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Metallogeny of Iron with Special Reference to Odisha

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Abstract: Iron ore, the mother of all industries, is the oldest recorded metallic ore deposits of the world dating back to 3.8 Ga in Isua Greenstone belt of Greenland occurring within Banded Iron Formation. Although this deposit is sub-economic in tonnage and grade, it provides a very important clue to understand the Palaeoarchaean crustal development in the history of the Earth. Iron metallogeny like all other metals follow a secular trend, it is episodic in nature and spatially distributed in suitable distinct geotectonic segments and thus can be correlated with reconstructed Supercontinents. It is also governed by atmosphere-hydrosphere evolution, climate change episodes, Supercontinent cycles and the more empirical Wilson cycle. Three major metallogenic epochs coinciding with prevailing redox state of elemental Fe within the major oxygenation events have resulted into three types of BIFs: the Algoma type, the Superior type and the Rapitan type. The Archaean supracrustals containing BIFs in north Odisha-Jharkhand region, commonly referred as Iron Ore Group basins, represented by Badampahar-Gorumahisani belt, Tokma –Daiatari belt and Bonai-Keonjhar belt skirt the Singhbhum Granite massif in the east, south and west respectively. The BIFs in these basins possibly correlatable, formed during 3.51 Ga to 3.2 Ga over a span of 300 Ma. These are classically known as Proterooic Superior type but the late age data put them well within Palaeo-to MesoArchaean era neither show typical Algoma characteristics nor Superior type characters. Another sub-basin, represented by Gandhamardan iron ore hill is well correlatable with Bonai-Keonjhar belt, separated by later granitic magmatism. A minor occurrence of BIF at Hirapur in Nabarangpur district falls within the eastern extension of Bastar craton and the ores are sub-economic with minor difference in characteristics.

Key words: Palaeoarchaean, Dacite, BIF, Supra crustals, Komatiite

Introduction

Our understanding of the predominant source rock for Iron Ore, the Banded Iron Formations (BIFs) provide clues to visualize its genesis to a time when the atmosphere was free from oxygen, abundant in Fe2+ and the episodic availability of free oxygen as well as Fe2+, exemplified by the oldest BIF of 3.8 Ga age, Algoma type in Isua Belt, Greenland, reappearance after 750 million years in the next episode during 2.7 Ga to 1.7 Ga, Superior Type and again after a gap of about 1000 million years in 580-523 Ma as in (Canada) ,Western China and elsewhere, the Rapitan type. The Iron metallogeny is typical on its own as it provides sufficient evidence to look into the prevailing crustal development in the history of earth. The IOG basins of Odisha stand next to Isua Supracrustals in age which follow the iron metallogeny trend as in other Achaean terranes in the world, is the subject of discussion in this paper.

Types of Iron Ore Deposits

Classically Iron ore deposits are named after the host rock association. Accordingly, five groups of iron ore deposits are identified: 1. Orthomagmatic deposits, 2. Sedimentary deposits, 3. hydrothermal deposits, 4. Lateritic deposits and 5.Channel iron deposits. The modern trend is naming metal deposits by certain types as every deposit is inherently characterized by the terrane it is associated with, tectonic regime, host rock-ore associations and age. In case of Iron ore deposits; it is Algoma type, Superior type, Kiruna type, Minette type, Clinton type, etc. Each classification has its own merit and both are followed.

Orthomagmatic iron ore deposits-The world's large iron ore clusters of this type include the Panzhihua-Xichang in Sichuan Province of China, Bushveld Complex, South Africa and Kajikanar in Ural of Russia. The proven iron ore reserves of magmatic iron deposits occupy 7%–10% of the world's iron ore reserves. In Layered intrusions**,** typical titanium $\pm$ V bearing magnetite occur in Mayurbhanj Gabbro bodies of Singhbhum Craton in Jharkhand, Mayurbhanj district, Odisha. Magnetite deposits in Hassan districts of Karnataka are associated with gabbroid and ultrabasic rocks. These deposits contain 55 to 61%of iron. In amphibolites and hornblende schists of Hassan district, the typical titano-magnetite concentrate contains 57% Fe, 12% Ti and 0.5% V2O5.

Sedimentary Iron Ore Deposits – Iron ore deposits of huge dimension and resources are found world over in Banded Iron Formation (BIF**).** These are Precambrian chemical sedimentary rocks characterized by alternating Fe-rich and Si-rich bands and are the principal sources of iron for the global steel industries. They are reported from various parts of the world ranging in age from Eoarchaean to late Paleoproterozoic and late Neoproterozoic with the peak abundance around 2.5 Ga (Goodwin, 1973; James, 1983; Isley and Abbott, 1999; Huston and Logan, 2004; Klein, 2005; Bekker et al., 2010). These two types of BIFs that were identified as (a) Algoma Type –c3800-3000 Ma (Millions years ago),(b) Superior Type- c2500-2000 Ma (Gross 1965) and third as Rapitan Type). c1000-500 Ma (Trendall 1973; Dorr 1973). In spite of extensive study globally, the origin of BIF and enrichment process of BIF into iron ores remain partly unanswered (Morey, 1999; Taylor et al., 2001)

Minette type and Clinton type-These are basically oolitic iron ore deposits which were first to be commercially exploited in Europe and later in USA during Industrial in Revolution. Historically, a great deal of iron was mined from this type of chemically precipitated marine deposits of iron ore.

The European and North American oolitic iron deposits are commonly called Minette type and Clinton type deposit respectively. The ores contain pin head-sized ooliths. The ooliths are composed of siderite, a siliceous iron mineral known as chamosite and goethite in European deposits where as in in North America these oolitic iron deposits contain ooliths of haematite, siderite, and chamosite (small, rounded, accretionary masses formed by repeated deposition of thin layers of an iron mineral).

These oolitic iron deposits have been largely supplanted in importance by BIFs, but they once formed the backbone of the iron and steel industries in Western Europe and North America. These deposits were formed in shallow, near-shore marine environments. Goethite dehydrates slowly and spontaneously oxidised to change to haematite, that is probably the major difference between the two deposit types is age.

The European Minette type deposits are most extensively developed in England, the Lorraine area of France, Belgium, and Luxembourg. Clinton type deposits are found in the Appalachians from Newfoundland to Alabama, and they are several hundred million years older than the Clinton type deposits.

Kiruna-type -Iron oxide-apatite (IOA) deposits in the Kiruna district, Sweden Kiruna-type are an important source of Iron ore. These are magmatic iron oxide precipitation within larger volcanic super structures and in some deposits hydrothermal fluid involvement is reported. Local hydrothermal activity resulted from low temperature fluid circulation in the shallower parts of this system. Other localities of Kiruna type are in Iran, and in Chilean Iron Belt of Cretaceous age. Total resource of 602 million tonnes with 48.5% iron belongs to Kiruna type deposits.

Hydrothermal /Fault and fissure filling deposits- Fault and fissure filling deposits of haematite: Veldurty and Ramalla Kota in Kurnool district of Andhra Pradesh. Haematite is often slightly specular and jaspery in character.

Iron deposits in granulites- Weakly banded magnetite reported from Tamil Nadu, Andhra Pradesh and Karnataka have stray occurrences of iron deposits as magnetite quartzite.

Bog iron deposits -Sedimentary iron ore deposits of siderite and limonitic composition (Bog iron deposit)occur in Lower Gondwanas as in Raniganj Formation of Jharkhand and West Bengal and many other localities world overwhich are not economic.

Channel Iron Deposits-The Channel Iron Deposits (CIDs) are unique to Western Australia. These were formed in ancient meandering river channels as bedded iron deposits, eroded by weathering, iron particles were concentrated in these river channels as Iron deposits whose thickness varies from 5m and 40m forming mesa type topography and occur concealed under the cover of more recent sediments. Examples of such deposits are at Pannwonica,W.Australia and elsewhere.

Metallogeny

Metallogeny of Each Type of BIF vis-a-vis Crustal Evolution depicts the evolution of the atmosphere-hydrosphere, tectonic set-up, terrane evolution and metal formation events, and should be used as the first and foremost tool for ore deposit search in Greenfield exploration.

Algoma Type: The 3800Ma Isua greenstone belt and associated Itsaq (previously called Amitsoq) gneisses of western Greenland contain a major chert–magnetite banded iron-formation (Algoma Type, Gross 1965) in the mafic and felsic meta-volcanics and meta-sediments association. The Algoma type BIF were formed over an age range of 3.8 Ga in to 3 Ga and reappeared again in the Phanerozoics between 1.0 Ga -0 .5 Ga. The earliest BIF is that of Isua Belt in Greenland with age range of 3.9 Ga -3.8Ga (Mojzis,et al, 1996).

