NE of Balaghat town beside the Balaghat-Baihar road in toposheet no. TS 64C/1. Underground mining is currently carried out by MOIL (Figure 3.1). This is the largest underground mine of manganese mine in Asia. Open cast mines was also carried out in the early stage of mining but these are abandoned mine in the present scenario (Figure 3.3). Balaghat mine had installed a fully mechanized beneficiation manganese plant for upgrading the low grade manganese ore to high grade manganese ore (Figure 3.2).

The manganese ore bed in this area occupies a stratigraphic horizon between the phyllite and sericite-schist of Mansar formation and the conglomerate and grit of Sitasaongi formation. The ore bed in the Bharweli mine area forms the backbone of a narrow north-south trending ridge dipping steeply towards the west. The ore bed
extends of about 3 km. in this area and peters out at either ends. The thickness of the bed varies from 1 to 10 m. overlying the ore bed is a great thickness of sericite phyllite and schist. The Bharweli ore bed has been found depths of up to nearly about 450 m as proved in the underground mining and boreholes in the main portion of the mine. The ore has been explored up to 23rd level. Underlying the ore bed is a varying thickness of jasperoid quartzite and manganiferous quartzite associated with manganese ore, together known as banded manganese formation (BMnF) (Fig. 4.8a). The ore bed itself is thrown into minor folds plunging towards the south and southwest. The strike length of the ore body is 2.80 kms having a general strike NE-SW and dip varies from 25-85° towards W.

Psilomelane and braunite are important manganese mineral. The Manganese ore consists largely of psilomelane with some hollandite and braunite, the latter forming a very subordinate amount in the Bharweli area. Cryptomelane is also found it is compact and massive while the hollandite occurs as fine glistening crystals. Some rhodonite is also found with a black cherty quartzite. Spessartite or other manganese silicates are not associated with the ore. This is due to low degree of metamorphism suffered by the rocks in the area.

Manganiferous quartzite associated with pyrolusite also observed (Figure 3.8b). Ferruginous manganese ore is also found associated with braunite (Figure 3.8c). Braunite is generally massive, compact, showing grayish black to black colour. Large variation in grain size of manganese ore minerals is observed, especially in braunite (Figure 3.8a). Psilomelane is also found with ferruginous manganese (Figure 3.8d).
Figure 3.1 Photograph showing the location of Holme's shaft, Production shaft and other important surface structures of underground Bharweli mine, Balaghat district, M.P.

Figure 3.2 Photograph showing the manganese ore beneficiation plant at Bharweli mine, Balaghat district, M.P.
Figure 3.3 Field photograph showing the abandoned open cast mine of Bharweli mine, Balaghat district, M.P.

3.3 TIRODI BLOCK

The Tirodi mines area is located at 65 kms from Balaghat H.Q. in the Balaghat District across Bawanthari river in toposheet no. TS 55O/10. At present mining activity is confined to opencast working at North Tirodi and South Tirodi with the producer of high grade and low grade manganese ore (Figure 3.4 a & b). At North Tirodi mine, quartzite-manganiferous quartzite is seen to occur in contact with TBG followed by the Manganese ore horizon and then the mica schist. At South Tirodi mines, mica schist is seen to occur on both sides of the ore horizon.

Ore horizon in Tirodi area is occurring between the mica schist (often sillimanite bearing) and biotite gneiss, and outcropping as a number of small and large lenses. Except at South Tirodi section where the individual lenses are co-sealed to appear as a continuous sheet or reef. The occurrence of manganese ore at North Tirodi is of shallow and thin nature. The thickness of the ore body varies from 1.5m to 10m and the thickest part of outercrop of ore is seen in South Tirodi section.

The 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 manganese minerals identified in this area are braunite, psilomelane, hollandite, rhodonite, juddite
and wad. The manganese ore is hard, soft, dark grey and fine to medium grained, composed mostly of braunite which gives a metallic lustre with streaks and patches of more bluish lustre.

Mostly braunite ore bands are inter-layered with psilomelane found in the area due to high grade metamorphism of sedimentary manganese deposits (Figure 3.9a). Primary manganese silicate oxide (braunite) ore is found about 60% of the total deposit and manganese content in these braunite ore is ranging from 42 to 49% (Figure 3.9a & c). Some dark black fairly weathered soft residual ore known as wad, about 5% of the total deposit is found in one of the corner of North Tirodi mine (Figure 3.9e). Psilomelane associated with hollandite is also found in North Tirodi mine (Figure 3.9b). Fine grained of pyrolusite also found in North Tirodi mine (Figure 3.9d). Red colour of manganiferous amphibole which is known as juddite is found at North Tirodi mine (Figure 3.9f).

