International Journal of Science and Research (IJSR)
ISSN: 2319-7064
SJIF (2020): 7.803

Occurrences of Manganese Mineralization in the Boringpadar-Amath Sector, Eastern Ghats Mobile Belt, Eastern India

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Abstract: ***In this paper, we have reported two bands of manganese ore and four bands of manganiferous quartzite for the first time to the southeast of Boringpadar and northeast of Amath area belonging to the Eastern Ghats Mobile Belt, Eastern India. The main purpose of the study has brought to light an array of manganese mineralization with promising values, hosted in manganese ore and manganiferous quartzite. The manganese ores are represented by bluish-black to brownish-black, massive to foliated, metallic luster, nodular, and botryoidal forms whereas the manganiferous quartzite are hard, white to black, highly jointed, fractured, and brecciated which occurs at the contact of khondalite. The manganese ore and manganiferous quartzite bearing horizons are dominantly observed between the calc-silicate granulite and garnetiferous quartzite of Khondalite Group, indicating the stratigraphic, lithology, and structure controls. Bands of manganese ore and manganiferous quartzite are delineated which shows a predominantly syngenetic type of deposit but, at places, the epigenetic nature of mineralization is also noticed. Braunite, bixbyite, jacobsite, and manganite are represented as the primary minerals which are attributed to the high-grade metamorphic minerals whereas the secondary minerals are made up of psilomelane, cryptomelane, pyrolusite, and goethite and are formed in the low grades of metamorphism. The analytical results of bedrock samples show high values of Mn, Fe (total), SiO_2, Al_2O_3, CaO and P_2O_5. The values of Mn and Fe (T) vary from 0.05 to 28.18 wt. % and 1.87 to 56.31 wt. % respectively whereas the Mn value ranges from 0.05 to 27.77 wt. % and the Fe (T) value ranges from 2.11 to 46.85 wt. % in the pitting/trenching samples.***

Keywords: Manganese mineralization, Mineralogy, Eastern Ghats Mobile Belt (EGMB), India

1. Introduction

Manganite (MnO), purpurite ($MnPO_4$), pyrolusite (MnO_2), rhodonite [(Mn, Fe, Mg, Ca, (SiO_3)], rhodochrosite ($MnCO_3$), and sugilite [KNa_2 (Fe, Mn, Al) $_2$ $Li_3Si_{12}O_{30}$] are represented by manganese minerals. They are also found in association with mineraloids like psilomelane and wad and are an important element for steel and non-alloying industries (Gandhi, 2010; Singh and Biswas, 2017). In Archean greenstone belts, the manganese mineralization is mainly associated with the association of Banded Iron Formation (BIF) and are mostly reported from the Barberton greenstone belt of South Africa, the Isua Formation of Greenland, the Superior and Slave provinces of Abitibi belt, Canada, the Yilgarn and Pilbara blocks of Western Australia, the Bababudan and Chitradurga belt of South India and the Iron Ore Group (IOG) of the Singhbhum Craton (Goodwin, 1973; Ramakrishnan et al., 1976; De Wit et al., 1980; Anhaeusser and Wilson, 1981; Chadwick et al., 1981b; Condie, 1981; Hallberg and Glikson, 1981; Dimroth et al., 1982; Gross, 1986; Machado and Carnerio, 1992; Myers and Kröner, 1994; Saha, 1994; Teixeira et al., 1996; Martin et al., 1997; Ghosh et al., 2015; Mishra et al., 2016). The manganese accumulations predominantly occur in the Archean and Proterozoic periods and few occurrences were also noticed in the Phanerozoic Era. The formation of manganese rocks and ores on many geological boundaries was closely connected with global climatic, tectonic restructurings, and biological events (Kuleshov, 2017). However, manganese ores were also derived from the volcanogenic and/or, hydrothermal and freshwater sources which are also reported from the different parts of the world (Achary et al., 1994; Roy, 2000, 2006; Mishra, 2015).

In Odisha, the manganese ore is found to occur in three stratigraphic horizons and spatially distributed wide apart i. e. IOG in Bonai-Keonjhar belt, Gangpur Group in Sundergarh, and Eastern Ghats Mobile Belt in Rayagada-Kalahandi-Bolangir belt (Spencer, 1948; Sen, 1951; Ray, 1954; Mohapatra and Bagchi, 1961; Murty and Ghosh, 1971; Dasgupta et al., 1999; Mohapatra et al., 2009; Mishra et al., 2016). Manganese ores are predominantly reported in the Vizianagaram-Visakhapatnam sector in Andhra Pradesh belonging to the EGMB (Straczek, and Krishanswamy, 1956; Krishna Rao, 1963; Rao, 1969; Siddique and Raza, 2008; Siddique and Shaif, 2015; Siddique et al., 2015). In contrast, only a few such occurrences have been reported from the EGMB in Odisha by the Geological Survey of India (Jayaram, 1956; Jena and Devdas, 1994; Dash et al., 2005; Dash and Behera, 2009; Yadav et al., 2017).

The main focus of the study is aimed to assess the manganese mineralization based on field observations, ore petrography studies, and geochemical inputs in the Boriningpadar-Amath sector in the Eastern Ghats Granulite Belt belonging to the EGMB, Odisha, Eastern India. In this paper, two bands of manganese ore (200m X 50-70m; 250m X 40m) and four bands of manganiferous quartzite (150m X 10m; 230m X 10m; 150m X 5m; 100m X 5m) have been delineated in detail for the first time to the southeast of Boringpadar and northeast of Amath areas.

2. Regional Geological Setting

The EGMB covering an area of over 50, 000 sq. km broadly trends NE-SW and extends from Brahmani River in Odisha to Ongole in Andra Pradesh for a distance of over 900 km with a maximum width of 300 km in Odisha in the north. It tapers down to a few tens of km in width in Andra Pradesh. The EGMB is a distinct geological entity and is known for its regionally developed granulite facies lithopackage, intense polyphase ductile deformation, metamorphism, migmatisation, and Meso-to Neoproterozoic magmatism (Ramakrishnan et al., 1998). It consists of granulite facies metapelitic and meta-psammatic gneisses, mafic and felsic orthogneisses/granulites and S-type granites. Massif-type anorthosite-leuconorite complexes and alkaline complexes are significant products of Meso to Neoproterozoic magmatism (Murthy and Ghosh, 1971; Narayanswami, 1975; Chetty and Murthy, 1994; Bhattacharya et al., 1998; Ramkrishna et al., 1998). Ramakrishnan et al. (1998) have divided EGMB into four longitudinal lithozones on the basis of dominant litho-suite present, viz. Eastern Khondalite Zone (EKZ), Central Charnockite-Migmatite Zone (CMZ), Western Charnockite Zone (WCZ) and Western Khondalite Zone (WKZ). The prominent NE-SW trending Tel lineament running sub-parallel with the Tel River course possibly separates the main belt from the nappe block.

The manganese ore bodies are confined to the Khondalite Group of rocks of the Eastern Ghats Granulite Belt in Odisha. The prominent known areas are the 32 km long Kutinga-Nishikhal zone in Rayagada district and the 30 km long Kanaital-Uchhabapalli zone in Bolangir district (Jena and Devdas, 1994; Dash et al., 2005; Dash and Behera, 2009). The manganiferous ore bodies or horizon are mainly associated with the quartzite±garnet (psammitic facies) and calc-silicate granulite (calcareous facies) with manganese ore bodies lying in between the two along with garnetiferous quartzo-feldspathic sillimanite schist/gneiss±graphite (psammo-pelitic facies). In general, manganese ore bodies are intimately associated with calc-silicate granulite with profuse quartz veins in the vicinity of garnetiferous quartzo-feldspathic sillimanite schist/ gneiss±graphite. In domal outcrops, granitoids and gneisses contain all the litho-variants of the manganiferous zone/horizon as enclaves usually in the proximity of the rich deposits of manganese. The present area i. e. Boringpadar-Amath sector forms a part of the WKZ in the proximity of the Tel lineament zone. The dominant rock type exposed in this block is calc-silicate granulite, quartz + K-feldspar + sillimanite + garnet + biotite±graphite (khondalite), Mn-ore/manganiferous quartzite/ferruginous quartzite and garnetiferous quartzite (Khondalite Group), garnetiferous granite-gneiss, and megacrystic garnetiferous granite-gneiss.

