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Occurrence of Manganese Mineralization in Rayavalasa and Tudi Villages of Eastern Ghat Mobile Belts, Andhra Pradesh*

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Abstract

In this paper,we have reported small bands of Manganiferous quartzite at S. Gopalapuram, Tudi, .Some other small occurrences also ob-served as float ore/boulders and/or small manganese ore observed north of Nandala-meta, Tangidi and Rayavalasa The pockets of Mn ores are lithologically controlled but the disposition of manganese bands are structur-ally controlled, localized near the hinge zones and at some parts in the limb areas. The Mn-rich silicates are converted to manganese ore due to leaching or oxidation. The relict phases of silicate with Mn-rich rim and inclu-sions indicate that they were derived during leaching. Some features such as colloform bands, relict silicates and rare pseudomorphs, indicate its secondary nature formed due to the alteration of manganiferous silicates. Braunite, and psilomelane are represented as the primary minerals. secondary minerals are made up of psilomelane, cryptomelane, py-rolusite, and goethite and are formed in the low grades of metamorphism. Analytical val-ues of manganese (Mn) in bedrock samples collected from the Mn-enriched horizons of calc-granulite and khondalite rock types range from 0.16% to 39.70%. The analytical results of float ore samples have maximum values of upto 23.64%

Keywords: Alteration, Psilomelane, Cryptomelane, Pyro-lusite, Silicates, EGMB, Metamorphism

1. Introduction

The manganese mineralization in the study area is observed in the form of manganiferous zones, which show an intimate association with quartzite. They occur in the form of bands, lenses and pockets having varied dimensions. Structurally, the reported manganiferous zones within the area are part of the same stratigraphic horizon with several bands which are controlled by D2 deformation represented by F2 fold. This serves as a marker zone depicting the stratigraphic control with a syngenetic signature. The pockets of Mn ores are lithologically controlled but the disposition of manganese bands is structurally controlled, localized near the hinge zones and at some parts in the limb areas. The Mn-rich silicates are converted to manganese ore due to leaching or oxidation. The relict phases of silicate with Mn-rich rim and inclusions indicate that they were derived during leaching. the main focus of the study is aimed to assess the manganese mineralization based on field observations, ore petrography studies, and geochemical inputs in Rayavalasa and Tudi villages of Eastern ghat mobile belts, Andhra Pradesh

Some features such as colloform bands, relict silicates, and rare pseudomorphs, indicate its secondary nature formed due to alteration of manganiferous silicates. One mappable manganese ore body have been delineated around SE of Tudi. The dimension of the ore body is 100m X 5m. Some other small occurrences were also observed as float ore/boulders and/or small manganese ore bands at S. Gopalapuram, Tangidi and Rayavalasa. All these locations have float ores associated with quartzite having approximately 1-2m in width and 10-15m in length..

2. GEOLOGY

Regional Geology

The Eastern Ghats Mobile Belt has been considered as one of the classical Precambrian deep crustal sections that has different “memories” of the continental growth processes through orogenesis and is a focus of intense research for last two decades. Ramakrishnan et al. (1998) presented a detail geological map of the EGB in which they identified four longitudinal lithotectonic domains, named as Western and Eastern Khondalite Zones, Central Migmatite Zone, and Western Charnockite Zone . They also identified a transition zone bordering the adjoining cratonic blocks to the west and contact between the craton and mobile belt was marked by a prominent frontal thrust. Chetty and Murthy (1994) and later workers identified several major lineaments, interpreted as mega-shear zones, both along the craton-mobile belt contact and transecting the EGMB (Fig. 1). Some of these shear zones were later considered by Rickers et al. (2001) as terrain boundaries, as these workers identified several distinct isotopic domains, based on Nd-model ages (Fig. 2a). These isotopic domains are transverse to the litho-tectonic domains recognized by Ramakrishnan et al. (1998). Dobmeier and Raith (2003), on the other hand, divided the entire EGB into several crustal provinces (in turn divided into crustal domains) by arguing that the provinces have different geological histories. The major crustal provinces identified by Dobmeier and Raith (2003) are the Eastern Ghats Province, Krishna Province, Rengali Province and Jeypore Province.

