CHAPTER - VII

7. Evolution of Ore Deposits

7.1 Introduction

Several factors need to be considered while interpreting the evolution of manganese and iron ore bodies and syngenetically deposited cherty and shaly lithofacies in Roida Group. The Banded Iron Formation (BIF) of this region dominantly represents primary deposition excepting very localized secondary ores (conga) Banded Manganese Formation (BMnF) syngenetically deposited with BIF in the same basin and is termed as stratiform ores. However, most of the manganese ore bodies in the area are of supergene type, formed through solution and replacement, and are termed as stratabound ores. Limited lateritoid Mn-deposits owe a different origin. Thus, the probable genesis of IOG of rocks/ores in this part of Bonai-Keonjhar belt is described in this section in some detail.

Before discussing the evolution of manganese and iron ore bodies in Roida Group it is necessary to i) to overview the genesis of ore in IOG and ii) highlight the significant findings on present area of investigation.

7.2 Overview on ore genesis in IOG rocks

Over last few decades several workers have studied on the genesis of IOG rocks with special reference to iron/manganese ores in the Bonai-Keonjhar belt. Some of the important earlier hypotheses discussed below:

1. BIF formed due to hydrothermal-replacement of altered tuffs and phyllites (Dunn, 1935, 1941). Separate mode of origin for BIF and iron ore was reported.

2. BIF has volcanogenic and exhalative – sedimentary origin (Percival, 1931, Spencer and Percival, 1952; Banerji, 1977).

3. BIF is a shallow, marine sedimentary deposit (Jones, 1934, Rai et al, 1980).
4 Submarine volcanism was the source of manganese for development of Mn-ore bodies (Sen 1951).

5 Murty et al (1970) on the basis of their studies in the part of Koira belt suggested the formation of Mn-ore bodies through epigenetic concentration of the disseminated manganese in variegated shales, aided by supergene solutions.

6 Roy (1981) described the manganese ore deposits associated with Iron Ore Group of Orissa as belonging to non-volcanogenic sedimentary manganese deposits. He ascribed the genesis of the bulk of Mn-ores to the process of dissolution of manganese from the bedded manganese ores and subsequent remobilization.

7 Mature terrestrial paleo-weathering of pre-existing basic lavas and associated acid effusives that constituted the surrounding provenance and basin floor seems to have provided the main bulk of iron and silica which were precipitated as chemogenic sediments in a shallow intra-continental basin bordering on a land mass of low relief (Rai & Paul, 1990). No major and direct role of volcanism seems to have been involved in the origin of BIF and iron ores in Jamda-Koira valley, Orissa.

8 Majumdar (1990) stated that BIF of Eastern India are bi-component chemical precipitates, consisting of primarily granular magnetite and colloidal / gel silica that were precipitated in a shallow, low energy environment in which although contemporaneous volcanism had taken place, it probably did not make any significant contribution to the formation of BIF.

9 Dasgupta et al (1999) reported that the deposits are gradually evolved over a protracted period of time in a fresh water milieu as a consequence of contributions of Mn, Fe and other constituents from diverse sources including dominantly felsic magmatism, hydrothermal recycling of Mn, Fe and subsequently leaching of Mn from and its reprecipitation in the IOG shale.
7.3 Significant observations on present area of investigation

7.3.1 Observations on regional geological set-up

The following regional geological features of the area have some relevance to the genesis of manganese and iron ores:

1. Large stretches of volcanics and volcanoclastics are recorded in the peripheral boundary of horseshoe synclinorium. Besides, a NE-SW trending volcanic strip occurs in the centre of the basin.
2. The whole synclinorium (60x20 kms approx) comprises of thick tuffaceous shale with iron and manganese ore bodies exposed intermittently.
3. Drilling at Barsua valley confirmed the continuity of volcanic tuff beyond 50mt depth.
4. The pyroclastic nature of shale is seen at different geomorphic level at many places that is obliterated due to prolonged weathering.
5. Iron ore body occurring above Mn-ore body and the vice versa is seen at many places. Existence of single shale formation is supported by both surface and sub-surface studies carried out in the entire basin.
6. Variation in trace chemistry between three shales (i.e., upper, middle & lower) reported by Mohapatra et al., (1991), Dasgupta et al. (1999) is due to differential leaching of the single shale formation.
7. Similar XRD pattern of shale units present as interburden between different Fe rich bands, encountered at borehole drill in Roida area, confirms to a single shale formation.