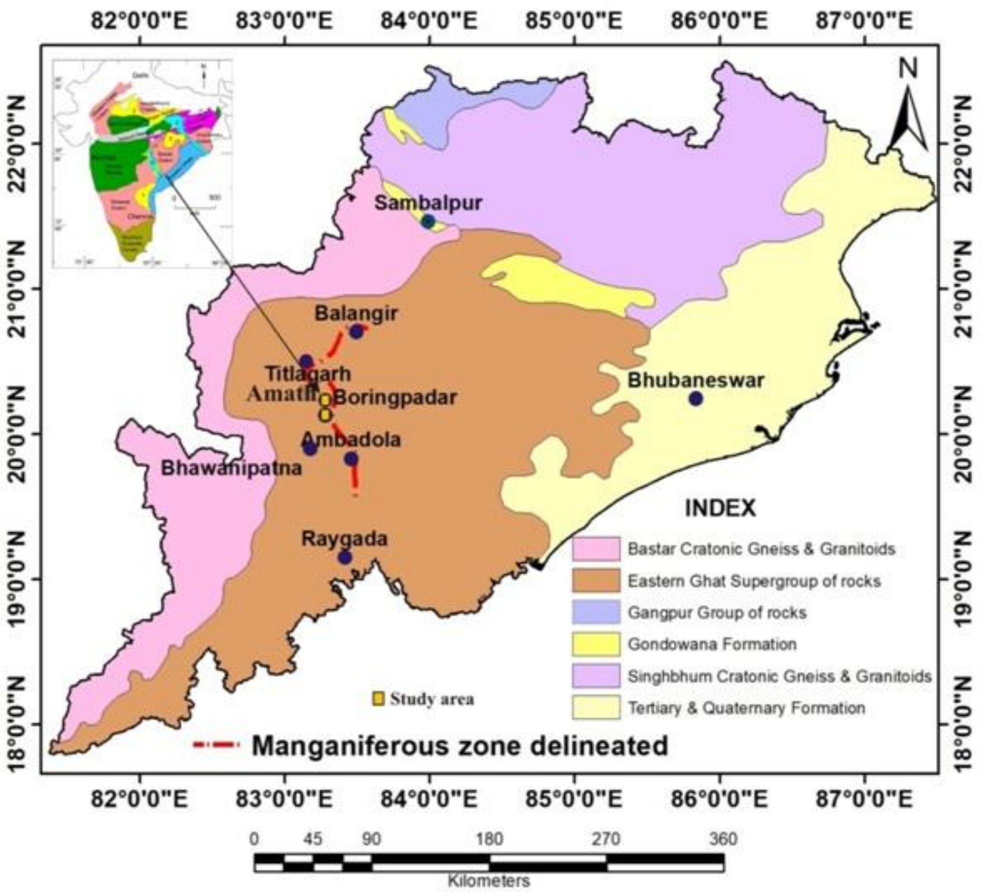

Figure 1: Generalized regional geological map of the Eastern Ghats Mobile Belt, Odisha showing location of the study area (modified after Ramakrishnan et al., 1998).

Geology of the study area

The study area forms a part of the Western Khondalite Zone in the proximity of the Tel lineament zone. The dominant rock type exposed in this block is calc-silicate granulite, quartz + K-feldspar + sillimanite + garnet + biotite±graphite (khondalite), Mn-ore/manganiferous quartzite/ferruginous quartzite and garnetiferous quartzite (Khondalite Group), garnetiferous granite-gneiss and megacrystic garnetiferous granite-gneiss (Figure 2; modified after Yadav et al., 2017). Two bands of manganese ore have been observed in the mapped in Boringpadar-Amath sector (Figure 2). The first band of manganese ore is mapped to the southeast of Boringpadar which occurs in the lower flank of the hill. The manganese ore is bluish-black to brownish-black, massive to foliated, metallic luster, and having nodular and botryoidal forms (Figure 3a & b). The manganese minerals are mostly pyrolusite and psilomelane and the ore body is mainly bedded and fragmental type. The strike length of this ore body is 200m having a width of 50-70m on a hill slope at an elevation of 270m which is having variable trends from N20ºW to N40ºE direction. The second band of manganese ore has been mapped towards the northeast of the Amath area having a dimension of 250m and 40m trending N10ºW-N30ºE direction. The manganese ore is mainly bluish-black, massive to foliated, metallic luster, and having botryoidal and nodular forms (Figure 3c & d).

Four bands of manganiferous quartzite have been mapped to the southeast of Boringpadar area with dimensions as follows: (i) 150m X 10m trending NNE-SSW (ii) 230m X 10m trending N40ºE-S40ºW, (iii) 150m X 5m trending N40ºE-S40ºW, and (iv) 100m X 5m trending N-S to N45ºE-S45ºW. They are hard, white to black, highly jointed, fractured, and brecciated (Figure 3e & f). At places, a small band of ferruginous quartzite is also observed at the contact of manganiferous quartzite and khondalite towards the southeast of Boringpadar which is hard, massive to foliated, chocolate, fine to medium-grained, and consists of quartz as an essential mineral (Figure 3g). The strike length of this band is 50m and with a width of 10m trending in the N-S direction. The sharp contact between the manganiferous quartzite and ferruginous quartzite is also noticed (Figure 3h).

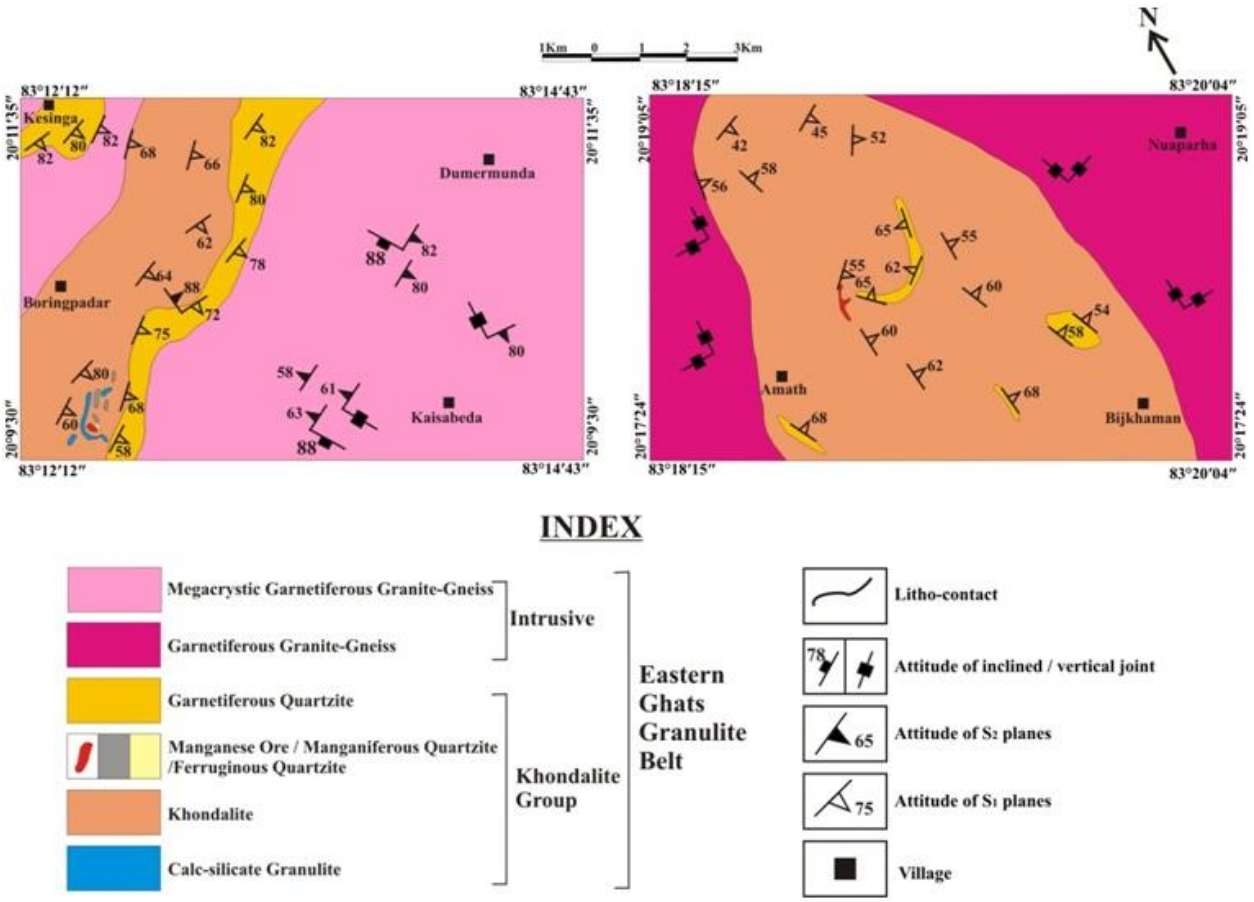

Figure 2: Geological map of the study area showing the occurrence of manganese ore and manganiferous quartzite towards southeast of Boringpadar and northeast of Amath areas, Kalahandi district, Odisha (modified after Yadav et al., 2017).