The trend of the rock types varies from WNW-ESE to NW-SE. The other dominant trend of foliation is N-S to NNE-SSW indicating second phase of deformation. Three phases of deformation are discernible of which the first phase is represented by tight to isoclinal folds with ENE-WSW to NE-SW axial trend which are folded during second phase of deformation along N-S. The 'M' 'W' shaped fold in khondalite band indicates second phase of deformation. Khondalite, calc-granulite, charnockite interbedded sequence in the north-eastern quadrant folded into overturned antiform (F2 folding). Broad warps are the result of third phase of deformation with E-W axial trend. The joints are present in granite gneiss charnockite and even khondalite with dominant sets along N-S and ENE-WSW with vertical to sub-vertical dips.

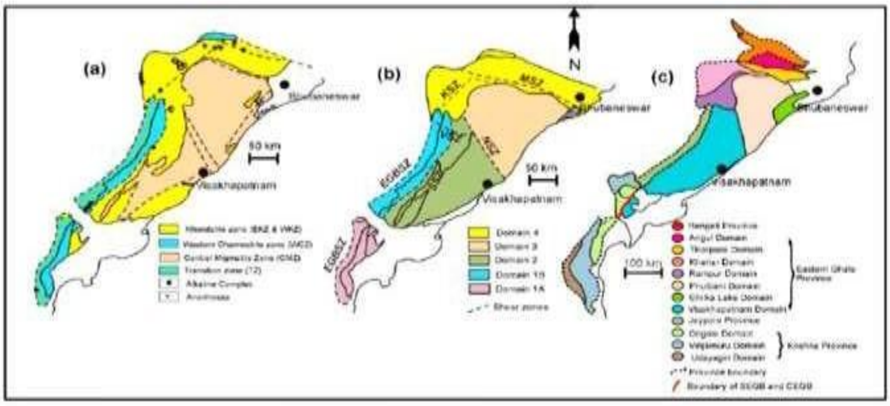

Figure 1: Division and classification of EGB based on A) lithological character (modified after Ramakrishnan et al 1988 B) isotopic (Nd model age) characters (modified after Rickers et al 2001) C) combination Lithological, Metamorphics and isotopic characters (modified after Dobmeier and Raith 2003

Geology of the Study Area

The mapped area mainly consists of rocks of Khondalite Suite, Charnockite Suite and Migmatite Suite (A. Krishnamurthy et al., 1969), which is part of Visakhapatnam domain and Eastern Ghats Province (Combination of lithological, metamorphic and isotopic characters; after Dobmeier and Raith, 2003) of the Eastern Ghats Mobile Belt (EGMB). Khondalite Suite mainly consists of garnet-sillimanite gneiss ± graphite (khondalite), calc-silicate granulite and garnetiferous quartzite, which are dominantly exposed as bands and lenses within charnockite. Charnockite covers major part of the area. It occurs as porphyroblastic gneiss which is invariably garnetiferous and at places as leptynitic. Migmatites are formed by partial melting of both khondalite and charnockite. Leucosomes/ neosomes intrudes/occur along primary bedding plane in the khondalite. All the rock type shows regional foliation trend varying from NNE-SSW to ENE-WSW in the mapped area. The manganese mineralization shows intimate association with calc-silicate granulite and khondalite in the form of bands, lenses and pockets of varying dimensions. The Mn-rich silicates are converted to manganese ore due to leaching or oxidation. Khondalite Suite comprises an assemblage of regionally metamorphosed pelitic, psammitic and calcareous sediments with manganese components. The delineated manganiferous zone / horizon is characterised by association in space and time with calc-silicate granulite (calcareous facies) together with garnetiferous quartzo - feldspathic sillimanite schist / gneiss ± graphite (psammo-pelitic facies) constituting the Khondalite Suite of the Eastern Ghats Supergroup.