7.3.2 Observations on Manganese ore

1. Significant observations recorded by the present author on manganese and iron ores around Roida area are highlighted below:
   1. Conformable Mn-ore bodies closely follow the primary layering in the Shale Formation.
2. Concordance between pattern of distribution of major tabular ore bodies and the regional structure.

3. The major ore bodies are cofolded with the enclosing Shale.

4. Soft sediment deformational structures are noticed both in the ores as well as the associated shale.

5. The shale varieties, almost devoid of manganese minerals, when analysed showed manganese content between 1.03% and 1.2%.

6. Exposures of manganese ore conformable with iron ores, former occurring both above and below iron ore bands (confirmed from sub-surface drilling). These features suggest that the manganese ore bodies were originally sedimentary in origin and syngenetically deposited with iron ores (*stratiform* ores).

II) The following observations indicate that some of these ore bodies are of secondary origin:

1. Discordant Mn-ore bodies linked to the conformable shaly/ore bands (BMnF) or concordant bodies below reef quartz horizon are present.

2. The manganese ores in bands and lenses exhibit colloform, botryoidal, kidney-shaped and mamillary outline against the associated shale.

3. The bulk of the ore constitutes of higher oxy-hydroxides of manganese and iron phases indicating their formation by low temperatures supergene enrichment process.

4. Structural and textural characters of the ore assemblages indicate that the bulk of ores were formed by cavity filling and replacement processes. Hence, the above categories of ore are designated as *stratabound* ore.

III) The following observations indicate that some of these ore bodies are subsequently affected by fragmentation, weathering and lateritisation:
1. Deep and large-scale lateritisation is often noticed extending beyond 30mt depth.
2. Presence of thin sub-horizontal to curvicular pebble zones below 20mt depth indicating old erosional surface.
3. Bouldery nature of ore bodies.
4. Diversified morphology of ores, viz., spongy, platy, recemented, massive varieties in a single deposit.
5. Difference in physical appearance of ore varieties despite their broadly similar mineralogy.
6. Wide compositional variation from boulder to boulder, some being considerably rich in iron.
7. Significant difference in chondrite-normalised REE patterns between morphological varieties. Such ore bodies are termed as lateritoid ores.

7.3.3 Observations on Iron Ore

1. Concordant relationship between Fe-oxide and Mn-oxide bands at depth
2. Presence of concealed Fe-mineralised zones (BIF 1, 2 & 3), disposed one over the other.
3. Presence of tuffaceous rock (cherty/shaly), in variable thickness, between two iron ore bands.
4. Fine dispersion of aluminium silicate clastics in the interspace of two iron-bearing laminae and also within Fe-oxide phase.

7.3.4 Resemblance to Lake Superior/Algoma-type Iron Formation

The following findings in the study area suggest its resemblance to Lake-Superior type Banded Iron Formations.
1. Large strike length (trending NE-SW) of IOG in Bonai Keonjhar belt (>60km) of which RG forms a part (James, 1992: superior type BIF are laterally continuous for tens to hundreds of kilometers).

2. Textural and mineralogical assemblage (oxide dominating facies).

3. Low absolute abundance of ferromagnesian trace elements. Average concentration of these elements (Co, Cr, Cu, Ni, Zn & Sc) in iron ore is very poor.

4. No typical greenstone association, characterized by abundant bimodal tholeiitic-calcalkaline volcanics or komatites at the base (that would suggest resemblance to Algoma type) has been recognized.

5. Above all, Force and Maynard (1991) reported “indeed many (if not all)
• early Proterozoic manganese deposits” are associated with Lake Superior type iron formation.

