CHAPTER 7
SUMMARY AND CONCLUSIONS

In Balaghat district, conformable bedded deposits and lensoid bodies of manganese ores as well as their residual weathering products are found in intensely deformed meta-sedimentary rocks belonging to the Mansar formation (which includes the Gondritic rocks), belonging to the Precambrian Sausar Group. Three types of deposits are found viz., the primary bedded type, the supergene lode type and the boulder types. Balaghat District district extends from 21°19' to 22°24' N latitude and 79°31' to 81°3' E longitude. The “Bharweli manganese mine” in Balaghat district is the largest underground mine operating in the Asian sub-continent. 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. In Tirodi group of mines, the manganese ore horizon belongs to the Lohangi zone at the contact between Tirodi biotite gneiss and Mansar muscovite schist. The rocks are intensely folded, overturned, isoclinals and at places also having recumbent types of folds. The manganese ore deposits are represented by meta-sedimentary beds of braunite-quartzite and gondite forming “Reef deposits” as well as ‘boulder ore’ or detrital deposit derived from the above primary deposits. The Ukwa manganese ore deposit occurs within the Sitasaongi and Mansar formations of the Sausar Group. Manganese ore is interbanded with quartzite.

The manganese deposits of Balaghat District, Madhya Pradesh, occur as syn-sedimentary banded sequence, conformable with the enclosing metasediments like phyllite, sericite schist, quartzite, schistose, sericite, gondites, quartzite, Tirodi biotite gneisses and gritty conglomerate. The physical properties of the manganese ores vary widely because of the presence of different gangue minerals in the ore. Mineralogical studies suggest that braunite is the main manganese ore mineral which was formed during sedimentation and were developed later during metamorphism as second generation along with hausmannite, hollandite, manganese, and bixbyite; pyrolusite, cryptomelane and psilomelane were formed during supergene enrichment of the metamorphosed ores. Geochemical studies show that the MnO₂ % is high (i.e. 29.74% to 63.65 %) with very low amounts of phosphorous. The high concentration of manganese in all ore samples is derived from braunite, hausmannite, hollandite,
manganite, bixbyite and pyrolusite. MnO₂ shows relatively negative correlation with Al₂O₃, SiO₂, CaO, MgO and P₂O₅ indicating increase in manganese content.

Detailed optical studies of the manganese ores which were collected from the study area are dominantly the primary ores. The manganese rich formation consists of three Mn ore mineral types, viz (i) Mn oxide ores, (ii) Mn silicate-oxide ore and (iii) Mn silicate-carbonate-oxide ore types found in the study area (Roy et al. 1986) and (Siddique, et al. 2015b &c). Braunite, bixbyite, hollandite, pyrolusite, psilomelane and hausmannite are observed as predominance manganese mineral of these mines. The mineralogical characteristics between the manganese ores of different location from the study area reveal some variation in mineral assemblages of the primary and secondary manganese ores. The mineral chemistry of study area is necessary to establish the paragenesis and textural relation which will be helpful to delineate the phase equilibrium condition of the manganese ore and associated host rock of the study area. There are various types of ore textures associated with manganese ore of Balaghat manganese deposit, such as, granular, replacement, mutual boundary, veined, contact, coloiform, Framboidal and crystallographic intergrowth textures.

The results of geochemical data of manganese ores of study area show that light rare earth elements (LREE) are enriched and heavy rare earth elements (HREE) are depleted. LREE enrichment in the study area suggested manganese ores are oxidizing condition during the formation of manganese ore deposits (Jiancheng et al. 2005). Light rare earth elements (LREE) show enriched pattern and heavy rare earth elements (HREE) show near to flat pattern on the plotting of the Chondrite normalized (Taylor and McLennan, 1985). The value of light rare earth elements (LREE) is more concentration than heavy rare earth elements which indicates more felsic source of manganese deposits in the study area and the ratio of light rare earth elements and heavy rare earth elements (ΣLRHE)/ΣHREE) is 9.95 (Table 5.7). The ratio of (ΣLREE)/ ΣHREE) in the study area shows that light rare earth elements (LREE) were the primary enrichment during the manganese oxidation process and indicate mineralization in association with hydrothermal solutions (Fernandez and Moro, 1998; Fitzgerald, 2006; and Xie et al. 2006). Positive correlation of ΣLREE)/ ΣHREE (r=0.62) (Figure 5.31) also indicate that the same mechanism was also responsible for REE uptake during the ore formation (Oksuz, 2011). LREE's are
supplied by volcanoclastic while HREE are come from MnO₂ that is precipitated in seawater. ΣREE concentration of hydrogenous deposits is significantly greater than those of hydrothermal deposits.