Although the lithounits of the Eastern Ghats Supergroup dip in a general south-easterly direction, their present order of superposition is essentially tectonic and is a result of high grade metamorphism and intense repetitive deformations that have obliterated the original stratigraphy and completely modified the primary features that are so essential for building up stratigraphic column. the following stratigraphic sequence is tentatively proposed as well as incorporated in the geological map (Fig 3 on 1:1:25000 scale)

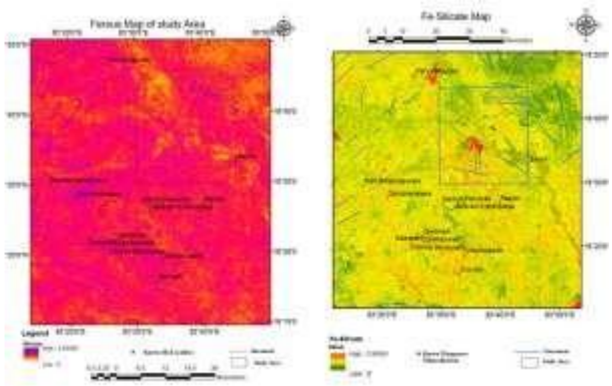

Figure 2: Aster data band Ratio Map of Mn/Fe with Known Manganese Mineralization Localities (By V.K. Singh)

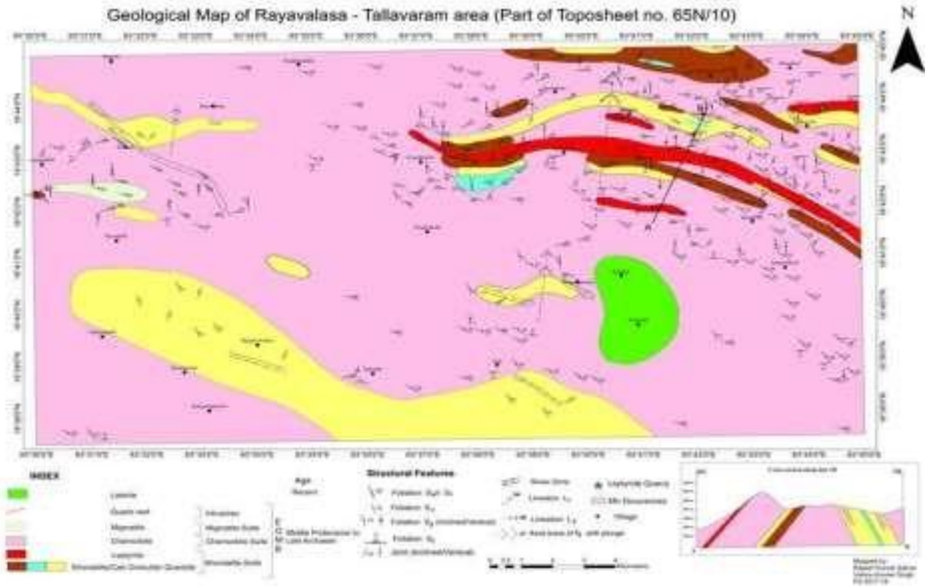

Figure 3: Geological map of the study area (modified by V.K. Singh & R.K. Sahoo,2017-18)