7.4 Genesis of Roida Group of rocks, the study area

7.4.1 Geotectonic setting of the Roida Basin

A number of geotectonic settings have been proposed for Superior type BIF deposits. For the Hamersley BIF, for instance, an intracratonic basin model and a subsiding continental shelf or platforms have been postulated (Alibert & McCulloch, 1993). James (1992) postulated for “Superior-and related types” of BIF a depositional model based on either “simple broad shelves, open to the sea” or “discrete marginal basins of varying size, depth, and degree of restriction”. Buhn et al. (1992) indicated that shelf-related depositional sites for manganese deposits predominated during the Precambrian.

Deep-seated arcuate and linear fracture systems along this region were probably responsible for i) development of basin and ii) intrusion of mafic to felsic magma and pyroclasts. No indication for independent basins or for a different stratigraphic position of some of the surveyed BMnF and BIF occurrences of the
RG (Roida Group) has been found. Hence, they are interpreted as belonging to a unique stratigraphic level deposited on a passive continental margin. As already mentioned, the present strike length of the (folded) RG sequence, without outstretching the folds is above 60kms.

7.4.2. Environment of Deposition

The typical depositional environments for Superior type BIF may presently be considered in the broader context of plate tectonics. Superior type BIF were deposited in shallow water, under more oxidizing conditions, they are part of continental shelf association and are often associated with extensive rifting (Jacobsen & Pimentel-Klose, 1988, Gross, 1991).

1. Review of lithological association in this part of IOG rocks indicates that volcanism played a dominant role during its deposition. Such voluminous rocks/ores could not have been derived merely through the weathering and erosion of Singhbhum granite platform. Hence, direct volcanic source must have supplied the materials of these rocks.

The association of Mn and Fe oxides with volcanic tuffs, their stratigraphic conformity, their quantity and purity suggest that exhalative-sedimentary rather than weathering processes were responsible for their formation. James (1969) reported rich iron sediments associated with volcanism near the crest of oceanic ridges. Variable composition of tuff such as basic, intermediate and acidic indicates basaltic and acidic volcanism in different periods. Acid volcanism may provide an adequate source of silica to account for the associated chert in the region.

2. Possible source for the volcanic rocks could have been the deep-seated fractures, may be extending to the mantle, occurring to the east, west and south of the platform. Through this fracture volcanics and volcaniclastics (basic, intermediate, ultrabasic and acidic composition) were erupted.
3. Such a volcanic belt might have been partly submarine and partly above sea level and may have separated an inner shallow sea, marginal to the platform. The pillow structure shown by basalt near Nomira (Plate 24A) indicates volcanic eruption under submarine condition.

4. The presence of fine clastic input as a component of the otherwise chemical sediments (in the BIF/BMnF and associated chemical sediments, cf. below), and the absence of oolitic iron-formation (Klein & Beukes, 1992) suggest a non-shoal depositional site within the basin.

5. Occurrence of widespread fine laminations of uniform thickness and a general absence of coarse clastics, except in beds rich in pyroclastics, indicate that these were deposited around a stable platform.

6. Different types of primary sedimentary structures like bedding, current bedding (Plate 24B), ripple marks, along with pene-contemporaneous and post depositional structures like intra-formational fold and fault, pinch and swell, pod etc., indicate that the deposition took place in shallow water epicontinental environment or in marine shelf during certain stage of basin evolution.

7. Paucity of trace elements particularly Ba, Co, Ni, Cu, Mn and Pb are characteristics of iron-rich sediments deposited under shallow water condition (Nicols, 1967, James, 1966, Rai et al., 1980).

8. Indistinct Eu anomaly suggests either a non-deep depositional site or deposition in a marginal basin.

9. Following Frietsh (1970), low Co/Ni ratios, generally below unity and very low contents of elements such as V, Cr, Zr, Ni, Cu etc in the BIF provide convincing support to low temperature condition of their precipitation under sedimentary condition.
Plate 24 Field photograph showing pillow lava and cross-bedded structure
A. Pillow lava from Namira-Jalpaposi area. The chilled border, and radial joints are distinctly seen
B. Small scale cross-bedding in cherty stratiform Mn-ore body of Road Side deposit
7.4.3 Protolith

The genesis of the BMnF & BIF occurring within the Iron Ore Group of rocks is related to the sequence of tectono-volcanic activity around the platform that gave rise to these rocks. These, essentially chemical precipitates with significant volcaniclastic, represent phases of exhalative volcanism. This is evidenced by the presence of thick volcanic rocks of varied composition (basic, intermediate to acidic) bordering the synclinorium.