The BIF consists necessarily of repeated bands of alternate silica and iron minerals, very thin and discontinuous in nature, lack oolitic and granular texture and invariably associated with volcanic and greywacke, replaced by volcanic sequences. They are considered as sedimentary deposits but display diagenetic and metamorphic imprints which significantly altered the original sediment in terms of composition and mineralogy. The BIF seen today contains haematite, magnetite, chert and stilplomelane [$K(Fe^{2}Mg,Fe^{3})_8(Si,Al)_{12}(O,OH)_{27}$] which are actually secondary minerals. Primary minerals as proposed by Koehler et al(1996) are ferric hydroxide[$Fe(OH)_{13}$,Siderite, partially secondary Greenalite [$(Fe)_3\,Si_2O_5(OH)_4$] and amorphous silica (Klein,2005).

Presence of minor occurrences of copper–iron sulphides, volcanogenic massive sulphide style (VHMS) mineralization in the sedimentary succession points to sea floor processes present even that time. The lithologic-association also suggests a submarine-exhalative origin. The supracrustals associated Algoma type iron occurrence during low oxygen levels in the atmosphere and the abundance of ferrous iron sourced from exhalative activity at the mid-ocean ridges was debatable but generally agreed that the atmosphere contained very little free molecular oxygen contributed by inorganic photo-dissociation of water vapor. The iron Fe2+ in soluble state originated through submarine hydrothermal vents and subsequently transformed to Fe3+ in the upper water column by abiological or biological oxidation. The Fe3+ then rapidly hydrolyzed to ferric hydroxide and settled to the sea floor where further transformation took place. James (1954, 1966) categorized early BIFs as carbonate rich, oxide rich and silica rich varieties. The Carbonate rich variety is composed of alternate layers of chert and inorganic carbonate rich mineral layers (ankerite and siderite); the oxide rich variety with high amount of haematite and magnetite with traces of siderite and iron silicates; the third category is dominantly silica rich (chert) with alternate bandings made of stilplomelane, minnesotaite, greenalite and carbonates.

Superior type-The vast BIFs around Lake Superior, USA-Canada and are called Lake Superior-type BIF, are both spatially and quantitatively most important type. These are found in sequences of sedimentary rocks (clastics sediments), deposited in the shallow waters of continental shelves or in ancient sedimentary basins, during marine transgression coinciding with continental dispersal. The BIFs occur coeval in large pericratonic basins (Khlodov, 2008). These were formed in a narrow time window of 2.7 Ga to 1.7 Ga which suggests that the chemistry of the oceans and atmosphere at the time of formation differed greatly from that of the present day. The post Huronian Glacial age saw abundant O2 in the atmosphere and gradual reduction of Co2 with precipitation of carbonates and carbon rich sediments helping BIF formation from 2.7 Ga to 1700 Ma, peak of oxygen abundance being the sharp rise in pO2 at 2200 Ma known as the " Oxy-atmoinversion"(Rye and Holland, 1998) (Fig. 1). This event is related to the evolution of primitive life and the development of Cyanobacteria capable of photosynthetically producing oxygen. It is also the period which heralded in development of Superior type BIFs.

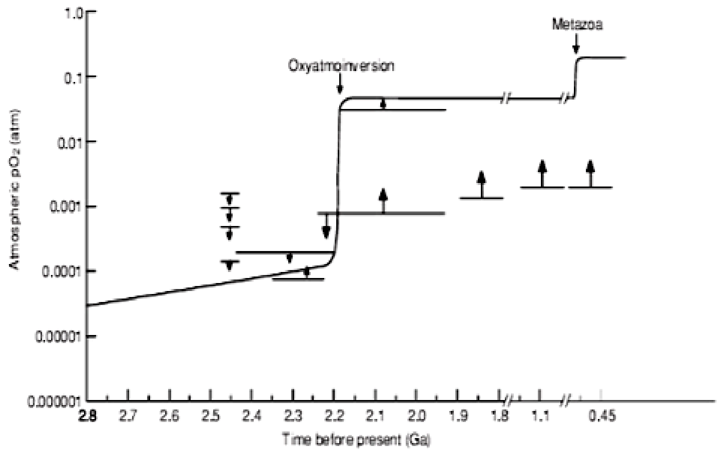


Fig.1 Graph showing Time before present in Ga Vs Atmospheric pO2

The distinguishing features of Superior type that Individual sediment layers in the BIF are as thin as 0.5 millimetre) or as thick as 2.5 centimetres (1 inch) with alternation of a siliceous and an iron mineral band. Individual thin bands have enormous continuity. A.F. Trendall (1980s) noted that individual thin layers could be traced for more than 100 kilometres in Hamersley Basin, Western Australia. This suggests that evaporation played a major role in precipitating both the iron minerals and the silica seasonally under suitable pH-Eh. Litho-assemblage closely associated with superior type BIF are quartzite, black carbonaceous shale and stromatolitic limestone, dolomite, massive chert, chert breccia and argillites and conglomerate (Platformal sequence), volcanic rocks are not always directly associated but always present in the stratigraphic column as in IOG basins in Odisha. The Superior type ores contain mostly oxidised minerals, independent of other metal associations, dominated by haematite, magnetite, siderite, ankerite and greenalite.

Temporal and spatial distribution of Superior type BIF : Large deposits of iron ore hosted by Superior type BIF in the world are in Superior Province,USA-Canada, Hamersley Range in Western Australia (~2.5 Ga), Transvaal Supergroup (Kuruman and Griguatown iron-formations (~2.5-2.3 Ga), Sishen-Beeshoek and Thabazimbi districts, South Africa, Labradore Trough, Quebec-Newfoundland, Canada (~2.1 Ga), Gunflint and Biwabik, North America (2.2–2.0 Ga),Quadrilatero Ferrifero, Minas Gerais (~2.3 Ga), Carajás Formation (2.6 Ga) and Urucum Region (0.8 Ga), Brazil, Krivoy Rog Supergroup, Ukrainian Shield (~2.2 Ga); Singhbhum-Bonai-Keonjhar-Mayurbhanj region, Odisha-Jharkhand (3.5 to 3.2 Ga) and Dalli Rajhara districts, Chhattisgarh, India (~3.0 Ga); Imataca Complex, Venezuela (~3.4 Ga);Sebakwian Group in Zimbabwe (3.2 Ga-3.6 Ga), Tamka-Daitari belt of 3.5Ga, Vani Vilas Formation in Dharwar Supergroup (2.6 Ga-2.8 Ga), Transval Supergroup, S.Africa (2.7-2.5 Ga).Global Distribution of big deposits of iron of Lake Superior Type is shown in Fig.2.

Rapitan type: The third category of BIF, after Trendall 1973; Dorr 1973 reported first in the Rapitan Group, Canada is interpreted to have been formed with the melting of ice after the Snow Ball Earth of Cryogenian Global Ice age (Hoffman and Scherg,2000). The BIF associated essentially with continental sequence with marine incursions at Jacadigo Group, Brazil and Bolivia; in the Windermere Supergroup ,Alaska are of Neoproterozoic age (755 – 730 Ma.) and its formation coincides with the interglacial period of a major transgressive event.