Table 1: Stratigraphy of the Study Area

3. Methodology and Analysis

chemical analysis from the manganese ore and manganiferous quartzite. During the sample preparation process, about five hundred grams of sample was collected and crushed with an iron mortar and then pulverized with an agate mortar and finally processed through-80 mesh and-200 mesh. Two sets of samples (original and duplicate) were prepared through coning and quartering.50 nos. of bedrock samples (BRS) and 40 nos. of petrochemical samples (PCS) were collected for analysis Mn, Fe (total), SiO2, Al2O3, CaO, and P2O5, and the same samples were analyzed by X-Ray Fluorescence (XRF) instrument at GSI Chemical Laboratory, Eastern Region, Kolkata, India. For Chemical analysis of rock samples using the XRF technique, the pulverized samples were pressed in the form of a pressed pellet of 40 mm diameter in an aluminum cup over a bed of boric acid by applying a pressure of 20 tonnes in a Hydraulic press pelletizer (INsmart Systems). The prepared pellets were analysed in a 2.4kW WD sequential X-ray fluorescence spectrometer (PAN analytical Magix-2424) having PX1, PE 002, Ge 111, LiF 200, LiF 220 diffracting crystals and flow scintillation and duplex detectors.

4. Result & Discussion

Mode of occurrence and nature of mineralization

During the course of thematic mapping, one important bands containing mapable manganese ore bands/bodies with more than 30% Mn from Tudi area has been identified. Ore body details were also studied block-wise and delineated in the area shown below. In Tudi area, NW–SE trending ore bodies occur as bands, fragmental bodies, lenses and lenticles dipping moderately towards NE respectively. A total of one ore body is observed of the manganiferous zone within the mapped area of 350 sq.km. covering parts of 65N/10. They are associated with quartzite bands

Serial no	Locality Name	Dimension of the ore body (Meters)	Trend	Form (physical)
1	Tudi	100 X 05	NW-SE	Botryoidal, bedded

At Tudi, the Mn occurrence is observed within the sheared quartzite which has a dimension of 100m x 5m. The manganese oxides like pyrolusite, psilomelane are observed which are associated with hematite and quartz having botryoidal and fibrous structure and high specific gravity. The exposed ore is of powdery type and at places it is lumpy having potential with more than 30% Mn. The analytical values are followed

Sample no	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**
	(weight%)								
L149A	28.50	1.46	59.40	0.04	0.76	0.05	0.10	0.14	0.07
L149B	25.68	1.33	62.22	0.03	0.83	0.05	0.10	0.12	0.05

Figure 3: occurrences of A.Botryoidal and B. Bedded form of manganese ore minerals near the Tudi village

At Dasuguda an ore bearing zone was sampled for manganese mineralization. The dimension of the body is 30m long trending E-W. The ore body is intimately associated with the quartzite. The ore is majorly associated with limonite and goethite. Manganese concentration is seems to be in lower side from the hand specimen. Ore band measuring 50m x 5m. But the analytical values shows that manganese concentration is less than 1%.

Sample no	**SiO_2**	**Al_2O_3**	**Fe_2O_3**	**MnO**	**MgO**	**CaO**	**Na_2O**	**K_2O**	**P_2O_5**
	(weight%)								
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L149B	25.68	1.33	62.22	0.03	0.83	0.05	0.10	0.12	0.05

Figure 4 : occurrences of A.Blocky and B. Botryoidal form of goethite and Magnetite ore minerals near the Dasguda village

Some other small occurrences also observed near

(1) Float ore/boulders and/or small manganese ore bands observed near Mekava. The Mn band is occur within khondalite with varying thickness from few cm to 4 cm and shows cumulative band thickness of appx. 20cm and 4m length.

(2) At Tangidi, occurrence of Mn is observed, which are mainly float ore associated within quartzite as small bands / pockets. The Mn band shows E-W strike and gentle dip towards south, indicating its presence on the hinge of the F2 fold. It is having approx. 15m in length and 1m in width.