**Figure 3.4a** Field photograph showing the working open cast mine of South Tirodi mine, Balaghat district, M.P.
3.4 UKWA BLOCK

The Ukwa mines are located at 44kms from Balaghat H.Q., beside the Balaghat-Baihar road in Balaghat District of toposheet no. TS 64C/5. Both underground and open cast mining is carried out in this area by MOIL. Vertical shaft is recently constructed at Ukwa underground mine (Figure 3.5). In Ukwa underground mine, dip of ore body at shallow level is 25°-65°. At some channel, width of ore body is around 5m (average) and dip varies from 30°-45° northerly. Psilomelane is important manganese mineral contains 45-50% manganese. While taking traverse across the block, the different litho units observed are Tirodi Biotite gneiss, quartz muscovite schist of Sitasaongi Formation, sericite phyllite of Mansar Formation. Open cast is operated at Gudma village by MOIL (Figure 3.6).

The Ukwa manganese deposit occurs within the Sitasaongi and Mansar formations of the Sausar Group. The ore bed at Ukwa is general about 3 to 3.5 m. thick in the middle portion and thins down towards both ends to nearly 90 cm. at western end of the deposit. The ore bed has an average thickness of 105 cm. thickness gradually increases towards the north-east and the ore bed near Ukwa-Gudma track is about 1.8 m. thick. 450 m. long section of the ore bed just west of Ukwa-Gudma track is known as Gudma section. The ore bed consists of manganiferous quartzite intercalated with thick layers of manganese ore (braunite) is found at Gudma open cast mine (Figure 3.7). 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 varies in thickness from 2.4 to 3.6 m. The general dip is shallow and the beds show gentle warping. This makes the ore bed suitable for open cast mining. Further northeast, the thickness of the ore bed again dwindles down to nearly 0.6 m. and thereafter near the boundary of the underground mining, the horizon is traceable as a 15 cm. bed of ore in a white cherty quartzite till it finally gets covered by the trap.

Manganese ore is interbanded with quartzite (Figure 3.7 & 3.10a). 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 found as both in coarse grained and fine grained (Figure 3.10b). Hematite occurs in close association of braunite and bixbyite. Psilomelane associated with braunite is also observed at underground mine (Figure 3.10d). Braunite intercalated with jasperoid quartzite and quartz also found at underground mine (Figure 3.10c). Low grade manganese ore associated with parallel quartz vein is also found at Ukwa underground mine (Figure 3.10e).
Figure 3.5 Photograph showing the newly construction of Holme’s shaft of Ukwa underground mine, Balaghat district, M.P.

Figure 3.6 Photograph showing the water logging during rainy season at Ukwa open cast mine (Gudma section), Balaghat district, M.P.
Figure 3.7 Field Photograph showing the thin bands of manganese ore contains jasperoid quartzite single band at Ukwa open cast mine (Gudma section), Balaghat district, M.P.

3.5 MINERALOGY OF MANGANESE ORES

The manganese ores collected from the study areas i.e. Bharweli mine, Tirodi mine and Ukwa mine are studied megascopically and observed braunite, psilomelane, pyrolusite and hollandite as important mineral. Wad, juddite, rhodochrosite, jacobsite, bixbyite, cryptomelane, manganite and hausmannite are also found in this area. Braunite is found associated with psilomelane and manganiferous quartzite. Braunite is also found as prominent bands with jasperoid quartzite. Quartz, orthoclase, garnet and muscovite are found as gangue mineral associated with manganese ores.

3.5.1 Braunite

Braunite is found at Bharweli mine, Tirodi mine and Ukwa mine. It is products of metamorphism as manganese silicates and oxides; and also as a product of weathering. It is commonly found associated with minerals such as pyrolusite, hausmannite, bixbyite, rhodonite, jacobsite, spessartite, and haematite. It can be identified by colour variations between grayish black, brownish gray and dark
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brownish black (Figure 3.8a &c, 3.9a, 3.10a-d). It is found as fine to very coarse grained (Figure 3.8a, 3.9a & c, 3.10a-d). It has a sub-metallic lustre with brownish gray black streak. The fracture on this mineral is brittle. The density of braunite is 4.72-4.82 g/cm$^3$ with a hardness of 6.0-6.5 and specific gravity of 4.17. Braunite is also found as thin bands (Figure 3.7).