Paper ID: SR211231161027 DOI: 10.21275/SR211231161027

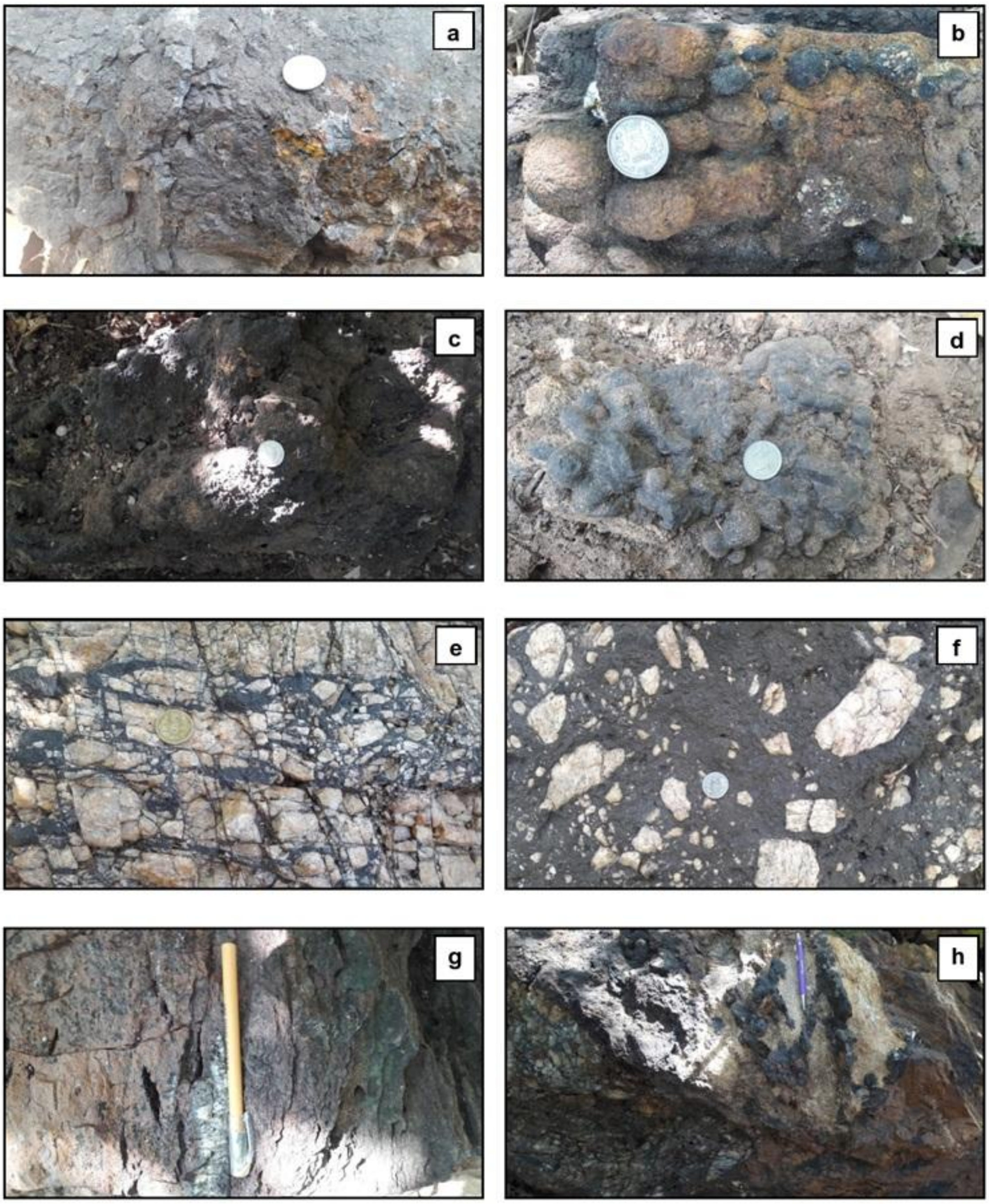

Figure 3: (a & b) Outcrop of massive manganese ore (bluish to brownish), which shows size variations of botryoidal form, southeast of Boringpadar. **(c & d)** Massive manganese ore in bluish-black displaying the botryoidal form, northeast of Amath. **(e)** Highly fractured and jointed manganiferous quartzite, southeast of Boringpadar. **(f)** Highly fragmented and brecciated pieces of manganiferous quartzite embedded in the matrix of manganese ore, Boringpadar. **(g)** Outcrop of ferruginous quartzite, southeast of Boringpadar. **(h)** Contact between manganiferous quartzite and ferruginous quartzite, southeast of Boringpadar.

Ore Petrography

Manganese ores

Braunite, bixbyite, jacobsite, and pyrolusite are primary minerals that occur as inclusions and anhedral shapes within the manganiferous quartzite. The minerals of manganese ores are identified as pyrolusite, psilomelane, goethite, and quartz gangue. Pyrolusite occurs as subhedral and relict pyrolusite and exhibits white, bluish grey, anisotropism with shades of grey and weak pleochroism, moderate reflectivity in the association of psilomelane and goethite. The contact is irregular, concave, and contorted with secondary manganese ores and it has one set of cleavage. Colloform and spheriodal forms of pyrolusite, cryptomelane, psilomelane, goethite, quartz, and these spherules sizes occur invariably at places. Spotted/porous textures are noticed in pyrolusite, cryptomelane-psilomelane. Psilomelane displays bluish grey, light grey to bluish-grey anisotropism along with fibrous cryptomelane (bluish-grey) and it subsequently altered to goethite with grey and dark brown internal reflection. Manganese ore band exhibits replacement, colloform /spheroidal, and vein textures (Figure 4a). Replacement and vein textures are common in it. Subhedral braunite has grayish-white to light grey with brownish-grey anisotropism and contains silicate gangue and it occurs as a vein and exhibits spotted/porous texture. Manganite, an alteration product of braunite, exhibits grey, weak pleochroism/anisotropism with low reflectivity in association with braunite and pyrolusite. Pyrolusite shows cream white to light grey, moderate reflectivity with the abundance of pores and one set of cleavage. Psilomelane-cryptomelane pyrolusite ore minerals (Figure 4b) exhibits bluish-grey with strong anisotropism (bluish-grey to light grey) and are fibrous. Few fibrous cryptomelane occurs at the wall between silica and pyrolusite (Figure 4c). In a few samples, manganese ore consists predominantly of todorokite and pyrolusite-psilomelane as an accessory along with quartz and garnet as gangues. Todorokite occurs as fibrous/fine bands, (Figure 4d) grey with dark brownish-grey anisotropism alternate with silica. Pyrolusite is light grey and occurs as non-crystalline or amorphous forms replacing todorokite. Sub-idioblastic garnets are replaced by psilomelane-goethite and their void spaces are occupied by quartz grains. Many garnets contain sub-rounded to rounded inclusion of braunite (Figure 4e) which is light grey with a yellowish tint, strong pleochroic (brownish-grey to bluish-grey), and has moderate brown internal reflection. At places, idiomorphic manganite (Figure 4f) occurs within secondary manganese ore and quartz which exhibits medium grey, weak pleochroism with blood-red internal reflection. A thick vein of manganese ore displays crosscutting relationship with the quartz at places (Figure 4g). Bixbyite occurs as inclusion within the pyrolusite and it is subsequently altered to psilomelane-cryptomelane and goethite and forms the colloform texture (Figure 4h).