(3) Manganese ore observed at east of Rayavalasa village. The Mn band shows NE-SW strike and steep SE dip, having approx. 20m in length and 1m in width. The ore body is intimately associated with the quartzite. The ore is of lumpy type in quartzite

Mode of occurrence of manganese ore bodies

Manganese ore occurs in form of lensoidal and lenticular bodies and often as float ore/boulder having length up to more than 50 metres (Tudi area) with width varying from less than one metre to as thick as 05 metres; having length up to 50 metres (Dasuguda area) with width up to 5 metres and having length up to 40-50 metres. As already stated, the main ore-bodies are restricted within quartzite as conformable and co-folded units where the banding within the ore bodies traceable for considerable distance even on exposures. The manganese ore-bands and lenses lie always parallel to the foliation of quartzite and exhibit diffused contacts.

Graphite is ubiquitous and concentrated along narrow zones parallel to the litho-contact with calc-granulite at north of S. Gopalpuram. The schistosity and fracture planes probably represent small-scale avenues for incompetent ductile flowage of graphite minerals to form cavity filling along the S2 foliation.

Controls of ore localization:

The manganese ore bodies are strata-bound occurring within quartzite, together constituting and defining a narrow characteristic stratigraphic horizon within a vast and wide litho-sequence of the Khondalite Suite within Eastern Ghats Supergroup. This itself serves as lithological control for manganese ore localization in this area. The rich pockets of Mn ores are lithologically controlled but disposition of manganese bands are structurally controlled, localized near the hinge zones and at some parts in the limb areas. This serves as a marker zone depicting the stratigraphic control with a syngenetic signature. Structure has played an important role in localizing pockets of ore near the fold closures and at places along limb. The ore-bodies are well preserved in F2 fold closures and some time at limb. Richer concentrations are confined to schistosity; cleavage and fracture planes related to S1 and S2. At places, epigenetic nature of mineralization is also noticed within these ore bodies which are mainly inferred from the replacement type of ore occurring as lenses, box-work, streaks, reticulate veins, and discontinuous patches within the host rock along foliation/cleavage, fracture, joints, and shear planes

Ore petrography

During present study, some of the mineral phases like primary minerals Braunite ,psilomelane, because the manganese ore in the area mainly associated with quartzite while secondary minerals- psilomelane,Hausmanite ,romenchite and pyrolusite have also been reported. The textures as banding, colloform structures (Figure 5(N) and (O)), relict silicates (Figure 5E) and rare pseudomorphs (Figure 5J), indicate its secondary nature formed as an alteration product of manganiferous silicates of an early paragenetic sequence. Pyrite (Figure 6B), magnetite (Figure 6A) and ilmenite (Figure 6A) are found as interstitial minerals, in cracks and cleavages of silicates forming the latest paragenetic minerals. Three types of iron oxide and oxy hydroxide minerals such as hematite, goethite and limonite are recorded in stratiform manganese ore. Out of these minerals goethite/limonite is ubiquitously observed in almost all grade and types of **Mn-ore/rock**

Figure 5: A) Cryptomelane replacing plagioclase B) Extremely fine grained cryptomelane replacing country rock along cracks as veins C) Psilomelane showing characteristic growth texture. D) romanchite (mammillary structure) cross cut by the psilomelane veins E) relict silicate structure concentration of pyrolusite F) Psilomelane colloform banding G) Birnessite alteration product of Mn oxide precursors, hydrothermal H) Birnessite (lighter grey fibres) alteration product of Mn oxide precursors, indication of deep sea hydrothermal alteration I) Polianite brownish and greyish pleochroism associated with Goethite (dark grey) J) Garnet (spessartine) replaced by Rhodonite K) garnet and magnetite in quartzite L) Replacement texture of cryptomelane M) Symplectite intergrowth between braunite and hausmannite N-O) banded colloform texture of pyrolusite & Psilomelane

The possible mode of formation of the main primary type Mn-ore deposits around Rayvalasa-Tallavaram area can be described as follows. The Mn-mineralization is mainly banded, with in alternate disposing of manganese and silicate layers, even in micro-scale reflecting its stratiform nature. The ore petrographic studies have revealed pyrolusite, psilomelane-cryptomelane, Birnessite, Romanéchite and Polianite to be the major ore minerals in the area.