Gas accompanying such lavas would form acid solutions in seawater and these solutions in contact with the lava would extract much of its iron and manganese. Seawater normally contains dissolved oxygen, so that the iron would be gradually oxidised as the original acids are neutralised by mixing with more and more water. The manganese would remain in solution until the pH had climbed to nearly its normal value in the sea. Thus between different eruptive phases, silica, iron and manganese were contributed to the basin, which then precipitated cut in alternate bands, under different Eh & pH conditions.

7.4.3.1. Chemical Precipitates

The protolith for the BMnF and BIF is considered to be a bi-component chemical precipitate composed of Mn-(± Fe)-Si-rich and a Fe-(± Mn)-Si-rich mudstone-like chemical sediment, respectively. Some evidence has been found to support that carbonate was a constituent of such precursor sediment, although subsequent decarbonation processes during digenesis / metamorphism could have caused virtual absence of carbonate within the surveyed area. Detailed investigations on inclusions armored in hematite are important as they represent "frozen" earlier paragenesis. X-ray image mapping reveals the presence of Ca-rich phase as minute inclusion within hematite. The shape and smooth grain boundaries of the carbonate inclusions (Plate 23) suggest that the carbonate is an older phase in the paragenetic sequence (older than hematite). Moreover,
carbonate is present as limestone in the adjacent area (Kasia) apart from a few supergene or hydrothermal carbonate-bearing veinlets (in Belkundi area).

A. Source of Fe, Mn & Si

1. As already indicated, iron, manganese and part of silica were contributed to the basin through exhalative volcanism, which then precipitated out in form of bands. Part of silica is attributed to acid volcanics. These bands range in thickness from less than a millimeter to several centimeters and are made up of layers of i) chert, ii) chert-hematite / chert-cryptomelane and iii) hematite / romanochite or cryptomelane. Each such triple layer represents either a single exhalative phase or in two/three exhalative phases in quick succession along the fracture zone. Manganese gets precipitated depending upon the Mn-saturation in the mineralised solution under suitable Eh/pH condition. Alternatively, it can be envisaged that iron/manganese was precipitating continuously from the seawater (Holland, 1973) and the silica bands represent the exhalative phases when the precipitation of silica dominated over that of iron/manganese. Fine disseminated clay rich particles in iron/manganese and silica rich particles in iron/manganese band along with widely spaced tuffaceous shaly partings represent the minor eruption of tuffaceous matter along the fracture zone interrupting the precipitation of major phases for relatively short periods.

2. Rare earth element geochemistry provides useful tools to evaluate the source of Fe, Mn, and Si, the main elements in the investigated BMnF /BIF of the RG. Assuming that part of REE were co-precipitated from seawater along with Mn & Fe (as documented for modern Mid Oceanic Ridge equivalents and marine manganese nodule of present day basin) and that they were subsequently basically immobile, REE data reflect the chemistry of the contemporaneous oceans during BMnF and BIF deposition. In both Archean and Proterozoic BIFs, positive Eu anomalies combined with low \( \Sigma \text{REE} \)
contents have been explained by derivation of the chemical constituents from hydrothermal fluids generated and emplaced at ocean ridges (Danielson et al, 1992, Arora et al, 1995, Khan and Naqvi, 1996, Khan et al, 1996) Khan et al (1996) separately studied chert and Fe-oxide bands of Indian Archean BIF. The REE patterns obtained suggest a "dominant hydrothermal source for FeO and SiO₂."  

3 For the studied area a dominant exhalative hydrothermal origin is proposed for the Fe as well as Mn (and some of the REE). Additionally, other factors might have played a certain role. For instance, a distal (i.e., non-proximal) precipitation of the chemical constituents relative to the site of the hydrothermal input appears evident, as suggested by the missing Eu positive anomaly.  