Manganiferous quartzite

Highly brecciated and elongated braunite shows light grey with reddish-brown internal reflection and it occurs in the manganiferous quartzite (Figure 4i). Subhedral to anhedral braunite shows medium grey, brown internal reflection, and irregular contact with pyrolusite is also observed within this unit at places. A cross-cutting relationship between the Psilomelane-cryptomelane veins and the braunite-pyrolusite veins is also seen. The quartz grains occur as angular within the manganese ore matrix and few manganese ore veins are also seen along the fracture of quartz (Figure 4j). Manganiferous quartzite is predominantly made up of pyrolusite, psilomelane, goethite, bixbyite, jacobsite, and quartz (Figure 4k). These ore minerals have interstitially occurred between quartz grains. The psilomelane and goethite occur together within the manganiferous quartzite along with the primary minerals like jacobsite and bixbyite (Figure 4l). Psilomelane shows bluish grey to cream white with strong brown internal reflection occurs with goethite and quartz. Goethite has grey with bluish tint with strong yellow-reddish brown internal reflection and is fibrous (colloform texture). Cream white with shades of grey-bluish grey anisotropism is seen in pyrolusite and jacobsite occurs as anhedral and is characterized by light grey, isotropic with concave and contorted contacts with psilomelane and quartz gangue (Figure 4m). A thick manganese ore vein traversing in manganiferous quartzite is also seen at places that are represented by colloform texture (Figure 4n). A zonal patchy occurrence of darker grey manganite (bluish-brown internal reflection) and cream white pyrolusite is replaced by fibrous cryptomelane are also noticed within this rock (Figure 4o). Idiomorphic manganite shows medium grey with dark brown-red internal reflection and it has remobilized along the fracture plane of quartz as psilomelane (Figure 4p).

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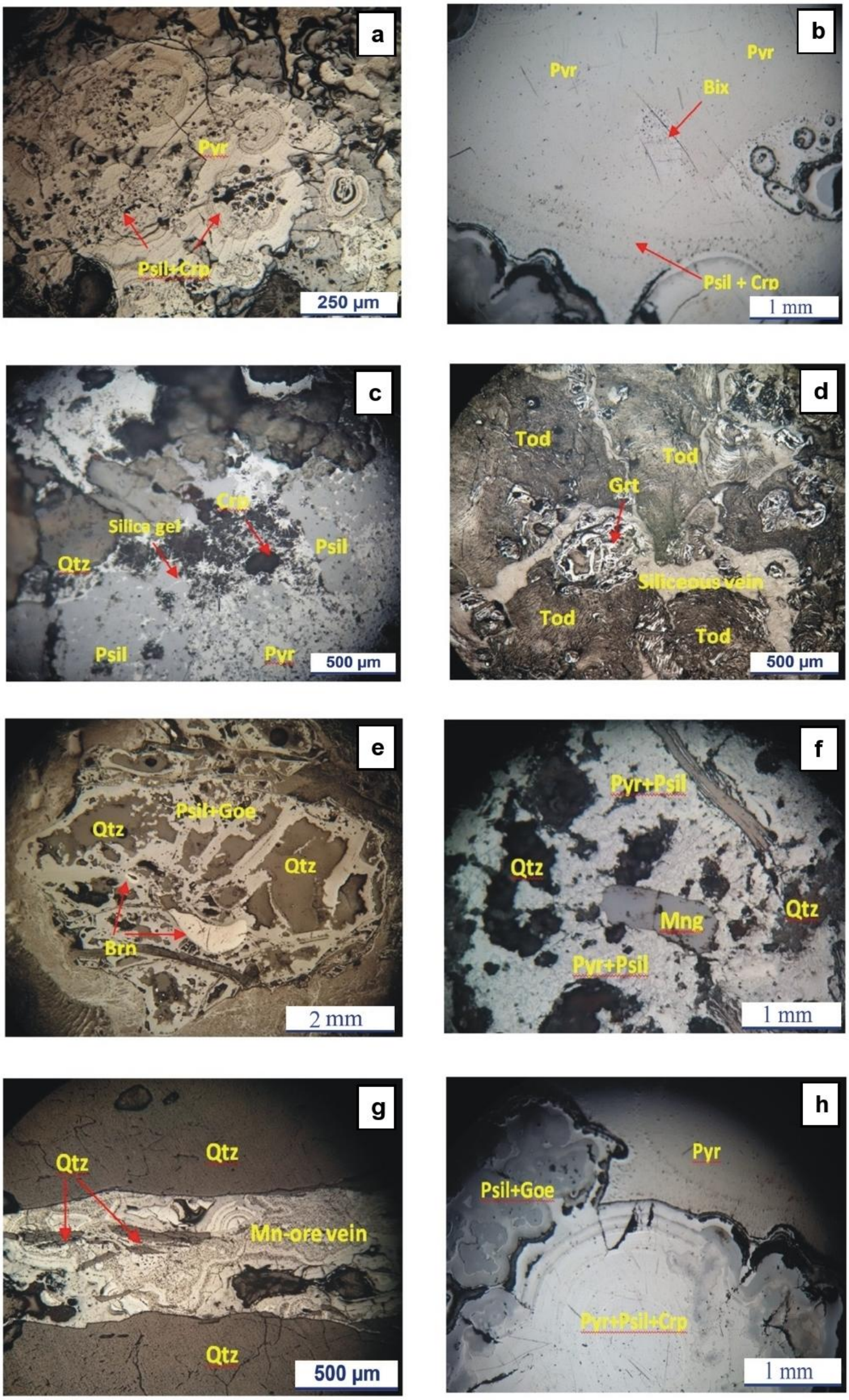

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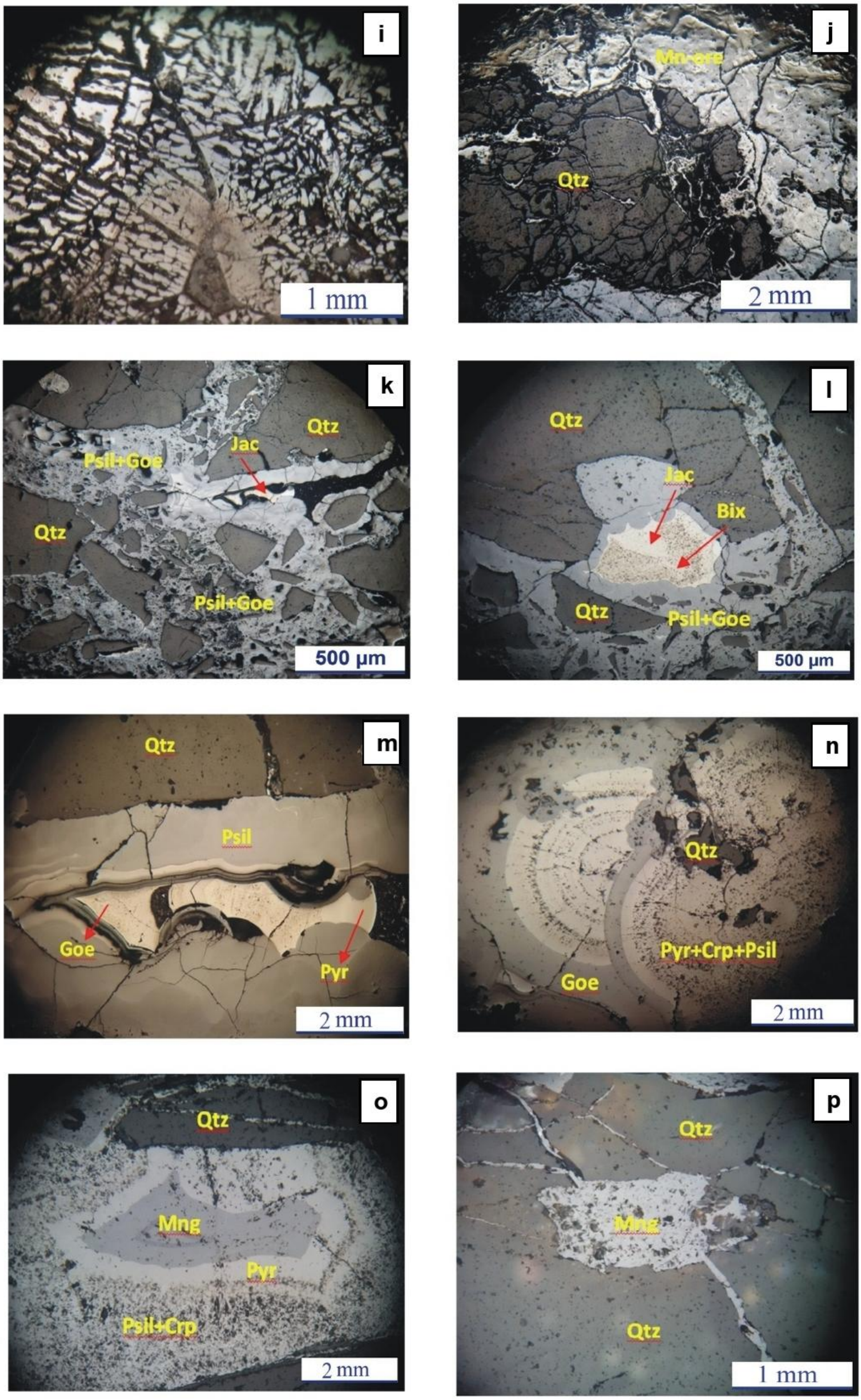