3.5.2 Pyrolusite

Pyrolusite is found at Bharweli mine and Tirodi mine. It is an important mineral of manganese. It has colour of black to greyish black (Figure 3.9d), amorphous appearing mineral. It is found as a granular, fibrous or columnar structure (Figure 3.8a). It has a metallic lustre with black or bluish-black streak and readily soils the fingers. The specific gravity is about 4.8 with a hardness of 1-1.65. It is found associated with hollandite, hausmannite, psilomelane and braunite.

3.5.3 Psilomelane

Psilomelane is found at Bharweli mine, Tirodi mine and Ukwa mine. It is considered to be hydrous manganese. It is occur as amorphous, massive, botryoidal and stalactitic masses with a smooth shining surface and sub-metallic lustre. It has colour of iron black and dark grey (Figure 3.8d, 3.9b, 3.10d). It can be distinguished from other hydrous manganese oxides (manganite and wad) by its greater hardness 5-6 and specific gravity ranges from 3.7 to 4.7. The streak is brownish black and the fracture is smooth. Owing to its amorphous nature, the mineral often contains admixed of impurities, such as iron hydroxides (Figure 3.8d, 3.9b).

3.5.4 Hollandite

Hollandite is found in Tirodi mine (Figure 3.9b). It belongs to the monoclinic and pseudo-tetragonal system. It has colour of black, grayish black to silvery gray and it streak is black in colour. It has metallic lustre. It has distinct and good prismatic cleavage. The specific gravity of hollandite is about 4.84 with a hardness of 4-6. It is belongs to manganese oxide mineral. It was firstly discovered from the Kajlidongri mine, Jhabua district, Madhya Pradesh by Fermor (1906) and named after Thomas Henry Holland, then director of the Geological Survey of India. It is found associated with bixbyite, braunite and psilomelane.

3.5.5 Bixbyite

Bixbyite is occasionally occurs at Bharweli mine. It is a manganese iron oxide mineral with chemical formula (Mn, Fe)$_2$O$_3$. It has black colour and also black in
streak. It is a metallic lustre with a hardness of 6.0-6.5 and specific gravity of 5.02. It has imperfect cleavage (flat surfaces) and fracture in an uneven to irregular pattern. It belongs to euhedral isometric crystals exhibiting various cubes, octahedral, and dodecahedral. It is commonly associated with braunite, psilomelane and pyrolusite. It was firstly discovered in 1897 and named after the American mineralogist Maynard Bixby (1853-1935).

3.5.6 Jacobsite

Jacobsite is a manganese iron oxide mineral with chemical formula MnFe$_2$O$_4$. It is in the spinel group and forms a solid solution series with magnetite. Its colour is black to brownish black and its streak is reddish black to brown. It has a metallic lustre with a hardness of 5.5-6.0 and specific gravity of 4.76. It is found as a primary phase or as alteration of other manganese minerals during metamorphism of manganese deposits. It is associated with hausmannite, braunite, pyrolusite, hematite and magnetite. It is found in Tirodi mine. It was first described in 1869 and named after the Jakobsberg Mine, Nordmark, Filipstad, Värmland, Sweden.

3.5.7 Hausmannite

Hausmannite is a complex oxide of manganese containing divalent and trivalent manganese with chemical formula Mn$^{2+}$Mn$^{3+}$$_2$O$_4$. It belongs to the spinel group and forms tetragonal crystals. Hausmannite is a brown to black metallic mineral with hardness varies from 5-5.5 and a specific gravity of 4.86. It has imperfect cleavage (flat surfaces) and fracture in an uneven to irregular pattern and sub-metallic lustre. It is found associated with other manganese oxides, pyrolusite and psilomelane and the iron-manganese mineral bixbyite. It is found in Ukwa mine in the study area. Haidinger (1827) named it in honour of Johann Friedrich Ludwig Hausmann (1782-1859), professor of mineralogy, University of Göttingen, Germany.