Inferred tectonic setting of deposition was in narrow continental rift basins during early stage of cratonic rift under fluvio-glacial conditions. As it occurs as lenses and inter-bedded massive haematite and red jasper with restricted

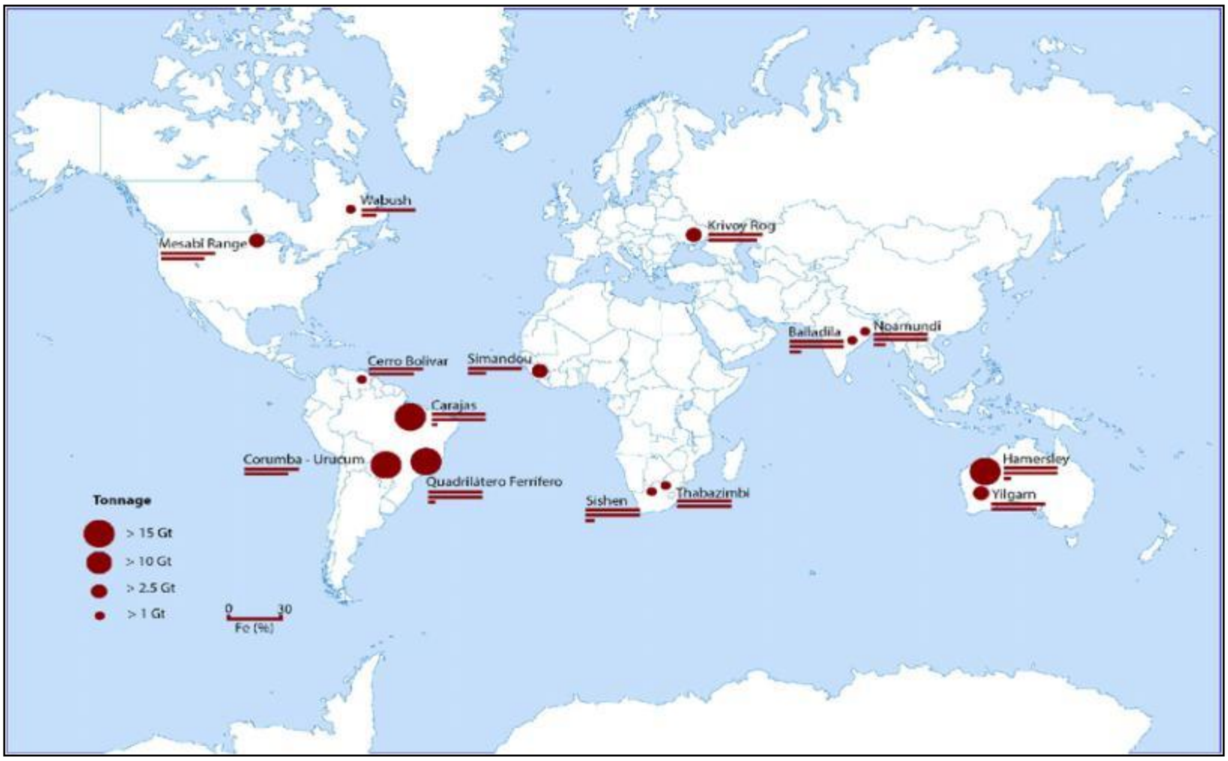


Fig.2 Global Distribution of big deposits of iron of Lake Superior Type (source- Google map)

extension and thickness, looks like Algoma type**.** The Youngest BIF (Rapitan Type?),in Western China, has been conclusively dated as 527 Ma is claimed to be the youngest BIF, formed in a back-arc rift basin-Algoma type setting where hydrothermally sourced iron drove the deposition of a BIF-like protolith akin to Rapitan type. BIF bands are reported in Central African Cu belt in the Roan Formation of Katanga Province in DRC, Congo in Kolweji area which could be related to Rapitan occurrence of Neoproterozoic age in post- glacial volcanoclastic sedimentary sequence.

A large part of Peninsular India exposes Archaean cratonic blocks surrounded by Proterozoic mobile (metamorphic /fold) belts. The granite-greenstone terranes of the cratons preserved as supracrustal sequences, many of which have Archaean – Palaeoproterozoic BIFs. These chemogenic sedimentary formations with 15-20% Fe have been eventually enriched to ~ 60% Fe in Tertiary or younger periods by supergene / hydrothermal geological processes leading to some of the large hematitic (locally magnetitic) iron ore deposits. The sedimentary BIF hosted Iron Ore deposits, considered as Superior type, have been spatially distributed in Singhbhum Craton in IOG basins in Odisha-Jharkhand region, Bastar Craton in Chhatishgarh as at Bailadila and Deli-Rajhara etc areas and in the Eastern Dharwar Craton, as in Shimoga, Bellary,Bababudan and Goa region.

Iron Ore Metallogeny in Odisha

As per UNFC system, total resources of haematite as on 1.4.2010 are estimated at 17,882 million tonnes of which 8,093 million tonnes (45%) are under 'reserves' category and the balance 9,789 million tonnes (55%) are under 'remaining resources' category. By grades, lumps constitute about 56% followed by fines (21%), lumps with fines (13%) and the remaining 10% are black iron ore, unclassified, not-known and other grades. Major resources of haematite are located in Odisha – 5930 million tonnes (33%) (IBM MYB 2014). . The state has a total iron ore reserve of 3360 million tonne of all grades varying from 55 to 66% Fe. The iron ore deposits in the state of Odisha occur in five distinct geographic regions, namely-1. Bonai- Keonjhar Belt (BKB) in Jamda--Koira Basin, 2. Gandhamardan Hill, 3. Tamka- Daitari belt (TDB), 4. Badampahar-Gorumahisani belt (BGB) and 5. Hirapur occurrence in Bailadila Group of Bastar Craton, but lions share is contributed by BKB. The parent rocks of the iron ore deposits are BIF, represented mainly by Banded Haematite Jasper (BHJ) or Banded Haematite Quartzite (BHQ) and ferruginous shales. The iron bands are also represented by magnetite, martite, goethite and magnetite-haematite. Besides BIFs, orthomagmatic gabbro hosted magnetite with or without Vanadium occur in Mayurbhanj district. The supracrustals containing BIF hosted Iron Ore deposits in the Singhbhum Craton (SC) are dealt in detail.

The Palaeo to Mesoarchaean supracrustal sequences, Iron Ore Group (IOG)-~3.5 Ga) with well developed BIFs hosted large deposits of Iron ore has a share of 38% of the Indian reserve. The IOG basins represented by green stone belts occur encircling the Singhbhum nucleus as BGB in the east, TBM in the south and BKB in the west.

Besides, smaller sub-basinal outcrops of BIF occur lying over Keonjhar Granite (Singhbhum Granite) at Gandhamardan hill, Keonjhar district, not far from the BKB.

The Singhbhum granite encloses synformal keels of BIF –bearing mafic volcanics dominated greenstone belts, the IOG. All the isolated BIF-bearing supracrustal sequences of the SC belong to a single stratigraphic unit as considered by Jones, 1934; Dunn, 1940; Dunn and Dey, 1942; Sarkar and Saha, 1962, 1977; Acharya, 1993; Sengupta et al., 1997. Originally designated as the 'Iron Ore Stage' by earlier workers, Sarkar and Saha (1962) redesignated all the BIF-bearing supracrustals of the SC as belonging to the 'Iron Ore Group" by Dunn and De ,(1942) and Sarkar and Saha (1962) opined that the Singhbhum granite is intrusive into the IOG. However, subsequently Saha et al. (1988) considered tha only part of the Singhbhum granite (SBG-B) is intrusive into the IOG and the older component (SBG-A) along with the OMG and OMTG suites formed the basement. Several other authors considered the Singhbhum granitic complex as the basement for the IOG supracrustals (Iyengar and Anand Alwar, 1965; Banerji, 1974; Mukhopadhyay, 1976; Banerjee, 1982b). Iyengar and Anand Alwar (1965), Iyengar and Banerjee (1964), Banerjee (1974), Iyengar and Murthy (1982) and Chakraborty and Majumdar (1986).

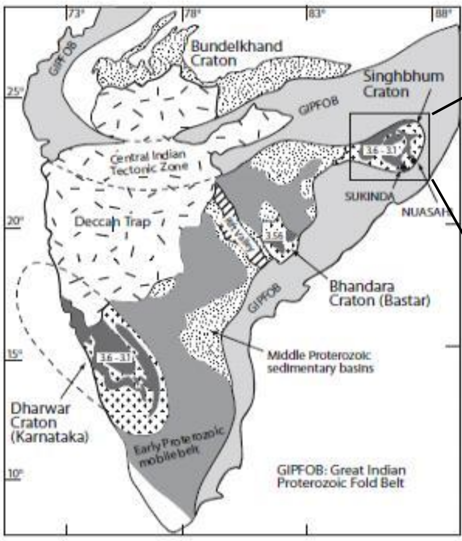


Fig.3 Generalized geology of the Indian shield showing four ancient cratons(modified after Mondal et al.2007a:after Radhakrishna and Naqvi,1986; Leelalanandam et al.2006)

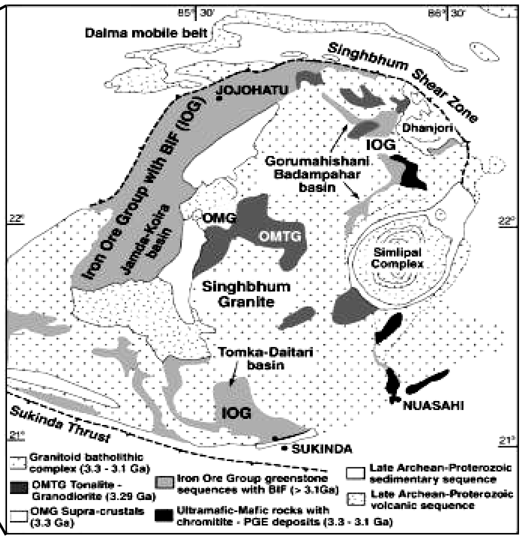


Fig.4 Expanded Portion of the Singhbhum Craton showing IOG (Iron Ore Group) Basins.