Figure 4: Photomicrographs of manganese ore and manganiferous quartzite under reflected light (RL): (**a**) Colloform and spheroidal textures of pyrolusite-psilomelane-cryptomelane in manganese ore. (**b**) Replacement of bixbyite to pyrolusite

observed in Mn ore. (**c**) Fibrous cryptomelane at the wall between pyrolusite and silicate gangue was preserved within this unit. (**d**) Fibrous todorokite was crosscutting by siliceous vein with garnets in Mn ore. (**e**) Inclusion of braunite in garnet where the garnet is completely replaced by manganese oxide. (**f**) Idiomorphic manganite and quartz gangue were noticed within manganese ore. (**g**) A thick vein of manganese ore (colloform texture) displays crosscutting relationship with the quartz. (**h**) Manganese ore showing colloform texture. (**i**) Brecciated braunite in manganiferous quartzite. (**j**) Manganese ore and quartz showing vein texture in manganiferous quartzite. (**k**) Veined manganese ore in brecciated quartzite. (**l**) Jacobsite and bixbyite occur within the secondary manganese ore seen in brecciated quartzite. (**m**) Concave and contorted contact of goethite and pyrolusite occur with secondary ore minerals. (**n**) Colloform texture well preserved along the manganese ore vein. (**o**) Zonal texture between manganite, pyrolusite, cryptomelane-psilomelane has been seen in manganiferous quartzite. (**p**) Sub-idiomorphic manganite with secondary manganite was noticed in manganiferous quartzite.

Abbreviations: Bix-Bixbyite; Jac-Jacobsite; Brn-Braunite; Mng-Manganite; Pyr-Pyrolusite; Psil-Psilomelane; Crp-Cryptomelane; Tod-Todorokite; Goe-Goethite; Grt-Garnet; Qtz-Quartz.

3. Methodology and Analytical Techniques

Appropriate care has been taken in selecting samples for 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.61 nos. of bedrock samples (BRS) and 50 nos. of pitting/trenching samples (PTS) were collected for analysis Mn, Fe (total), SiO_2, Al_2O_3, CaO, and P_2O_5, 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 analyzed 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. The standard reference materials used for creating an application for analysis of rock samples were BEN, JP1, JGB1, ANG, NIM-P, MO-10, DRN, JB2, JA2, STM, SY3, JA1, GSN, MAN, ACE, JG1A, JR2, GH, JG2, NCS DC 73304 and Quartz. The analytical data are presented in Tables 1 and 2.

4. Results and Discussion

Mode of occurrence and nature of mineralization

In Archean greenstone belts, the manganese mineralization occurs predominantly with the association of Banded Iron Formations (BIFs) which are mainly reported from Australia, Brazil, Canada, India, and South Africa (Ramakrishnan et al., 1976; Anhaeusser and Wilson, 1981; Hallberg and Glikson, 1981; Gross, 1986; Machado and Carnerio, 1992; Saha, 1994; Martin et al., 1997; Mohapatra et al., 2009; Ghosh et al., 2015). In Odisha, the manganese ores are mostly delineated in the two stratigraphic horizons and spatially distributed wide apart i. e. Iron Ore Group and Gangpur Group (Sen, 1951; Ray, 1954; Mohapatra and Bagchi, 1961; Murty and Ghosh, 1971; Saha, 1994; Mohapatra et al., 2009; Mishra et al., 2016). In contrast, only a few such occurrences have been reported from the EGMB in Odisha by the Geological Survey of India which is mainly associated with calc-silicate granulite with profuse quartz veins in the vicinity of garnetiferous quartzo–feldspathic sillimanite schist/gneiss ± graphite (Jayaram, 1956; Jena and Devdas, 1994; Dash et al., 2005; Dash and Behera, 2009; Yadav et al., 2017).

In the study area, two bands of manganese ore and four bands of manganiferous quartzite are delineated towards the southeast of Boringpadar and northeast of Amath. The manganese ore bodies occur as fragmental and discontinuous bands, pockets, and stringers which are mainly restricted to the contact between calc-silicate granulite and garnetiferous quartzite. The ore is closely interbanded within calc-silicate granulite with diffused contact and very often shows pinch and swell structure along the strike. Manganese ore bands are generally noticed parallel to the prominent foliation of calc-silicate granulite and garnetiferous quartzite. The schistosity and fracture planes probably represent small-scale paths for incompetent ductile flowage of manganese minerals to form cavity filling and replacement type of deposits. The first band of manganese ore is bluish-black to chocolate (see Figure 3a), massive to foliated, metallic luster, and having nodular and botryoidal forms (see Figure 3b). The manganese minerals are mostly cryptomelane, pyrolusite, and psilomelane. The second band of manganese ore has been mapped towards the northeast of Amath which is mainly bluish-black, massive to foliated, metallic luster, and having botryoidal and nodular forms (see Figure 3c & d). Besides, four bands of manganiferous quartzite have been mapped to the southeast of Boringpadar which is hard, white to black, highly jointed, fractured (Figure 3e), and brecciated (see Figure 3f).

Controls of manganese mineralization

Manganese mineralization in the Bonai-Keonjhar belt of the IOG reveals that the recycling of manganese is compatible with the different phases of tectonic deformation, metamorphism, hydrothermal activity, and supergene processes (Mohapatra et al., 2009; Ghosh et al., 2015; Mishra et al., 2016). In the EGMB, the manganese mineralization is mainly reported from the Vizianagaram-Visakhapatnam sector, Andhra Pradesh, and also noticed a few places in Odisha that are mainly controlled by structural, lithological, and supergene processes (Jayaram, 1956; Rao, 1969; Jena and Devdas, 1994; Dash et al., 2005; Siddique and Raza, 2008; Dash and Behera, 2009; Siddique and Shaif, 2015; Siddique et al., 2015; Yadav et al., 2017).

In the Boringpadar-Amath sector, manganese mineralization is mainly controlled by stratigraphic, lithology, and structure (see Figure 2). The manganese ore bodies are strata bound occurring in between the calc-silicate granulite and garnetiferous quartzite which is defining narrow characteristics stratigraphic horizon within vast litho sequences of the Khondalite Group of rocks. Structurally, the ore-bodies are well preserved in F1 synformal keels within the granitoid and gneisses, at F2 fold closures and F3 synforms. Richer concentrations are confined to schistosity, cleavage, and fracture planes related to S1 and S2. Based on field observations, it is noted that the manganese ore and manganiferous quartzite bearing horizons are dominantly observed between the calc-silicate granulite and garnetiferous quartzite of Khondalite Group, indicating the stratigraphic, lithology, and structure controls. Bands of manganese ore and manganiferous quartzite are delineated which shows predominantly syngenetic type of deposit and these bodies occurring in form of fragmented bands and lenses at the contact of calc-silicate granulite and garnetiferous quartzite probably suggest their syngenetic nature. 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 (see Figure 3e & f).

Paragenesis of manganese minerals

In the study area, manganese ore and manganiferous quartzite consist of two types of Mn ore minerals. Braunite, bixbyite, jacobsite, and manganite are represented as the primary minerals which are associated with host rocks and these minerals are occurring as inclusions and anhedral shapes. The secondary minerals are mainly psilomelane, cryptomelane, pyrolusite, and goethite. The manganese ore minerals show distinct textures due to the presence of different mineral associations which are mostly identified as a replacement, colloform/spheroidal, veined, and brecciated. Based on the textural evidences of manganese ore of the study area, it is concluded that pyrolusite, psilomelane-cryptomelane has a wide distribution in all the low grades of metamorphism and all manganese ore horizon of different formation. Braunite, bixbyite, jacobsite, and manganite are spotted which are indicating high-grade metamorphic minerals. The pseudo-colloform and spheroidal textures are formed by the alteration of jacobsite and pyrolusite to psilomelane-goethite. Replacement and relict textures are usually noticed between the braunite-manganite-pyrolusite, jacobsite-braunite-pyrolusite, and pyrolusite-psilomelane-cryptomelane-goethite mineral assemblages. Goethite, quartz, and garnets are associated with manganese ore minerals which are metamorphic minerals. The primary manganese ore minerals are considered as most probably initial sedimentary manganese ore or metasediment which are laterally metamorphosed. The influx of hydrothermal to colloidal solution might be derivatives by the dissolution of the metamorphic manganese and the supergene enrichment might be due to mobilization both of metamorphic and colloidal manganese. The secondary minerals are formed by the process of colloidal influx or metasomatism which occurs in more quantity.