As pyrolusite belongs to colloidal and supergene alteration phases, it exhibits colloform banding (Fig 5F). Psilomelane results through alteration or from colloidal gels. They mostly constitute colloform banding or even appear as earthy mass (Fig 5C & 5O). Cryptomelane is of rather common occurrence in oxidized manganese deposits . where it occurs as replacements and open space fillings in veins and vugs (Fig 5A &5B). Hausmannite, the only lower oxide ore mineral recorded occurs commonly associated with garnet and magnetite in quartzite (Fig 5K). Romanechite in considerable quantity is observed in stratabound ore as mammillary veins (Fig. 5 D) and lesser quantity in stratiform ore. Pyrolusite in the study area commonly occurs as large crystals replacing cryptomelane and sometime cryptomelane gets oxidized to pyrolusite. With the increasing degree of oxidation pyrolusite tend to form larger crystals with distinct transverse cleavages, and may be termed as Polianite (Fig 5 I). Birnessite (lighter grey fibres) alteration product of Mn oxide precursors. Their appearance bears antipathic relationship with the ore grade. Symplectite intergrowth between braunite and hausmannite has been recorded (Fig 5 M). Replacement relationship is exhibited by colloidal ore with respect to early formed metamorphic mineral

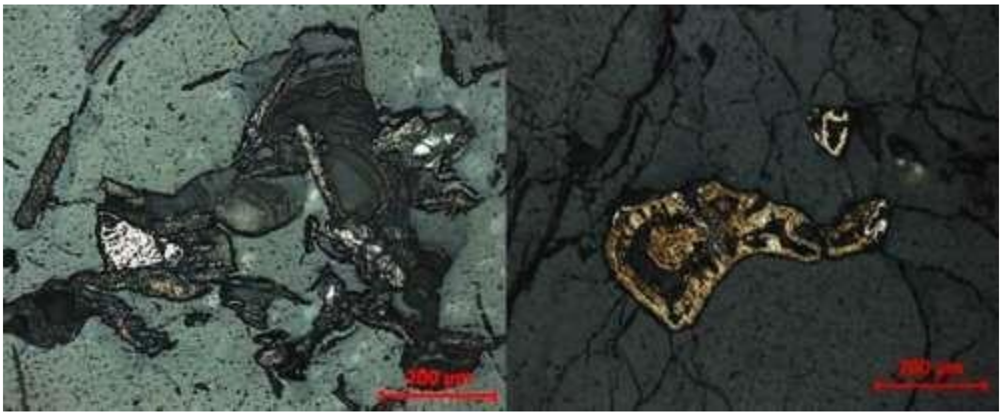

Figure 6A) Magnetite and ilmenite are found as interstitial minerals B) Pyrite as accessory mineral

At Tudi, the Mn occurrence is observed within the sheared quartzite, which has a dimension of 50m x 10m. The manganese oxides like cryptomelane, psilomelane are observed which are associated with hematite and quartz having botryoidal and fibrous structure and high specific gravity. The manganese mineralization in the area observed in the form of manganiferous zone / horizon, which shows intimate association with quartzite in the form of bands, lenses and pockets of varying dimensions. The Mn-rich silicates are converted to manganese ore due to leaching or oxidation. The relict phases of silicate with Mn-rich rim and inclusions indicate that they were derived during leaching. Such features as banding, colloform textures, relict silicates and rare pseudomorphs, indicate its secondary nature formed as an alteration product of manganiferous silicates of an early paragenetic sequence. The study of mineral composition and the texture of the manganese ores of the Vizianagaram-Visakhapatnam Manganese Belt revealed strong indications of high-grade metamorphism. The manganese ores of these districts in composition and mode of occurrence are closely related to Gondite type (Madhya Pradesh, India) of a definite metamorphic origin (S.Pradhan et.al)