The BIF-bearing supracrustal sequences belong to two stratigraphic units, the older one typified by the Gorumahisani/Gorumahisani-Badampahar Group and the younger one typified by the Bonai – Keonjhar sequence (Noamundi Group of Banerji, 1974). Iyengar and Banerjee (1964) correlated the Gorumahisani – Badampahar sequence with the Tamka – Daitari sequence. Prasad Rao et al., (1964) and Acharya, (1976, 1984), considered the BIF-bearing supracrustal sequences belong to at least three stratigraphic units, in order of youngling, these are: Gorumahisani, Daitari – Tamka and Bonai – Keonjhar sequences.

In general, rock types recorded in the various BIF-bearing meta supracrustal sequences are siliciclastic sediments, conglomerates, quartzites, quartz-schists, meta-argillites, ferruginous mica-schists, talc-tremolite, actinolite-chlorite and hornblende schists, amphibolites, ferruginous shales and phyllites, banded haematite/magnetite quartzites (BHQ/BMQ), banded haematite jasper (BHJ), banded chert, mafic/ultramafic rocks and volcanics (both mafic and felsic) etc. Mineable iron with or without manganese ore deposits characterize all the three IOG basins. However, there exists a subtle difference
in the order, nature and package of supracrustal assemblages in the preserved isolated basins. Iyengar and Murthy (1982) proposed the name 'Iron-Ore Supergroup' to include two sequences of BIF-bearing horizons, viz. older Badampahar Group (Gorumahisani Group of Banerji, 1974) and younger Koira Group (includes BIF-bearing supracrustals of Bonai – Keonjhar area which is correlatable with the Noamundi Group of Banerji, 1974). Lithologically dissimilarity among the three belts that the TDB shows bimodal volcanism free from Mn ore in the succession, the BGB contain Au incidences with a small deposit at Kundarkocha in Jharkhand, free from Mn ore but prominent ultramafic-mafic volcanic rocks with komatiites. The IOG basin, BKB is known both for iron and Mn deposits. Graphite occurrence in fault controlled sheared zones in Damurda area show graphite association in fractured cherts (Guru, Sar and Hussain, 2011).

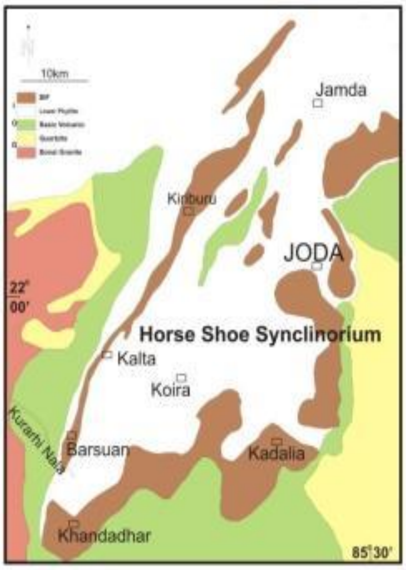
Bonai-Keonjhar belt

The BKB extends from Bonai in the south west through northwest part of Keonjhar district,well into the borders of Jharkhand in the north, approximately over a length of 50km and with of 22 km.at the central part, the IOG rocks forms an important mining district in the country famous for abundant source of iron ore and manganese(Fig.5a and 5b). It has two prominent arms, western arm with higher hill ridges of about 700m above MSL and relatively steep. The eastern arm, dissected at many places, forming highland plateau topography with synclinal ridges and anticlinal valleys. It is disposed as a "Horse Shoe shaped" shallow plunging Syncline with a NNE-ly plunging syncline with its closure facing south, is well defined by BIF high hill ranges. Outside the closure the relatively low lying areas are underlain by volcanic and tuffaceous ferruginous or manganiferous shale/.the horseshoe syncline is overturned towards east (Jones,1934), cross folded along E-W axis (Sarkar and Saha,1962,1977; Chatterjee and Mukherjee,1981; Saha,1994; Mukhopadhyay,2001; Mukherjee etal,2004). Acharya (1993) and Sengupta et al (1997), however suggested that the BIF which is the key horizon in tracing out the horseshoe structure, occurs as a gently folded sheet rather than as an overturned syncline. Ghosh and Mukhopadhyay, 2007 based on detailed structural analysis in the eastern arm and hinge one of the horseshoe syncline opined that the horse shoe syncline is a syncline and anticline pair which was later cross folded along an E-W axis. The dissected eastern arm shows dominantly a sub-horiontal orientation of form surfaces of folded BIF units coupled with symmetric folds and high bedding cleavage intersection angle. They noted a large anticlinal hinge zone between Noamundi-Bamibari and Joda-Malda. Its corresponding syncline lies to its west, both constituting the synclinorium. Mahakul & Bhutia,2015, carried out detailed regional studies and observed there phases of deformation, D1 related tight F1 assymmetric folds, a coaxial D2 related F2 folds having overturned inclined synclines and anticlines with compressional detachments, stacking due to D1 and cross folding along NW-SE typify the structure and resultant topography.

The volcano-sedimentary sequence in BKB commences with arenites, amygdular meta-basalt, manganiferous/ferruginous argillites followed by carbonates and chemogenic iron, silica alternate precipitation. It is a typical platformal succession amply evidenced in the field in different sections, like Batarani-Nomura-section. The deposition has taken place in Passive margin tectonic setting in shallow marine shelf condition. The chemogenic precipitates represented by a major BIF horizon (i.e., BHJ, BHQ and few BMQ) is the protolith for all the major iron ore deposits of the area.

Stratigraphy

Based on detailed structural analysis Murthy and Ghosh, 1972 in Sarkunda valley area proposed a stratigraphic succession under Iron Ore Group as Lower Shale Formation overlain by BIF and Upper Shale Formation which rests conformably above basic lavas and overlain unconformably by Kolhan Group sediments in conformity with the opinion of Misra, 1961, Sarkar and Saha (1962). Murthy & Acharya (1975) coined the term 'Koira Group' to designate the low grade metamorphosed volcano-sedimentary sequence of the Bonai-Kendujhar Belt.



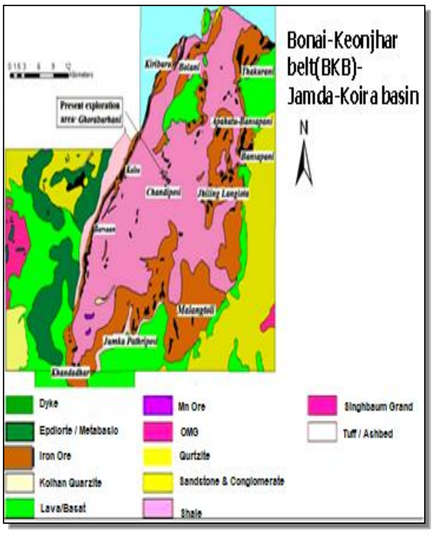


Fig.5 Fig 5a

Fig.5. Geological Map of (BKB) Bonai-Keonjhar Belt (after Jones, 1934)

Fig 5a Geological map of BKB (modified after Mahakul J.P and Bhutia S.P.,2015)

They suggested that the Singbhum Granite and Bonai Granite along with its enclaves of metamorphosed sediments constitute the basement for the Koira Group. For the first time they suggested a Mixed Facies Formation overlying the upper Shale Formation. Subsequent work of GSI (Mohanty et.al, 2000 & Jena et.al, 1999, Maharana, 2001, Parida & Maharana, 2002) brought out iron ore association with the Upper Shale Formation. Mahakul& Bhutia, 2015, after carrying out detailed structural analysis reinterpreted the regional stratigraphy as follows:

Newer Dolerite
Kolhan Sandstone with Polymict conglomerate at the base

-------------------Uncomformity-------------------
Singhbhum Granite (SBG-B of Saha,1994)
Upper Phyllitic Sequence.
BIF (BHJ, BHQ and minor BMQ).
Lower Phyllite Sequence: Ferruginous Phyllite, Impure Arenite, Manganiferous Phyllite , Chert and dolomite.
Basic Volcanic (Bonai range Volcanic, Brecciated chert, Dolomite,Lotapani volcanic, Jagannathpur Volcanic & Nuakot volcanic)
Quartzite with Quartz pebble conglomerate
---------------Uncomformity-----------------------
Singhbhum and Bonai Granite eq to SBG-A of of Saha, 1994
Singhbhum Granite with enclaves of OMG and OMTG

Iron Ore Deposit and Ore Types

Iron ore bodies up to 3 km long along strike and several hubdred meters wide (depending on dip of the strata), occur at various localities all along the strike of the main BIF unit of the IOG in Koira Synclinorium. The deposist are strata bound and located mainly at the lower part of the sequence. Prominent Iron Ore deposits under mining are Kiriburu, Balani, Meghataburu-Jharkhand & Tensa-Barsuan,Kalta on the western arm on the top of steep mountain range comprised of iron formation at elevations of about 900 m above mean sea level(msl). Eastern side has big deposits at Joda, Nuamundi Thakurani, Jhiling pahad, Khandband and Malangtoli, etc situated at relatively lower height forming plateus with average elevation of 700m above msl but gaining gradual height to the SW. Some of the iron ore deposits located in the valley portion are at Kasia, Gorhaburani-Sagasahi, Gandhalpada, Rengalbera, Kalamong, Pureibahal-Chandiposhi, Jumka-Pathiriposhi, etc. with elevation of 600m to 500m above mslThe iron ore deposits at Kiriburu,Meghataburu are located on the top of steep mountain range comprised of iron formation. The Noamundi and Joda mines on the otherhand are located on the eastern arm.Iron ore occurrences in the area can be broadly classified into two types: (1) Supergene enrichment from BIF forming important ore bodies at higher elevations of 700-900 m above msl , (II) Smaller isolated bodies occurring in lower elevations within the valley portion invariably associated with the manganese mineralization beneath. However, there is a marked absence of major iron ore bodies in the hinge part of the synclinorium at Khandadhar in contrast to that of Malangtoli.

The Iron ores confined to the higher elevations hosted by the main BIF occurring as - 1) Lateritic
2) Soft Laminated Ore (SLO) 3) Hard Laminated Ore (HLO) 4) Massive and 5) Powdery or biscuity types in a sequential manner from top to bottom.

Lateritic Ore

The lateritic type owes its origin as an alteration product of Iron ore/BIF as well as banded ferruginous shale. And occur mainly at hill tops. Lateral variation from lateritic to SLO and HLO is often found. This variety contains less than 45%, but is mined because of admixture of SLO.

Tamka-Daitari Belt

The Palaeo to Mesoarchaean supracrustals in the western IOG, Tamka-Daitari Iron belt(Fig.6) considered as the oldest BIF hosted Greenstone Sequence in India of 3.51 Ga (Jaydeep Mukhopadhyay,et al,2008), should be of a same chronological status as that of Isua belt, Greenland or elsewhere.

Fig.7.- A. Photograph of pillowed basalt from the lower part of IOG succession; B. Photomicrograph of the basalt under crossed polarized light; C. Photomicrograph of the dacitic lava under transmitted light(crossed polar) of the dacilitic lava ; D.SEN-EDS showing alternate Fe- and cherty mesobands in BIF.

The stratigraphic succession of the southern IOG is well exposed along the Tamka-Daitari Range (Prasad Rao et al.,1964; Chakraborty et al. 1980; Acharya 2002) and belongs to the southern limb of a large E-W trending, westerly plunging anticlinal structure. Daitari along with Sindurmundi hills makes the southern limb of the anticline while the Baghiathali ridge makes the northern limb of the anticline. Both the limbs strike almost E-W and dips southerly at $30^{0.}$ The succession,which consists from the base upward of massiveand pillowed basalts with a few thin (2–5 m thick) gray to green chert interbeds, felsic to intermediate volcanic and volcaniclastic rocks (tuffs), bedded chert, and BIF (fig. 2), is weakly deformed and, for the most part, has undergone only greenschist-facies metamorphism. Localized zone of amphibolite-grade metamorphism appear to be related to the proximity of the intrusive Singhbhum granite (Saha 1994), and intense structural deformation is restricted to some shear zones. The result is that primary depositional/diagenetic features are chert, which, in turn, is overlain by a thick pile of felsic to intermediate volcaniclastic rocks with interbeds of gray to black bedded chert. The volcaniclastic rocks, now in part metamorphosed to quartz-sericite schists, mainly represent massive sandy debris flows to plane, parallel-bedded, normally graded, fine-grained turbiditic subaqueous tuffs .They are devoid of wave-generated primary sedimentary structures.

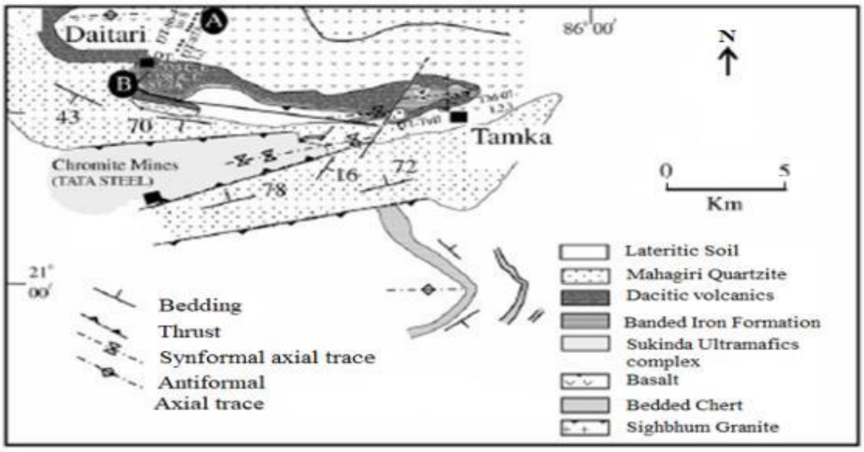
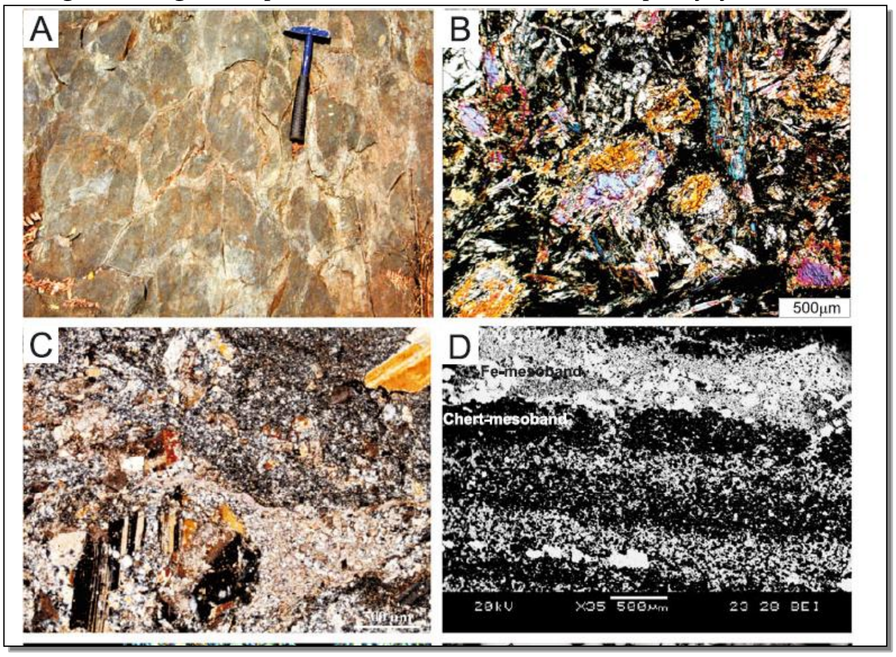


Fig.6. Geological map of Tamka-datari belt after Mukhopadhyay,et al,2008



Some beds are vesiculated. On the basis of consistent upward directions in pillow basalt below the dacitic lava and graded beds in volcaniclastic rocks , the succession is interpreted as normal and conformable, without major stratigraphic or tectonic breaks. The volcanic rocks overlying the dacitic lava grade upward through gray bedded chert into a ~120-m-thick BIF. The BIF displays well-preserved mesobandings defined by alternating iron- and chert-rich bands . It includes both oxide and carbonate facies members. The iron carbonates are now largely oxidized to goethite and/or haematite, but locally remnant carbonate is preserved. The iron oxides are mostly haematite after magnetite, i.e., martite. However, cryptocrystalline and microcrystalline haematites are present in chert mesobands as inclusions in microcrystalline quartz (fig. 3E, 3F). These haematites appear to be the earliest-formed oxide phase and have been partly converted to magnetite during diagenesis or low-grade metamorphism. The magnetites, in turn, were transformed to martite during recent supergene alteration. Petrographic study by Mukhopadhyay et al,2011 is shown in original in Fig.7A-DMukhopadhyay et al. recorded an age of 3506:8±2:3 Ma from the zircon extracted from the dacitic lava using U-Pb SRIMP technology and even correlated the greenstone succession to that of OMG.