Manganese mineralization in manganese ore and manganiferous quartzite

The purpose of the paper has brought to light an array of manganese mineralization with promising values, hosted in manganese ore and manganiferous quartzite.61 nos. of analyzed samples from the manganese ore and manganiferous quartzite show high values of Mn, Fe (total), SiO_2, Al_2O_3, CaO, and P_2O_5 (Table 1). SiO_2 values in bedrock samples (BRS) vary from 8.45 to 92.12 wt. % and Al_2O_3 value range from 1.01 to 20.80 wt. %. The Fe (T) value ranges from 1.87 to 56.31 wt. %. The Mn value ranges from 0.05 to 28.18 wt. %. The high values of Fe (T) recorded from manganese ore of Boringpadar area and maximum value of Mn comes from manganese ore of Amath area. Besides, CaO and P_2O_5 were also analyzed. CaO values vary from 0.01 to 4.73 wt. % whereas the P_2O_5 value varies from 0.77 to 2.81 wt. % in manganese ore and manganiferous quartzite. Analytical results of 50 nos. of pitting/trenching samples (PTS) is also showing the encouraging result of Mn, Fe (total), SiO_2, Al_2O_3, and P_2O_5 (Table 2). SiO_2 and Al_2O_3 values range from 9.75 to 87.54 wt. % and 1.3 to 25.60 wt. % respectively. The Fe (T) value ranges from 2.11 to 46.85 wt. % whereas the Mn value ranges from 0.05 to 27.77 wt. % in the study area. Besides, P_2O_5 was also analyzed and the value varies from 0.03 to 5.43 wt. %.

Table 1: Analytical value (%) of manganese ore and manganiferous quartzite from the bed rock samples (BRS) in the Boringpadar-Amath sector.

Sl. No	Sample No.	Rock name	SiO_2	Al_2O_3	Fe (T)	Mn	CaO	P_2O_5
1	BA/CH/1/1	Mn ore	10.59	2.84	20.88	27.65	2.37	2.37
2	BA/CH/1/2	Mn ore	14.22	3.16	18.57	28.18	2.45	1.77
3	BA/CH/2/1	Mn ore	27.60	5.30	36.88	2.26	0.52	1.89
4	BA/CH/2/2	Mn ore	32.94	5.20	31.09	3.22	0.42	2.52
5	BA/CH/3/1	Mn ore	20.10	4.69	42.39	0.58	0.27	2.36
6	BA/CH/3/2	Mn ore	28.78	5.04	32.53	5.81	0.27	2.1
7	BA/CH/3/3	Mn ore	40.78	2.78	31.89	1.21	0.49	1.7
8	BA/CH/3/4	Mn ore	30.41	4.72	29.51	7.50	0.75	2.10
9	BA/CH/3/5	Mn ore	15.31	5.46	39.68	5.26	1.06	2.81
10	BA/CH/3/6	Mn ore	18.28	13.39	28.17	9.17	0.62	2.19
11	BA/CH/3/7	Mn ore	18.72	12.72	28.28	9.14	0.63	2.25

12	BA/CH/3/8	Mn ore	17.77	15.97	26.88	9.28	0.46	1.47
13	BA/CH/4/1	Mn ore	31.79	2.04	16.21	20.04	3.29	2.73
14	BA/CH/4/2	Mn ore	29.99	3.12	13.08	23.78	2.67	1.95
15	BA/CH/4/3	Mn ore	54.50	1.79	10.60	14.82	1.09	0.77
16	BA/CH/4/4	Mn ore	34.95	2.95	14.56	19.33	2.79	1.86
17	BA/CH/4/5	Mn ore	49.58	1.97	11.98	16.46	1.26	0.99
18	BA/CH/4/6	Mn ore	30.44	3.29	17.08	20.33	1.95	1.71
19	BA/CH 5/1	Mn ore	24.68	4.47	39.49	1.93	0.55	
20	BA/CH 5/2	Mn ore	20.92	2.91	45.32	1.13	0.43	
21	BA/CH 5/3	Mn ore	23.02	4.14	41.87	1.51	0.67	
22	BA/CH 5/4	Mn ore	37.73	6.33	30.60	0.77	0.41	
23	BA/CH 5/5	Mn ore	29.95	6.17	34.54	1.14	0.78	
24	BA/CH 5/6	Mn ore	31.33	4.77	36.73	1.36	0.38	
25	BA/CH 5/7	Mn ore	30.84	7.6	32.72	0.47	1.35	
26	BA/CH 5/8	Mn ore	34.73	5.52	32.59	1.02	0.81	
27	BA/CH 5/9	Mn ore	33	2.35	37.30	1.53	0.54	
28	BA/CH 6/1	Mn ore	35.88	3.34	33.23	1.36	0.50	
29	BA/CH 6/2	Mn ore	37.22	1.22	37.62	0.78	0.30	
30	BA/CH 6/3	Mn ore	32.34	2.74	35.31	1.53	0.72	
31	BA/CH 6/4	Mn ore	23.95	5.83	39.47	1.64	0.53	
32	BA/CH 6/5	Mn ore	16.55	4.90	46.56	0.53	0.18	
33	BA/CH 6/6	Mn ore	20.76	3.32	42.57	1.22	1.02	
34	BA/CH 6/7	Mn ore	34.28	6.32	32.52	1.41	0.34	
35	BA/CH 6/8	Mn ore	31.83	6.05	33.56	0.80	1.00	
36	BA/CH 6/9	Mn ore	14.51	12.25	38.48	0.19	0.8	
37	BA/CH 6/10	Mn ore	30.8	3.15	36.84	1.50	0.47	
38	BA/CH 6/11	Mn ore	8.62	1.47	56.31	1.16	0.63	
39	BA/BRS/1	Manganiferous quartzite	41.95	2.19	24.49	9.60	0.09	
40	BA/BRS/2	Manganiferous quartzite	58.46	1.43	25.04	0.26	0.05	
41	BA/BRS/3	Manganiferous quartzite	61.07	2.56	20.16	0.88	0.09	
42	BA/BRS/4	Manganiferous quartzite	92.12	2.29	1.87	1.23	0.11	
43	BA/BRS/5	Manganiferous quartzite	31.21	2.81	23.04	16.57	0.20	
44	BA/BRS/6	Manganiferous quartzite	77.64	1.58	11.67	0.19	0.12	
45	BA/BRS/7	Manganiferous quartzite	37.09	1.01	39.09	0.12	0.03	
46	BA/BRS/8	Manganiferous quartzite	77.70	2.79	10.92	0.09	0.17	
47	BA/BRS/9	Manganiferous quartzite	33.98	1.06	43.93	0.05	0.01	
48	BA/BRS/10	Manganiferous quartzite	72.03	3.75	14.27	0.26	0.17	
49	BA/BRS/11	Manganiferous quartzite	72.03	10.11	4.82	2.22	0.23	
50	BA/BRS/12	Manganiferous quartzite	72.3	7.31	5.76	4.40	0.4	
51	BA/BRS/13	Mn ore	38.09	20.80	10.86	8.81	0.33	
52	BA/BRS/14	Ferruginous quartzite	26.73	9.80	35.03	0.51	0.08	
53	BA/BRS/15	Mn ore	18.72	9.67	38.92	0.95	0.08	
54	BA/BRS/16	Ferruginous quartzite	28.39	12.59	26.00	6.25	0.15	
55	BA/BRS/17	Mn ore	31.91	10.20	16.38	12.28	1.49	
56	BA/BRS/18	Mn ore	34.42	7.34	26.57	0.48	4.73	
57	BA/BRS/19	Mn ore	39.01	3.86	29.81	1.30	0.55	
58	BA/BRS/20	Mn ore	21.4	2.25	42.84	1.85	0.59	
59	BA/BRS/21	Mn ore	32.04	3.07	35.06	2.19	0.54	
60	BA/BRS/22	Mn ore	8.45	3.05	30.49	20.09	2.86	
61	BA/BRS/23	Ferruginous quartzite	74.78	4.50	8.30	0.64	0.01	

Table 2: Analytical value (%) of Pit/Trench samples (PTS) from Boringpadar-Amath sector