5. Genesis of Manganese mineralization

The possible modes of formation of the manganese deposits at Tudi, Dasuguda and Rayavalasa can be described as follows. The Mn-mineralisation is mainly banded, with an alternate disposition of manganese and silicate layers, even in micro-scale reflecting its stratiform nature. Soft sediment deformations appear to reflect the primary, sedimentary and diagenetic process. Field disposition strongly suggests that such deposit are formed as a part of metasedimentary sequence of Eastern Ghats complex. Continental weathering appears to be the source for the Mn and Fe, which were supplied through acidic surface water and the ground water, since both are soluble at room temperature and pressure (Hem, 1963 and 1972). Due to low concentration of barium (Ba) the other possibility of Mn-source may be alkaline volcanic rocks available in the boundary of EGMB. Hydrothermal Mn- rich fluids in felsic rocks are buffered by mica to a low pH at relatively low temperature (S.Pradhan et.al).

The mode of transportation of Mn and Fe and their deposition under oxidizing conditions has long been known (Rankama and Sahama, 1950; Krauskopf, 1957 and Stanton, 1972). Mn and a part of Fe might have been transported as finely divided particles in river waters, as adsorbed compounds on clay particles and / or, as sols and gels. Phase equilibria studies on manganese-water system at room temperature and pressure confirmed that manganese is more soluble than iron (Hem, 1963 and 1972). In case of stratabound ores, the mineral rich fluid might have been transported through surface run off / meteoric water to the structurally weak plane site where Mn and Fe precipitated under suitable Eh - pH conditions. Krauskopf (1957) emphasised the control of Eh - pH in the precipitation of Mn and its fractionation with Fe in inorganic aqueous systems. However, solution and precipitation of Fe and Mn may be additionally affected by the presence of HCO3-, SO4-2, and HPO4-2 in the system (Roy, 1992). These are later permeated through pegmatite and quartz veins, which are carrier of the phosphate minerals. Such ores are found to contain fragments of feldspar and quartz getting locally accumulated. The elements like Mn, Fe, and P are enriched and Mg, Ca and Si are leached out from primary manganese minerals. Structural and textural characters of the ore assemblages indicate that the bulk of ores were formed by cavity filling and replacement processes.

The mineralogical assemblage of the various rock types recorded in association with the manganese horizons is suggestive of granulite facies of regional metamorphism. The metamorphic manganese oxides like braunite and hausmannite also reflect this grade of metamorphism. The presence of wollastonite in the metamorphites possibly indicate zones of low pressure during regional metamorphism. At times, the accentuation of sillimanite in khondalite is possibly because of the break down and consequent reaction between quartz and muscovite with rise of temperature and pressure (Winkler, 1975).

The proto-ore or the manganese silicate-oxide rock represents the metamorphic equivalent of impure sediments may be presented as an admixture of oxides and hydroxides of Mn, silica, clay. On metamorphism this admixture gave rise to garnet, Rhodonite, braunite, quartz, etc. which can be represented through following reactions

$MnO_2 + SiO_2 + Clay = 3MnO + Al_2O_3 + 3SiO_2$

(Mn - garnet)

$2MnO + 2SiO_2 = 2MnSiO_3 + O_2$

(Rhodonite)

$7MnO + SiO_2 = 3Mn_2O_3 . MnSiO_3 + 2O_2$

(Braunite)

The coexistence of rhodonite and braunite is indicative of variable oxygen fugacity during metamorphism. With some Ca and Fe in the sediment, Mn would get replaced by them giving rise to silicates like bustamite. The original sediment was probably devoid of carbonate as can be inferred from the lack of carbonate mineral or any silicate like knebelite/tephroite in the mineralogical assemblage. And hence it is presumed that the environment of sedimentation was an oxidising one. The presence of graphite in this rock is considered as a reconstituted material from the adjoining khondalite and not a part of the original sediment, because, if Eh-pH condition allowed carbon to form the sediment, carbonate ore must have developed in the rock**.**

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