Iron Ores in the Daitari Mines- are Soft Laminated Ore (SLO)/Friable Ore (FO) is the predominant ore type. 60% of the total reserve comprises of SLO/Friable Ore, at many places biscuit type of ore and Hard Laminated/ Hard Massive Ore. The northern part of the deposit is dominated by hard laminated and hard massive variety of ore. Around 20% of total Daitari deposit is of Hard Laminated type ore. Ore minerals are magnetite, Haematite mainly. Total Iron minable Iron Ore Reserve is 159 mt with Fe 62.2% av (Data OMC source).

Gandhamardan Iron Ore Deposit- Gandhamardan hill in Keonjhar dist with a high elliptical plateau, BIF hosted greenstone succession with iron ore deposits (Fig.8) is under active mining by the State owned OMC. With a volcano-sedimentary succession the Gandhamardan hill corresponds to the IOG setting, Prasad Rao et al. (1964), Acharya (1984) and Lahiri (2002). The banded iron formation lying above the volcanics contains stratabound fracture filling and replacement vein-type iron ore bodies with irregular outline. Further up the hill section, the iron ore bodies grade to barren banded iron formation, which continues for 60 to 100m. Near the top of the hill the banded iron formation is overlain by a sheet like low easterly dipping iron ore body (10 to 30 m thick), which is ultimately capped by ferruginous laterites, Bhattacharya and Ghosh.2012. Ore mineralisation is both stratabound and hydrothermal vein replacement type. A total reserve of 223.227 mt.of all grades iron ore has been calculated by the OMC Ltd.

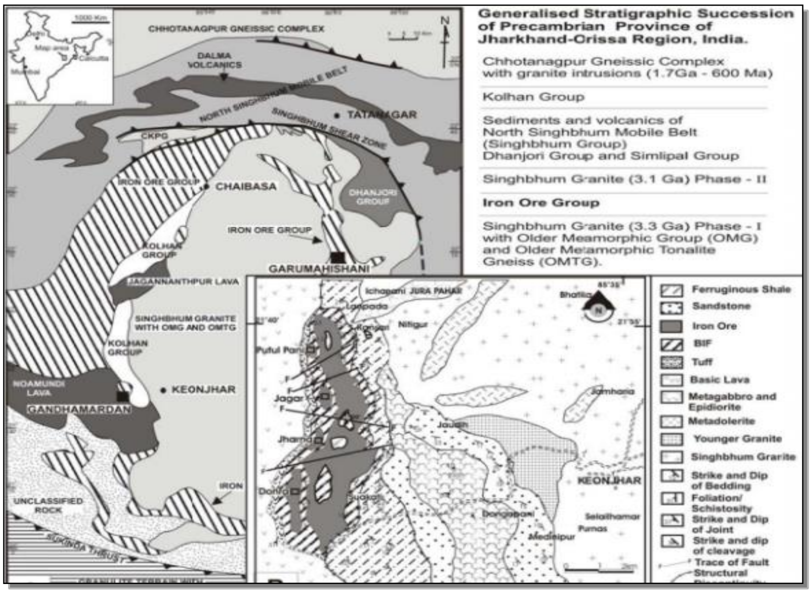


Fig.8.Geoogical Map of Gandhamardan Iron Ore Hill (after Bhattacharya and Ghosh,2012)

Badampahar-Gorumahisani belt- Iyenger and Murthy (1982) designated the rock types of the supracrustal belt as Badampahar Group. Banerjee, 1974 and 1988; Jena and Behera, 1987, 1989a and 1989b, 1990-91 designated this belt as Gorumahisani Group and mapped it and have shown a 120 km long belt extending from Rajnagar in South Singhbhum district (Jharkhand) to Jashipur in Mayurbhanj district(Odisha) (Fig.9). The north 70 km stretch has NW-SE trend but remaining 50 km, to the south of Rajnagar-Bisoi sector where it attains maximum width of nearly 10km, extends in a NNE-SSW direction (Fig. 9).

The belt bifurcates at few places and a narrow but long appendage like projection extends from the main belt into the surrounding gneisses at a number of places, the more conspicuous being at Debradihi and Baghia in the northern, and central part of the belt respectively which are the xenoliths of the supra crustals of the BGB. To the south of Badampahar, the BGB bifurcates, one arm running in a south westerly direction gradually becomes E-W westwards and the other arm continues southwards and tapers out and terminates against granitoids to the south of Jashipur. The maximum width of 6 km of the belt narrows down to nearly 1 km.

A sub parallel belt to that of the main BGB,a 20 km long " mini belt', (Jena and Behera, 1998) observes has a NNE-SSW orientation, width being 1-2kms., lie between Badra in the north and Raipada in the south similar lithology and deformational pattern.

The BGB comprises dominantly meta- basalts (amphibolites and hornblende schist), pillowed and deformed at many places, minor meta ultramafites (serpentinite, meta pyroxenite and talc-tremolite schist), spinifex textured komatiites(Fig.10), meta acid volcanics (rhyodacite composition often tuffaceous). Interbedded metachert and BIF with its variants as magneitite-fibrous amphibole banded rock, calcsilicate (rock) alternate with bands of meta chert are frequent in mafic volcanic. Mafic-ultramafic-chert alternations akin to ophiolite are common in the southern part of the belt. This volcanics-dominated curvilinear Badampahar-Gorumahisani belt has been intruded by the latest phase (3000 Ma) of Singhbhum granite (SBG) and possibly by a still earlier phase of SBG -3300 Ma. Spinifex textured Peridotitic Komatiite (STPK) has been reported at a number of localities like Tiring, Dhipasahi, Kapili (Pradhan and Mukherjee F.S of GSI for 2012-13) and Patharkata(Sahu and Mukherjee,2001),etc by GSI workers in the last two decades from north to south indicating typical Archaean crust.

BIF represented by Banded magnetite quartzite (BMQ) is conspicuous in the southern part where 2 to 3 bands of BMQ have undergone supergene enrichment to form Iron Ore deposits over a stretch of 15 kms.in a linear tract from Suleipat in the NE through Gorumahisani to Badampahar in the SW.Iron Ore deposits are mined at Gorumahisani and Badampahar hills.

The BGB is bordered by Singhbhum Granite phase-1 and Singhbhum Granite Phase-II shows intrusive relationship. The whole sequence is intruded by Mayurbhanj Gabbro and Mayurbhanj granite-granophyre. Geochemistry studied by Ghosh & Vaidya,2017 observed that ,the BIF inter layered metavolcanic rocks of the BGB have negative Zr-Hf anomalies in the average upper continental crust normalized trace element patterns and strong LREE enrichment in CI normalized REE patterns.