Sl. No	Sample No.	Rock name	SiO_2	Al_2O_3	Fe (T)	Mn	P_2O_5
1	BA/T1/1	Mn Graphite bearing khondalite	34.01	11.04	28.43	0.47	1.12
2	BA/T1/2	Mn Graphite bearing khondalite	41.01	10.56	20.96	0.40	2.22
3	BA/T1/3	Mn Graphite bearing khondalite	38.45	9.32	22.66	0.36	3.19
4	BA/T1/4	Mn Graphite bearing khondalite	38.99	6.35	23.07	0.43	5.43
5	BA/T1/5	Mn Ore	27.58	10.26	6.41	24.48	1.18
6	BA/T1/6	Mn Ore	33.90	6.55	28.95	3.40	2.24
7	BA/T1/7	Mn Ore	31.00	9.09	34.07	0.48	1.39
8	BA/T1/8	Mn Ore	15.53	5.00	46.85	1.58	0.91
9	BA/T1/9	Mn Ore	36.16	6.60	21.93	11.18	1.53
10	BA/T1/10	Mn Ore	29.09	7.13	26.00	5.60	1.83
11	BA/T1/11	Mn Ore	28.18	4.69	38.19	0.29	2.29

12	BA/T2/1	Mn Ore	18.19	7.79	44.70	0.30	0.77
13	BA/T2/2	Mn Ore	30.13	7.17	36.75	0.79	0.94
14	BA/T2/3	Mn Ore	19.30	6.36	45.25	0.33	0.80
15	BA/T2/4	Mn Ore	35.83	14.11	18.73	10.21	0.86
16	BA/T2/5	Mn Ore	35.94	9.01	29.02	2.72	0.75
17	BA/T2/6	Mn Ore	29.77	11.36	33.02	0.16	0.53
18	BA/T2/7	Mn Ore	35.73	14.00	18.21	10.44	0.85
19	BA/T3/1	Mn Ore	30.77	9.04	28.98	5.01	0.95
20	BA/T3/2	Mn Ore	41.93	7.58	22.18	6.69	0.54
21	BA/T3/3	Manganiferous quartzite	52.79	25.08	2.56	0.12	0.36
22	BA/T3/4	Mn Ore	23.80	5.82	40.84	1.84	0.72
23	BA/T3/5	Mn Ore	44.71	10.10	20.99	4.21	0.62
24	BA/T4/1	Mn bearing khondalite	47.83	25.40	7.55	0.12	0.08
25	BA/T4/2	Mn bearing khondalite	36.38	22.12	20.33	1.94	0.47
26	BA/T5/1	Mn Ore	61.91	1.41	16.98	6.08	0.28
27	BA/T5/2	Mn Ore	73.02	2.47	8.93	2.19	0.77
28	BA/T5/3	Mn Ore	43.60	1.66	29.98	2.60	0.68
29	BA/T5/4	Mn Ore	38.71	1.33	35.20	1.22	0.29
30	BA/T5/5	Mn Ore	46.28	1.45	29.58	1.78	0.21
31	BA/T5/6	Mn Ore	59.95	2.67	18.55	2.67	0.31
32	BA/T5/7	Mn Ore	64.73	1.74	18.12	1.07	0.18
33	BA/T5/8	Manganiferous quartzite	73.48	3.15	10.06	2.76	0.10
34	BA/T5/9	Mn Ore	51.95	2.30	23.15	1.78	0.73
35	BA/T5/10	Mn Ore	37.87	2.12	31.57	3.78	0.92
36	BA/T5/11	Mn Ore	58.85	1.40	17.93	5.70	0.40
37	BA/T5/12	Manganiferous quartzite	52.92	1.78	23.80	4.97	0.37
38	BA/T6/1	Mn bearing khondalite	36.70	12.12	29.27	0.09	0.16
39	BA/T6/2	Mn bearing khondalite	44.09	25.14	15.25	0.10	0.18
40	BA/T6/3	Mn bearing quartzite	80.67	10.21	5.47	0.09	0.08
41	BA/T6/4	Mn bearing khondalite	47.06	25.60	11.06	0.05	0.03
42	BA/T6/5	Mn bearing quartzite	87.54	6.72	2.11	0.10	0.06
43	BA/T6/6	Mn bearing khondalite	26.66	7.14	37.94	1.97	0.76
44	BA/T7/1	Mn Ore	13.70	4.68	30.09	16.08	2.75
45	BA/T7/2	Mn Ore	19.24	11.64	19.17	18.84	1.29
46	BA/T7/3	Mn Ore	29.59	4.17	16.07	22.53	0.55
47	BA/T7/4	Mn Ore	59.89	4.55	10.01	8.20	0.90
48	BA/T7/5	Mn Ore	9.75	3.28	21.41	27.77	2.42
49	BA/T7/6	Mn Ore	22.92	11.78	17.47	17.10	1.98
50	BA/PT/1	Manganiferous quartzite	60.06	20.55	5.01	0.73	0.33

5. Conclusion

Two bands of manganese ore and four bands of manganiferous quartzite are mapped for the first time in the Boringpadar-Amath sector which are described in terms of their field distribution, ore-petrology, and geochemistry The manganese ores are made up of bluish-black to brownish-black, massive to foliated, metallic luster, nodular, and botryoidal forms whereas the manganiferous quartzite are hard, white to black, highly jointed, fractured, and brecciated respectively. The analytical results of these lithologies show encouraging values of Mn, Fe (total), SiO_2, Al_2O_3, CaO, and P_2O_5. The values of Mn and Fe (T) vary from 0.05 to 28.18 wt. % and 1.87 to 56.31 wt. % in the bedrock samples whereas the Mn value ranges from 0.05 to 27.77 wt. % and the Fe (total) value ranges from 2.11 to 46.85 wt. % in the pitting/trenching samples. The highest values of Mn are observed in the Amath area whereas the maximum values of Fe (total) are recorded from the Boringpadar area. Based on field observations, ore petrography, and geochemical data, it can be attributed that the manganese ores and manganiferous quartzite are the targeted lithologies for manganese and iron mineralization in the EGMB.

Acknowledgments

The authors express their gratitude to the Director-General, Geological Survey of India, (GSI) for permitting the publication of the paper. They are also thankful to the Deputy Director-General and Shri Priyadarshi Sahoo, Director, SU: Odisha, Bhubaneswar for providing necessary logistics support while carrying out fieldwork and laboratory studies. Sradhanjali Subhadarshini and Manorama Das are also acknowledged for their help during the fieldwork. The authors are highly indebted to the officers of the Chemical Division, State Unit: Odisha, GSI (ER), Bhubaneswar, and ER, Kolkata for providing chemical analysis and details of analytical techniques. This paper is the outcome of the Annual Field Season Programme (ME/ER/ODS/2016/014) of Geological Survey of India, State Unit: Odisha, Bhubaneswar.