4 Another line of evidence to evaluate the hydrothermal component could theoretically be gained from the discrimination diagram of (Co+Cu+Ni) abundances vs total REE content (Dymek and Klein, 1988, Klein and Beukes, 1989 and 1993, Arora et al., 1995). The plot for the BMnF /BIF samples of the RG, though not conclusive, show a certain link to the hydrothermal fields (with enriched ~REE) rather than a relation to the field of "hydrogenous deep-sea sediments."  

B. Separation of Mn and Fe  
A major task in deciphering the origin of certain Precambrian Mn-deposits is to explain the separation of Mn from more abundant Fe, both elements showing a similar geochemical behaviour. To enter into such a discussion it would be convenient to first highlight the significant observations in the present area and elsewhere in the world.  

1 Most Paleo-proterozoic BMnF deposits like those of the largest single manganese district of the world, the Kalahari deposits of the Transvaal basin,
South Africa (Force and Maynard, 1991, Tsikos and Moord, 1997), and also the deposits of RG, occur inter-bedded with oxide facies BIF.

2 From Nigeria, Mn-rich BIF (MnO up to 18 wt%) has also been reported (Mucke et al., 1996, Annor et al., 1997) and so also from the present set-up.

3 Fe is subordinate at the giant Nsuta Mn-deposit (Kleinschrot et al., 1994, Mucke et al., subm) as well as other occurrences in Ghana (Melcher and Stumpf, 1994).

4 In the study area, Fe, Mn and SiO$_2$ occur as independent facies, besides BMnF often grading to BIF, presumably as lateral facies equivalent. Though due to subsequent deformation followed by weathering, no systematic lithostratigraphic order is evident in the field, deep bore hole study in 'R' block area confirms the above interpretation.

The separation of Mn-oxides from Fe-oxides in the deposit reflects the geochemical characteristics of the depositional basin at the time of oxide precipitation (Krauskopf, 1957).

Isolation of manganese in solution can be accomplished by precipitating the iron first. The iron compounds to be expected in nature are uniformly less soluble than the corresponding manganese compounds, and that ferrous ion is more easily oxidised than manganous ion under any naturally occurring pH-Eh conditions. The manganese oxide mineralogy points to an oxidation potential of 0.3 to 0.8v. As reducing-acidic mineralising solutions (Fe-rich) entered the alkaline-oxidising basin, Fe-oxides precipitated close to the source (nearer to volcanics), whereas Mn-oxides precipitated farther away, in response to the gradual increase in pH and Eh through mixing of the mineralised solutions with the waters in the depositional basin.

7.4.3.2. Clastic input

1. High concentration of Al$_2$O$_3$ and TiO$_2$ are visibly related to volcanoclastic impurities in the oxides. The two elements show a strong positive correlation with each other in both Mn and Fe-ore sample. This indicates the influence of
volcaniclasts debris that was added to the chemical precipitates. The association of elevated TiO\(_2\) contents with high Al\(_2\)O\(_3\) in some samples suggests admixture of a clastic component to the chemical sediments (Ewers and Morris, 1981; Dymek and Klein, 1988). Additionally, the diagram La vs Sc exhibits a trend suggesting some clastic "contamination" (Dymek and Klein, 1988).

2. To know the clastic contribution in terms of felsic and mafic input, the triangular plot Fe\(_2\)O\(_3\) (tot) - K\(_2\)O - MgO has been proposed by Arora et al. (1995). But as already stated cryptomelane host K (of secondary origin) in the BMnF is more prominent such a diagram may not be very useful. Instead of such a ternary plot, shows that Al\(_2\)O\(_3\) positively correlates with Zr, thus indicating a felsic dominance within the clastic debris in the BMnF / BIF of the RG. Strongly fractionated LREE and relatively flat HREE in chondrite-normalized plots would indicate that a LREE-enriched component may have been involved (Dymek and Klein, 1988). More or less a similar feature has been observed in several samples of BMnF in the study area.

3. For the evaluation of a possible mafic clastic input, the detrital provenance of Mg has to be demonstrated. The positive correlation between Mg and Al probably suggest that a certain volcaniclastic fractions are of basaltic composition. The presence of basalt all along the western boundary BMnF and BIF bearing horseshoe shaped belt justifies such an interpretation.