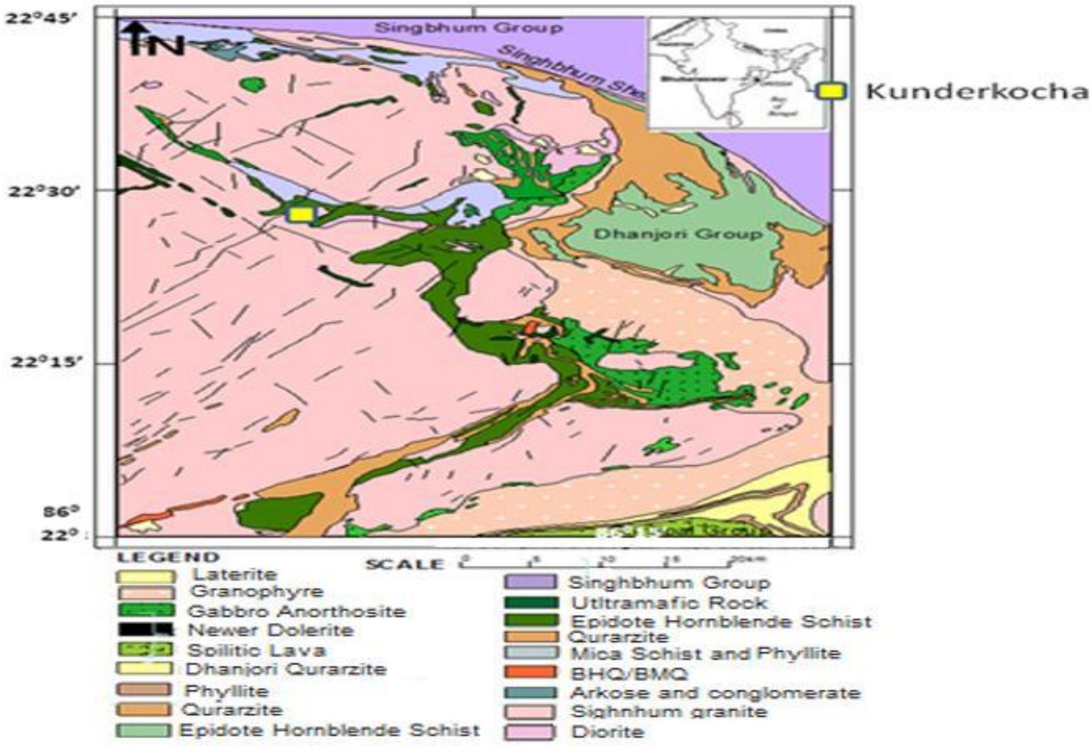


Fig.9. Compiled and digitized map of BGB from GSI maps

Fig.10. Field Photograph of Spinifex textured komatiite north of Kapili-(photograph by R.N.Sar)

These are typical characteristics of subduction related arc basalts (Pearce and Peate, 1995; Kelemen et al., 2004; Pearce, 2008). The basal pillowed metavolcanic rock has Zr-Hf enrichment relative to Nb-Ta and depleted LREE similar to NMORB. In traditional tectonic discrimination Ti vs. Zr diagram, with arc basalt-like, REE plots in the overlapping MORB-island arc lava domain, the island arc lava.
According to Taylor and Martinez (2003), back-arc basin basalt modified by subduction components acquires features of both arc-like and MORB like components. Therefore, they concluded that the metavolcanic rocks were likely to be generated in a back-arc basin. Existence of the Phanerozoic-style plate tectonics in the early Archaean time is still debated (Stern, 2005; Harrison et al., 2005; Rollinson, 2007; Condie and Kröner, Geochemical characteristics of the volcanic rocks interlayered with BIFs from other Archaean greenstone belts (e.g. IGB of west Greenland, NCGB of Superior Province and Yinshan Block of North China Craton) also dominantly show an affinity to arc-back-arc-like setting with mantle plume volcanism (Polat and Frei, 2005; Hollings and Kerrich, 1999; Ma et al., 2014). In summary, BIF and associated volcanic rocks of the Archaean greenstone belts are plausibly originated in back-arc like settings with extensive volcanism. They concluded that the BIF and volcanic rocks of the BGB were deposited in the deeper part of a Meso Archaean back-arc basin without any significant detrital contamination. Geochemistry studied by Ghosh & Vaidya,2017 observed that ,the BIF inter layered metavolcanic rocks of the BGB have negative Zr-Hf anomalies in the average upper continental crust normalized

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Hirapur Iron Ore Occurrence

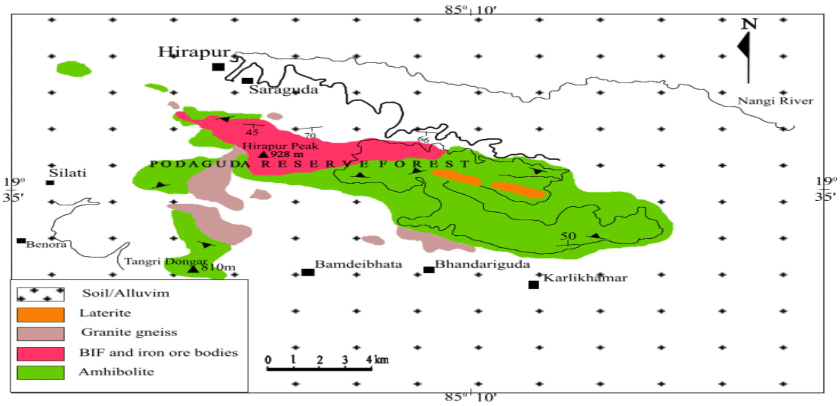

Fig. 11 Geological map of Hirapur iron ore deposit (after Majhi et al, 2017)

The supracrustals of Bastar Craton in Hirapur area, near Umarkot, Nabarangpur dist,Odisha belongs to Bailadila Group of Bastar Craton(Fig.11). It comprises grunerite quartzite, ferruginous phyllite and white quartzite, amphibolite and BIF (BHQ) near Hirapur in Umarkote Tahasil of Nabrangpur district and is considered to belong to the Bailadila Group (Ghosh, 1941). Iron ore occurs in banded haematite quartzite, banded ferruginous quartzite and ferruginous schist on the top of Hirapur hill and its northern margin along Podaguda and Saheb Dungri hills. The common ore types are hard massive, massive, laminated, lateritic and Conga ore-floats. The iron ore minerals include hematite, magnetite, goethite, specularite and limonite.

Magnetite ores

The titaniferous magnetite is an important ore for being used as principal source of Ti and V apart from Fe. In Singhbhum Craton, the titaniferous magnetite deposits are mainly located in Kumhardubi, Betjharan areas of Mayurbhanj district, Nuasahi of Keonjhar district of Odisha, Dublabera area of the West Singhbhum district, Jharkhand, Saltora – Mejia, Panrkidih – Bheladih and Ramchandrapur – Tiludi areas of the Purulia and Bankura districts, West Bengal. Among these locations only the first four locations fall within the Archaean terrain. Other occurrences of similar deposits in India are reported from Moulabhanj area of the Keonjhar district (Chakraborty and Mallick) of Odisha.

Discussion

The Older Metamorphic Group (OMG), considered being the oldest supracrustals in the SC is exposed mainly in the Champua – Onlajhari areas of Keonjhar and Mayurbhanj districts. The Singhbhum granitic complex occupies the intervening zone between these two supracrustal belts. Recent detailed mapping by GSI established the continuation of OMG-type lithologies across Singhbhum granite to Gorumahisani – Badampahar area through a chain of mappable xenoliths (Behera et al., 1994; Jena and Behera, 1998). Based on the above finding, Jena and Behera (1998) concluded that the supracrustal rocks of Champua (OMG) and Badampahar area (Gorumahisani – Badampahar Group) are temporaly correlatable, thus reiterating the earlier opinion of Iyengar and Murty (1982).

Pradhan et al (2012) based on Specialized Thematic mapping between Jashipur and north of Hadgad Group observed numerous enclaves of IOG lithounits,OMTG and OMG within Singhbhum Granite country upto the northern side of Hadgad hill ranges and suggested continuity of BGB to Hsdgad Group. Jena.P.K.carrying out Specia;ied Thematic Mapping (F.S.Programme of GSI 2006-08) in the area between TDB and Hadgad Group during 2006-08 noted that the BIF with banded opalescent & black chert, talc-tremolite schist, fuchsite quartzite, massive cherty quartzite & metabasic rocks occur mainly in the southern part of Mahagiri range with NNW-SSE to NNE-SSW strike, which swerves around Durgapur in ENE-WSW trend and extends further east of Belda-Saliganj-Patilo. These sequences of rocks are also exposed north of the Mahagiri hill in an ENE-WSW trend around Phuljhar and further east of Phuljhar, Tomka, Champajhar up to west of Raighati after which the Sukinda ultrmafics is exposed further west in the valley. The litho- package show similarity with that of Kamakhyanagar-Malayagiri- Telkoi sector in north west & Chenapadi- Notopahad- Jashipur sequence(parts of Hadgad Group) towards north east, which are considered equivalent to rocks of BGB based on similarity in lithological assemblage and structural fabrics. Thus they opined that the litho-package resembles with that of Badampahar-Gorumahisani schist belt. Thus from the age data and geological mapping data of GSI by Jena and Behera, 1998;Jena(2006-08) and that of Pradhan et al (2012),the author believes that the TDB, OMG and BGB are startigraphically of similar in age and tectonic evolution.