3.5.8 Rhodonite

Rhodonite is a manganese inosilicate with chemical formula (Mn$^{2+}$,Fe$^{2+}$,Mg,Ca) SiO$_3$ and member of the pyroxenoid group of minerals, crystallizing in the triclinic system. It is reported from Tirodi mine in the study area. It has colour of rose-pink to brownish red, gray or yellow and its streak is white. It has a perfect, prismatic cleavage, almost at right angles. The hardness varies from 5.5-6.5 and the specific gravity 3.4-3.7. Its lustre is vitreous, being less frequently pearly on
cleavage surfaces. It has also been worked as an ornamental stone. It has conchoidal
to uneven fracture.

3.5.9 Manganite

Manganite is a manganese oxide-hydroxide with chemical formula MnO(OH)
and crystallizing in the monoclinic system (pseudo-orthorhombic). Crystals of
manganite are prismatic or in columnar form or as fibrous masses. It has colour of
dark steel to iron-black and the lustre is brilliant and sub-metallic. The streak is dark
reddish-brown. The hardness is 4 and the specific gravity varies from 4.29-4.34. It has
less perfect cleavage parallel to the prism faces. Twinned crystals are infrequent. It
has uneven fractures. It is found associated with pyrolusite, braunite and hausmannite.

3.5.10 Juddite

Juddite is red manganese bearing amphibole with variable compositions.
Juddite was originally defined by Fermor (1908) as a manganiferous amphibole with
intense pleochroism (carmine, blue or green, and orange). It has colour of reddish
brown to bronze colour. It is found mostly in Tirodi mine, Madhya Pradesh, India
(Figure 3.9f). Juddite was named by Fermor in 1908 in honour of John Wesley Judd.
Judd was a field geologist and petrologist for the British Geological Survey.

3.5.11 Wad

Wad is also called Bog manganese, black and earthy substance that consists
mainly of hydrated manganese oxides. It varies considerably in chemical composition
and contains different impurities, often in large amounts. It is very soft, readily soils
the fingers and may be considered to be a mixture chiefly of pyrolusite and
romanechite. It results from the decomposition of other manganese minerals and is
often deposited in marshes or by springs. It is found in Tirodi mine in my study area
(Figure 3.9b). Fermor (1909) had first reported wad from Mysore (Karnataka), Sen, B
(1951) from Keonjhar, Orissa, Rasul, S.H. (1964) from Shivrajpur, Panchmahal
district, Gujarat and Siddiquie (1986, 2004), Siddiquie & Bhat (2008) from Pallapudi
quarry, Garbhamp, Vizianagram district, Andhra Pradesh.
Figure 3.8a Photo of hand specimen showing coarse and fine grained of braunite with manganiferous quartzite and Jasperoid quartzite from Bharweli underground mine, Balaghat district, M.P.

Figure 3.8b Photo of hand specimen showing pyrolusite and manganiferous quartzite from Bharweli underground mine, Balaghat district, M.P.

Figure 3.8c Photo of hand specimen showing braunite and ferruginous manganese from Bharweli underground mine, Balaghat district, M.P.

Figure 3.8d Photo of hand specimen showing psilomelane and ferruginous manganese from Bharweli underground mine, Balaghat district, M.P.
Figure 3.9a Photo of hand specimen showing contact between braunite and psilomelane from Tirodi mine, Balaghat district, M.P.

Figure 3.9b Photo of hand specimen showing psilomelane and hollandite from Tirodi mine, Balaghat district, M.P.

Figure 3.9c Photo of hand specimen showing medium grained braunite from Tirodimine, Balaghat district, M.P.

Figure 3.9d Photo of hand specimen showing pyrolusite from Tirodi mine, Balaghat district, M.P.

Figure 3.9e Photo of hand specimen showing soft and friable manganese, wad from Tirodi mine, Balaghat district, M.P.

Figure 3.9f Photo of hand specimen showing Tirodi juddite from Tirodi mine, Balaghat district, M.P.
Figure 3.10a Photo of hand specimen showing braunite having quartz vein intrusions from Ukwa underground mine, Balaghat district, M.P.

Figure 3.10b Photo of hand specimen showing fine and coarse grained of braunite from Ukwa Underground mine, Balaghat district, M.P.

Figure 3.10c Photo of hand specimen showing jasperoid quartzite and braunite having quartz intrusion from Ukwa underground mine, Balaghat district, M.P.

Figure 3.10d Photo of hand specimen showing contact between braunite and psilomelane from Ukwa underground mine, Balaghat district, M.P.

Figure 3.10e Photo of hand specimen showing parallel quartz veins with low grade manganese ore from Ukwa underground mine, Balaghat district, M.P.