7.4.4. Evolution of Primary Mn and Fe deposits

The observations summarized above indicate that the deposition and evolution of iron and manganese deposits in Roida Group have been much more complex than the various hypothesis which have been proposed so far.

1. The occurrence of manganese and iron deposits, in nearly consistent distribution pattern at different stratigraphic levels would suggest that both NNE-SSW and E-W fracture zones of the whole basin (horseshoe
synclinorium) was the site that yielded basic lavas, basic/acid pyroclastics and hydrothermal exhalative phases (rich in Fe and Mn). It was followed by precipitation of iron and manganese in shallow water epicontinental environment or in marine shelf during basin evolution, by analogy with the present day iron, manganese precipitates close to Mid Oceanic Ridge (Bostrom, 1967, Bonatti, 1967) or in other areas of submarine hydrothermal activity (Rona, 1978).

2. It could be envisaged that as the pH of the basin water slowly increased, due to progressive contamination with volcanic exhalation, iron compounds reached the limit of solubility first and precipitated out as Fe-sols, while manganese remained in solution and precipitated out latter as Mn-sols. Thus the deposition of major elements like Mn, Fe and part of Si is controlled by chemical precipitation. Later, during diagenesis Fe-oxide/hydroxide or Mn-oxyhydroxide phases are formed.

3. Al$_2$O$_3$, TiO$_2$ and part of SiO$_2$ are contributed to the deposit with the volcanoclastic fraction.

4. Trace and RE elements are partly adsorbed from sea water and partly from volcanoclastic input. However, Mn-oxides adsorbed relatively more trace than Fe-oxides.

5. The partitioning of trace and RE elements between the Mn-oxyhydroxide and Fe-oxides is dominantly a result of diagenesis and recrystallisation during which some elements initially incorporated into Fe-oxides get desorbed from it.

7.4.5 Evolution of secondary Mn and Fe deposits

The field and laboratory investigations reveal the following.

1. The stratiform manganese ores were consequently subjected to solution, remobilization and oxidation processes during weathering. As solubility of Mn in most natural environments is invariably greater than that of Fe (Krauskopf,
solution and precipitation of manganese in form of stratabound ore bodies may be considered to be an aftermath of primary ore/non-ore deposition.

2. The observed variation in the Fe/Mn ratios of the shale associated with stratabound ore bodies suggests that Mn has been preferentially leached from the shale (Plate 25A)

3. The circulating mineralized colloidal solution (low temperature) was then redeposited in structurally favourable planes (shear zones, bedding planes, joints) or zone of brecciation and silicification (Plate 25B)

4. The overwhelming dominance of tetravalent Mn-oxides in the manganese ores indicate overall high redox condition in the basin

5. These were accumulated mainly in a fresh water milieu as earlier indicated by some workers (Sambasiva Rao and Dasgupta, 1995, 1997, Dasgupta et al 1999)

The relative solubility of Fe over Mn is 4 to 40 times less. The possibility that iron in the Roïda basin, could have been derived through leaching is therefore minimal. However, the presence of congà as floats in some deposit indicates that leaching of iron was in low magnitude and of local significance only. Of course, leaching of BIF often results in development of blue dust pockets.

7.4.6. Evolution of Lateritoid Mn deposits

The lateritoid ore bodies owe their mode of origin to widely different environment and secondary processes. In the development of supergene ores of Groote Eylandt Mn-deposit, Australia, Ostwald (1976) and Bolton (1982) considered secondary processes as responsible while Pracejus (1986) emphasized on extensive lateritisation. Varentsov (1982) believes that the supergene ores of Groote Eylandt are formed as a result of reworking of pre-existing weathering crust. Pracejus et al. (1988) have discussed the transport and precipitation processes in development of supergene Mn-deposits of Groote Eylandt.
Plate 25 Field photograph showing remobilisation and reprecipitation of Mn-rich phase
A. Mn-rich veinlets, closely spaced on a shale unit.
B. Concordantly and discordantly disposed Mn-rich veins converging to a small lenticular ore body.
Considering the field disposition and inferences drawn thereof, the proposed sequential developmental stages of lateritoid ore bodies in the belt may be suggested as follows:

1. Initiation of subsidence of basin consequent to tectonism/folding of IOG rocks in this region
2. Resultant large-scale lateritisation of existing manganese and iron formations.
3. Mechanical disintegration and erosion of pre-existing crust ie. iron and manganese ores from higher horizons
4. Intensive leaching of Mn/Fe-bearing rocks/ores

Leaching of manganese into solution, necessary in the formation of supergene manganese deposit is described in detail (leaching at low pH, electrochemical reaction between Fe and Mn, reduction under the influence of bacteria etc.) by Pracejus et al (1988) for Groote Eylandt Mn-ores, Australia. Similar processes might have been effective in dissolution of manganese in to solution in the study area. The dominant process for the dissolution of Mn-oxides was probably the redox reaction between divalent iron and tetravalent manganese. However, the entire gamut of dissolution and depositional processes continued for a fairly large duration, over repetitive phases.

The Mn-carrying solution percolates both laterally and vertically slowly through openings in laterites and move on cracks and weak planes

5. Precipitation of remobilized Mn/Fe-rich solution followed by cementation of primary Fe-rich clasts and other Mn-ooliths / pisoliths either independently or together depending on their availability.

The Mn-rich solution may precipitate by several processes (Pracejus, 1988) but in the present set-up dehydration and subsequent oxidation seems to have influenced the most. Such process was most effective as evidenced by wide spread cementation of ooliths and pisoliths besides the presence of
The Mn-rich solution may precipitate by several processes (Pracejus, 1988) but in the present set-up dehydration and subsequent oxidation seems to have influenced the most. Such process was most effective as evidenced by wide spread cementation of ooliths and pisoliths besides the presence of shrinkage cracks etc. During dehydration, shrinkage cracks develop which are often filled with younger massive or needle like Mn-phases.

6. Fragmentation of recemented ores into large boulders followed by their short-distance lateral and vertical transport into adjacent basin during terrain evolution.

7. Deep burial of manganese/iron-rich boulders beneath thick sub-recent to recent lateritic cover and development of present topography.

7.4.7 Summarised model for the genesis and evolution of BMnF and BIF within RG

1. The present work supports the model of sedimentary pile generated from volcanics and volcaniclastics resulting the litho-assemblages of RG, and a subsequent low-grade tectno-metamorphic overprint.

2. Concerning the depositional paleoenvironment, the RG rocks/ores are probably deposited over a stable basin near the site of the hydrothermal volcanogenic exhalative input under a marine environment.

3. Ghosh (1993) stated that "in most of the Lake Superior type BIF the basin starts with a narrow, elongate trough (with basic volcanics at bottom) that subsequently broadens either with shallow marine elastics or carbonates. In analogy, a similarly evolving basin is proposed for the RG, resulting in basic/intermediate/acidic volcanics at the base which are overlain by chemogenic precipitates ± volcaniclastic sediments.

4. No indication for independent basin or for a different stratigraphic position of the surveyed BIF/BMnF of RG was found. Hence they are interpreted as belonging to a unique stratigraphic level.
Presence of two to three Fe-mineralised zones and one to two Mn-mineralised zones, individually separated by tuffaceous shale/chert, in single succession indicate volcanic exhalation and volcaniclastic eruption in several phases.

Available data do not allow an evaluation of the role of biogenic processes in the deposition of the original sediments of the BIF and BMnF of RG. The precursor sediment is considered to be Fe-rich mudstone ± carbonate, Fe-Mn-rich cherty mudstone and Mn-rich mudstone.

The source for the bulk of Fe, Mn and part of Si is considered to be through hydrothermal volcanic exhalation, Ca and parts of Mg derived from ocean water through normal marine sedimentation and Al, parts of Si, part of Mg and K have a volcaniclastic provenance.

Since Mn is soluble in ocean water under rather low temperature in a wide range of Eh-pH condition than Fe and can thus be transported over longer distances, Fe precipitates first nearer to the source and the Mn-rich protolith was differentially precipitated.

During precipitation, both Fe and Mn-oxide adsorbs trace and RE elements, the latter more than that of former but during oxidation and recrystallisation Fe desorb most of them. Some of the trace and REE are also contributed by volcaniclastic fraction.