References

[1] Acharya, B. C., Rao, D. S. and Sahoo, R. K. (1994) Mineralogy and genesis of Kutinga manganese deposit, South Orissa, India. J. Min. Petr. Econ. Geol., v89, pp.317-328.
[2] Anhaeusser, C. R. and Wilson, J. F. (1981) Southern Africa: the granitic-gneiss greenstone shield. In: Hunter, D. R. (Ed.), Precambrian of the Southern Hemisphere. Elsevier, Amsterdam, pp.423-499.
[3] Bhattacharya, A., Raith, M. and Hoernes, S. (1998) Geochemical Evolution of the Massif-type Anorthosite Complex at Bolangir in the Eastern Ghats Belt of India. Jour. Petrol., v.39 (6), pp.1169-1195.
[4] Chadwick, B., Ramakrishnan, M. and Viswanatha, M. N. (1981b) The stratigraphy and structure of the Chitradurga region: an illustration of cover-basement interaction in the late Archaean evolution of the Karnataka craton, southern India. Precamb. Res., v.16 (1-2), pp.31-54.
[5] Chetty, T. R. K. and Murthy, D. S. N. (1994) Collision tectonics in the late Precambrian Eastern Ghats Mobile Belt: Mesoscopic in satellite scale structural observations. Terra Nova, 6. DOI: 10.1111/j.1365-3121.1994. tb00635. x
[6] Condie, K. C. (1981) Archean Greenstone Belts. Elsevier, Amsterdam, 434p.
[7] Dasgupta, H. C., Sambasiva Rao, V. V. and Krishna, C. (1999) Geology, geochemistry and genesis of the freshwater, Precambrian manganese deposits of the Iron Ore Group from Noamundi basin, Eastern India. Indian Jour. Geol., v.71 (4), pp.247-264.
[8] Dash, C., Behera, S. N. and Patel, S. N. (2005) Delineation of potential Manganese ore bands/bodies within the Manganiferous horizon of the central sector of the Eastern Ghats Granulite Belt in Orissa covering parts of Bolangir, Kalahandi and Rayagada districts (P-II). Unpub. Rep. Geol. Surv. India, F. S.2003-05.
[9] Dash, C. and Behera, S. N. (2009) Search for potential manganese ore bands/bodies within the manganiferous horizon of the eastern part of the Eastern Ghats granulite belt in Orissa covering parts of Angul and Boudh districts, (P-I). Unpub. Rep. Geol. Surv. India, F. S.2005-06.
[10] DeWit, M., Hart, R., Stern, C. and Barton, C. M. (1980) Metallogenesis related to seawater interaction with 3.5 b. y. oceanic crust. EOS, v.61, pp.386.
[11] Dimroth, E., Imrch, L., Rocheleau, M. and Goulet, N. (1982) Evolution of the south-central of the Archean Abitibi belt, Quebec. Part I: stratigraphy and paleogeographic model. The Canadian Jour. Earth Sci., v.19, pp.1729-1758.
[12] Gandhi, A. (2010) Manganese Report, Ideas 1st Information Services Pvt. Ltd, Mumbai, India, pp.5-7.
[13] Ghosh, R., Chakraborty, D., Halder, M. and Baidya, T. K. (2015) Manganese mineralization in Archean greenstone belt, Joda-Noamundi sector, Noamundi basin, East Indian Shield. Ore Geol. Rev., v.70, pp.96-109.
[14] Goodwin, A. M. (1973) Archean iron-formation and tectonic basins of the Canadian Shield. Eco. Geol., v.68, pp.915-933.
[15] Gross, G. A. L. (1986) The metallogenetic significance of iron-formation and related stratafer rocks. Jour. Geol. Soc. India., v.28, pp.92-108.
[16] Hallberg, J. A. and Glikson, A. Y. (1981) Archean granite–greenstone terrains of W. Australia. In: Hunter, D. R. (Ed.), Precambrian of the Southern Hemisphere. Elsevier, Amsterdam, pp.33-103.
[17] Jayaram, B. N. (1956) Report on the investigation of reported occurrences of Manganese ore in the Boudh subdivision of Phulbani district, Orissa. Unpub. Rep. Geol. Surv. India, F. S.1954-55.
[18] Jena, S. K. and Devdas, V. (1994) Interim progress report on the exploration for manganese in Kutinga-Devjhola block and adjoining areas of Koraput and Rayagada districts, Orissa. Unpub. Rep. Geol. Surv. India, F. S.1992-93.
[19] Krishna Rao, J. S. R. (1963) Microscopic Examination of Manganese Ores of Srikakulam and Visakhapatnam Districts, A. P., India. Eco. Geol., v.58, pp.434-440.
[20] Kuleshov, V. (2017) The Major Epochs and Phases of Manganese Accumulation in the Earth's History. Isotope Geochem., pp.353-383. https: //doi. org/10.1016/B978-0-12-803165-0.00004-5.
[21] Machado, N. and Carnerio, M. (1992) U–Pb evidence of Late Archean tectono-thermal activity in the southern Sao Francisco Shield, Brazil. Canadian Jour. Earth Sci., v.29 (11), pp.2341–2346.
[22] Martin, H., Peucat, J. J., Sabate, P. and Cunha, J. C. (1997) Crustal evolution in the Early Archean of South America: example of the Sete Voltas Massif, Bahia State, Brazil. Precamb. Res., v.82 (1-2), pp.35-62.
[23] Mishra, B. (2015) Precambrian metallic mineralization in India. Geol. Soc. London, Mem., v.43, pp.327-337, http: //dx. doi. org/10.1144/M43.22.
[24] Mishra, P., Mishra, S. K., Singh, P. P. and Mohapatra, B. K. (2016) Reworked manganese ore bodies in Bonai-Keonjhar belt, Singhbhum Craton, India: Petrology and genetic study. Ore Geol. Rev., v.78, pp.361-370.
[25] Mohapatra, M. N. and Bagchi, T. C. (1961) Mineralogy and paragenesis of the lateritic manganese ores around Joda, Keonjhar district, Orissa. Quart. Jour. Geol. Min. Metall. Soc. India, v.23 (1), pp.5-14.
[26] Mohapatra, B. K., Mishra, P. P., Singh, P. P. and Rajeev. (2009) Manganese ore deposits in Koira-Noamundi province of Iron Ore Group, north Orissa,

India: in the light of geochemical signature. Chemie. der Erde., v.69, pp.377-394.

[27] Murty, V. N. and Ghosh, B. K. (1971) Manganese ore deposit of the Bonai-Keonjhar belt, Orissa. Indian Min., v.25 (3), pp.201-210.

[28] Myers, J. S. and Kröner, A. (1994) Archean Tectonics: Continental Deformation. In: Hancock, Paul L. (Ed.), Pergamon Press, Oxford, pp.355-369.

[29] Narayanswami, S. (1975) Proposal for charnockite-khondalite system in the Archean shield of Peninsular India. Geol. Sur. India, Mis. Publ., v.23 (1), pp.1-16.

[30] Rao, G. V. (1969) The Geology and Manganese Ore Deposits of Parts of Vizakhapatnam (Visakhampatnam) Manganese Belt, Srikakulam District, A. P., India. Bull. Geol. Surv. India, v.35 (A), pp.129.

[31] Ramakrishnan, M., Viswanatha, M. N. and Swami Nath, J. (1976) Basement-cover relationships of Peninsular gneiss with high grade schists and greenstone belts of southern Karnataka. Jour. Geol. Soc. India, v.17, 97-111.

[32] Ramakrishna, M., Nanda, J. K. and Augustine, P. F. (1998) Geological evolution of the Proterozoic Eastern Ghats mobile belt. *Proc.* Workshop on Eastern Ghats Mobile Belt, Geol. Surv. India Spec. Pub., v.44, pp.84-92.

[33] Ray, B. C. (1954) The manganese ore deposit of Orissa. Indian Miner., v.8, pp.1-4.

[34] Roy, S. (2000) Late Archean initiation of manganese metallogenesis: its significance and environmental controls. Ore Geol. Rev., v.17, pp.179-198.

[35] Roy, S. (2006) Sedimentary manganese metallogenesis in response to the evolution of the Earth system. Earth Sci. Rev., v.77, pp.273-305.

[36] Saha, A. K. (1994) Crustal evolution of Singhbhum-North Orissa, eastern India. Mem. Geol. Soc. India, v.27, 341p.

[37] Sen, B. (1951) Manganese ores of Keonjhar. Tra. Min. Geol. Metall. Soc. India, v.25 (2), pp.51-60.

[38] Siddiquie, F. N. and Raza, M. (2008) Geochemical Environment & Metallogenesis of Manganese Ores of Srikakulam-Visakhapatnam Manganese Belt (A. P.). Proceedings of the 24th Convention and National Seminar on Sedimentary Basin of India and Their Economic Resources, Aligarh, pp.86-87.

[39] Siddiquie F. N. and Shaif Md. (2015) Geochemistry of Major Oxides in Host Rocks in Vizianagarm Manganese Ores Belt (A. P.), India. Inter. Jour. Geosci., v.6, pp.350-372. http: //dx. doi. org/10.4236/ijg.2015.64028.

[40] Siddiquie, F. N., Alam, J. and Shaif, M. (2015) Occurrence of Manganese Ore Deposits and Their Mineralogy in Vizianagaram-Visakhapatnam Manganese Ores Belt (Andhra Pradesh) India. Inter. Jour. Geosci., v.6, pp.549-566. http://dx. doi. org/10.4236/ijg.2015.66043.

[41] Singh, V. and Biswas, A. (2017) Physicochemical processing of low grade ferruginous manganese ores. Inter. Jour. Miner. Proces., v.158, pp.35-44.

[42] Spencer, E. (1948) Manganese ore deposits of Jamda-Koira valley. Tra. Min. Geol. Metall. Soc. India, v.44 (2), pp.61-77.

[43] Straczek, J. A. and Krishanswamy, S. (1956) Manganese Ore Deposits of the Vizagapatnam (Visakhapatnam) District, A. P., India. Proceedings of the 20th International Geological Congress, Mexico, D. F., Symposium on Manganese, v.4, pp.141-157.

[44] Teixeira, W., Carneiro, M. A., Noce, C. M., Machado, N., Sato, K. and Taylor, P. N. (1996) Pb, Sr and Nd isotope constrains on the Archean evolution of gneissic–granitoid complexes in the southern Sao Francisco craton, Brazil. Precamb. Res., v.78 (1-3), pp.151–164.

[45] Yadav, P. K., Subhadarshini, S., Das, M., Singh, A., Shyam, R. and Gokul, G. S., 2017: Final report on the reconnoitory survey for manganese ore in Boringpadar-Amath block in the Eastern Ghats Granulite belt, Kalahandi district, Odisha (G4). Unpub. Rep. Geol. Surv. India, F. S.2016-17.