Results of REE patterns of the study area indicate that hydrogenous ferromanganese deposits are more enriched in REE’s, these are represented by positive Ce anomaly. In the study area, the ratio of La/Lu (100.29) and La/Yb (15.42) (Table 5.7) are higher and show significant fractionation of light and heavy rare earth elements which represent stratiform manganese deposits (Mishra et al. 2007). All manganese ore samples show strong positive Ce and Eu anomaly (Figure 6.28). The average values of Eu/Eu* and Ce/Ce* of the ores are 7.56 and 0.87 respectively indicating that the REE pattern and the Eu anomalies of manganese ores in the study area are influenced by the mixing of manganese rich sea water and volcanoclasts (Mishra et al. 2007). Positive Ce anomaly shows hydrogenous depositional environment and used to differentiate between oxic and anoxic condition. The most important feature is the positive Eu anomaly of the ores. The positive Eu anomaly is clearly seen in all samples of the study area and it increasing towards the high grade ores (Figure 5.28, 5.29 and Table 5.7). Strong positive Eu anomalies are characteristic of seafloor hydrothermal vent fluids. The REE patterns shown by the ores represent the end product of complex series of events that record the properties of the manganese rich solutions subsequently precipitated with volcanoclastic sediments. A low Ce/La ratio (3.56) indicated that most of the REE associated with hydrogenous manganese-hydroxides which are absorbed from seawater (Roy and Venkatesh, 2009). The average value of Ce/La ratio (3.56) in the manganese ores indicates inclusion of volcanoclastic components. The contemporaneous input of the volcanoclastic material appears to have significantly influenced the absolute abundance of REE.

In the study area, the primary manganese ores or manganese rich sediments were deposited as a consequence of upwelling anoxic deep ocean water entering into shallow water column and mixing with, the oxygenated water regime of the basin margin (Dasgupta et al. 1992). The ternary plot (Figure 5.33) of CaO-Na₂O-MgO (after Dasupta et al. 1999) distinguishes the lacustrine and marine field for the manganese ores samples. In this plot, most of the samples of the study area are lying in marine field except five samples which are in lacustrine field.
Summary and Conclusions

In the study area, manganese ore deposits are characterized by high SiO₂, Fe₂O₃, MnO and P₂O₅ are high from the sedimentary diagenetic. The negative correlation between MnO and Fe₂O₃ shows precipitation of manganese and iron in different environmental conditions. The average ratio of MnO/Fe₂O₃ is 8.65 which is high and the diagenetic hydrothermal deposits (Hein et al. 1994 and 1997). The different ternary diagram shows hydrogenous-hydrothermal origin. The ternary diagram (Figure 5.35) of Fe-Si*2-Mn by Toth (1980) confirmed the hydrothermal diagenetic origin of manganese deposit of the study area. Binary diagrams of Si vs Al, (Choi and Hariya, 1992), all manganese samples are concentrated in hydrogenous field. Therefore the positive correlation coefficients between trace elements; Co-Ni (r= 0.343), Co-Cu (r= 0.22). Co-Zn (r= 0.119), Cu-Pb (r= 0.232) (Table 5.5) suggest the precipitation of manganese ores from the hydrothermal solutions (Ibrahim et al. 2014). On the plotting of discrimination diagram Cu+Ni vs Cu+Pb+V+Zn (Figure 5.37) (After Nicholson, 1992b), all the manganese ore samples are showing hydrothermal origin. The binary plot Co/Zn vs Co+Ni+Cu (After Toth, 1980) also confirmed hydrothermal origin (Figure 5.38) for the manganese of the study area while the ternary diagram of Zn-Ni-Co (After Choi and Hariya, 1992) shows most of the samples are in hydrothermal origin except three samples are in hydrogenous origin (Figure 5.39) for the manganese ores of the study area which is supported by the discrimination diagram (Figure 5.40) of Mn-Fe-(Co+Ni+Cu)x10(after Bonatti et al. 1972 and Crerar et al. 1982).

The LREE and HREE also increase more or less simultaneously. This suggests mixing between clastic sediments and variable amounts of a diluting (REE) component. The concentration of rare earth elements, positive Eu anomaly are supported by hydrothermal origin and positive Eu anomaly suggest reducing environment conditions. Higher concentration of Ba in the manganese samples of the study area also reflects its oxidizing environment resulting from the development of pyrolusite and also could be due to volcanogenic source. Results of geochemical studies of ore and host rocks and information obtained from the field studies suggest that Balaghat manganese deposit has been derived from some nearby volcanic hydrothermal vent. Detailed studies of geology, field studies, ore mineralogy and geochemical aspects of the deposits, it is inferred that the manganese deposit of Balaghat district was initially volcano-sedimentary origin and was later on its hybridization took place by the process of metamorphism and or metasomatism.

204