Thus both BIF and BMnF were syngenetically precipitated along with volcaniclastics as primary iron ore and stratiform Mn-ores respectively (Fig. 7A) These are subsequently affected by tectonic / fold movements (Fig. 7B)
A. Chemical precipitation and intermittent volcaniclastics sedimentation

B. Affected by folding (Effect of Tectonism)

C. Remobilisation followed by Mn-rich solution entering into structural week planes and re-precipitation
D. Remobilized Mn-rich solution entered into open space available under a reef quartz zone

Stage – IIB
(Stratabound Mn-ores, concordant)

E. Fragmented Mn & Fe-rich boulders getting buried under a thick lateritised basin (allochthonous type) adjacent to an iron (-manganese) ore deposit

Stage – IV
(Lateritoid type Mn-ore bodies)

Fig. 7: Depositional Model of different Manganese-ore bodies (A, B, C, D, E) formed in Precambrian Iron-ore group

11. There are no geochemical data available so far on rocks of the RG. However, the association of BIF/BMnF and the REE features support a post Archean deposition age. Both BIF and BMnF share a common tectono-metamorphic evolution.
12. During a later stage following tectonism and large scale fracture/faulting, the existing Mn and some traces from bedded ore and other rocks undergo solution in fresh water milieu through supergene process, get remobilised and reprecipitated along weak planes. Such ores are termed as stratabound ores. It may be disposed discordantly (Fig. 7C) or concordantly (Fig. 7D) to the existing strata.

13. Mn-ores from both stratiform and stratabound deposits may develop rich Mn-pockets through oxidation and recrystallisation.

14. At a much later stage (Tertiary to Quarternary period) these ores undergo lateritisation, leaching, recementation, may subsequently fragmented and shifted from the original deposit and get buried in form of large boulders. Such ores are termed as lateritoid ores (Fig. 7E).

Figure 7.1 in the following page illustrates diagrammatic presentation of the genesis and evolution of BIF (-Iron ores) and BMnF (-Manganese ores) in 'Roida Group', Orissa.

Finally the lithologic nature and the postulated early paleo-proterozoic deposition age of Roida Group sequence implies a roughly coeval deposition with giant Lake Superior type Fe-Mn horizons in the Transvaal and Minas basins, south Africa (Kalahari) and Brazil.
## Primary Deposition of BIF and BMnF

<table>
<thead>
<tr>
<th>1</th>
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<tr>
<td>Rift causing deep-seated fractures at the boundary of North Orissa Craton near continental shelf.</td>
<td>Development of basin near to continental shelf (gets filled up with ocean water)</td>
<td>Eruption of large volume of volcanics (varied composition) and volcaniclastics through fractures in several phases under submarine condition.</td>
<td>The basin water gets saturated with Fe and Mn by interaction of gas accompanying volcanic flow with that of lava rock</td>
<td>Precipitation of Fe near the source followed by Fe±Mn &amp; then Mn and part of silica under suitable Eh and pH condition in other part of the basin</td>
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### Development of secondary Ore bodies

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<tr>
<td>Disolution of Mn, Fe and some other traces under fresh water milieu through supergene process from primary Mn and Fe-rich zones and other associated litho units</td>
<td>Remobilisation of mineral rich fluid along weak planes and its reprecipitation under low temperature condition.</td>
<td>Formation of stratabound Mn-ore bodies.</td>
<td>Primary modified iron ores (Blue dust &amp; Biscuit ore) are formed only through alkali leaching</td>
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<tr>
<td>Fragmentation of recemented boulders followed by drifting and burial—Development of Lateritoid Mn-ore bodies</td>
<td>Cementation of loose fragments by secondary Mn/Fe rich solution and development of secondary Iron ores (conga &amp; laterite) and mangcrete</td>
<td>Weathering, erosion and leaching of existing primary and secondary ores by lateritisation process.</td>
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</tbody>
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Fig.7.1: Diagrammatic presentation of the genesis and evolution of BIF (-Iron ores) and BMnF (-Manganese ores) in ‘Roida Group’, Orissa.