The author on the basis of his observation in the course of his field work in BKB, BGB and training of GSI officers in Hadgad and TDB is of the opinion that all IOG basins with or without BIF were formed in similar geological milieu during Archaean era and physically appearing as discrete basins due to later granitic magmatism.

References

Acharya,S. (1993).Greenstones from Singhbhum craton,their Archaean character,oceanic crust affinity and tectonics.Proceedings of National Academy of Science,India , 63.pp 211-222

Banerjee, P. K. (1982) Stratigraphy, petrology and geochemistry of some Precambrian basic volcanic and associated rocks of Singhbhum dist, Orissa, Mem. Geol. Surv.India VIII 52p.

Beukes,N.J.,Mukhopadhyay,J.,Gutner,J.(2007) Genesis of high grade iron ores of the Archaean IOG around Noamundi,India in Ec.Geol.103,pp-365-386

Bhattacharya, H. N. and Ghosh. K (2012) - Field and Petrographic Aspects of the Iron Ore Mineralizations of Gandhamardan Hill, Keonjhor, Orissa and their Genetic Significance. J.Geol.SoC.India, Vol.79 pp.497-504

Dunn, J. A. (1929) Geology of north Singhbhum including parts of Ranchi and Mayurbhanj districts. Mem Geol Surv India; 54:1-166.

Dunn, J. A. (1940) The stratigraphy of south Singhbhum. Mem Geol Surv India; 63, pt. 3, 303-369.

Dunn, J. A. and Dey, A.K. (1942) Geology and petrology of Eastern Singhbhum and surrounding areas. Mem, GSI Vol. 69(2).

Ghosh, J. G. 2004. 3.56 Ga tonalite in the central part of the Bastar craton, India: oldest Indian date. J. Asian Earth Sci. 23:359–364.

Ghosh, R. and Baidya,T.K.(2017) MesoArchaean BIF and iron ores of the Badampahar greenstone belt, Iron Ore Group, East Indian Shield. J.Earth Sc.(150) pp-25-44

Goodwin, A.M., Thode, H.G., Chou, C.-L. and Karkhansis, S.N. (1985): Chemostratigraphy and Origin of the Late Archaean Siderite-Pyrite-rich Helen Iron-formation, Michipicoten Belt, Canada; *Canadian Journal of Earth Sciences*, Volume 22, pages 72-84

Guru,S.K.and Sar,R.N.2011-Seminar volume OMEGA-2011, Geol.Surv.Ind.

Iyengar, S. V. P. (1954) Systematic Geological mapping in parts of Mayurbhanj district. Unpublished Progress report for Field Season 1953-54.

Iyengar, S. V. P. and Banerjee, S.(1964) Magmatic phases associated with the Precambrian tectonics of Mayurbhanj district, Orissa, India, Report of the 22nd Session of IGC India, part x.p. 515-538.

Iyengar,S. V. P and Murthy,Y.G.K. (1982) The evolution of Archaean-Proterozoic crutst in parts of Bihar and Orissa, Eastern India-Rec. Geol.Surv.Ind.,v.112,pt.3,pp.1-6.

Jena, B. K. and Behera, U. K. (1998) The oldest supracrustal belt from Singhbhum craton and its possible correlation. Proceedings Vol.,Int.Sem, Precambrian Crust in Eastern and Central India,IGCP-368,Bhubaneswar.

Jena, B. K. and Mohanty, A. M. (1988) Report on the preliminary investigation for gold in Suriagora-Gorumahisani area, Mayurbhanj dist, Orissa. Unpublished progress report of GSI. F.S.P. 1987-88

Jena,P.K.(2010)-Final Report on Specialized Thematic Mapping for iron ore in the IOG rocks occurring in the south eastern part of Tomka-Daitari Belt, Kendujhar and Jajpur districts,Odisha -Unpubl.P.R.of Geol.Survey.of India for F.S.2006-08.

Jones, H.C. (1934) The Iron Ore Deposits of Bihar and Odisha Geol.sur.of India,Mem.V.63,pp.357.

Kelmen,P.B.,Hanghoj,K.,Greene,A.R.2004.One view of the geochemistry of subduction related magmatic arcs, with an emphasis on primitive andesite

Mahakul,J.P. and Bhutia,S.P.(2015) Regional Structural analysis and reinterpretation in the Bonai-Kendujhar Belt, Singhbhum Craton: Implication for revision of the Lithostratigraphic succession in Jour.Geol.Soc.of India,Vol.85,pp-26-36

Mazumder, R.(2005) Proterozoic sedimentation and volcanism in the Singhbhum crustal province, India and their implications. Sedimentary Geology 176, 167-193.

Misra,G.B.,1961-A npte on the stratigraphy of Joda area,Keonjhar. Quart.Journ,Geol.Met.Soc.,India, Vol.33,No.1

Misra, S., Deomurari, M.P, Wiedenbeck, M., Goswami, J.N., Ray, S., Saha, A.K. (1999) $^{207}Pb/^{206}Pb$ zircon age and the evolution of the Singhbhum Craton, Eastern India: an ion microprobe study. Precambrian Research 93, 139-151.

Misra, S. 2006. Precambrian chronostratigraphic growth of Singhbhum-Orissa craton, eastern Indian shield: an alternative model. J. Geol. Soc. India 67:356–378.

Misra, S.; Deomurari, M. P.; Wiedenbeck, M.; Goswami,J. N.; Ray, S.; and Saha, A. K. 1999. 207Pb=206Pb zircon age ages and the evolution of the Singhbhum craton,eastern India: an ion microprobe study. Precambrian Res. 93:139–151.

Mukhopadhyay, D. 2001. The Archaean nucleus of Singhbhum: the present state of knowledge. Gondwana Res.4:307–318.

Murthy,V.N. and Ghosh,B.K.(1972)-Manganese ore Depositsof the Bonai-Keonjhar belt,Orissa-Indian Minerals,GSI publication,pp-201-210

Murthy,V.N. and Acharya,S,1975-Lithostratigraphy of the Precambrian rocks around Koira,Sundargarh district,Orissa-Jour.Geol.Soc.Ind-16,pp-55-68

Pearce,J.A..Peate,D.W.,1995. Tectonic implications of the composition of volcanic arc magmas.Annu.Rev.Earth Planet.Sci, 23,251-548

Pearce, J.A., 2008.Geochemical fingerprinting of oceanic basalts with applications to ophiolite classification and the search for Archaean oceanic crust. Lithos 100(I)

Pradhan,U,K,and Mukherjee Anamika(2014)-Unpubl.P.R.of GSI for 2012-13

Prasad Rao G. H. S. V. (1950) Progress report (mapping) for the F. S. 1949-50, Keonjhar, Mayurbhanj and Balasore districts

Saha, A. K. (1964) Emplacement of the northern part of Singbhum granite, Eastern India a study in precambrian magmatism and granitization, Report of the 22nd session of IGC India part XP 336-385.

Saha, A. K. (1988) Some aspects of the crustal growth of the Singhbhum-Orissa Iron Ore craton, eastern India. Ind. J. Geol. 60 (4), 270-278.

Saha, A. K. (1994)- Crustal evolution of Singhbhum North Orissa, Eastern India. Memoir 27 Geological Survey of India.

Sahu, N.K. and Mukherjee, M.M. 2001: Spinifex Textured Komatiite from Badampahar-Gorumahisani Schist Belt, Mayurbhanj district, Orissa. Journal of the Geological Society of India,Vol. 57, 529-534 pp.

Sar, R.N.,Guru,S.K.and Hussain,A(2011).Manganese Mineralisation in Jamda-Koira valley with special reference to Lasarda-Damurda sector,Kendujhar district,Orissa-in seminar Vol-I, OMEGA, Geol.Surv.Ind.,pp-123-145

Sarkar,S.N. and Saha,A.K.,1962-A revision of the Pre-Cambrian stratigraphy and tectonics of Singhbhum and adjacent regions.Quart.Journ,Geol.Met.Soc.,India, Vol.34,No.2-3

Sarkar, A. (2005) Observations on the Geology of Eastern Indian Craton: A Palaeo-Mesoarchaean Crustal Block. Proccedings-Seminar on Mineral and Energy Resouce of Eastern and Northeastern India, pp. 103-124, Kolkata, India.

Sarkar, S. N. and Saha, A. K. (1977) The present status of the Precambrian stratigraphy, tectonics geochronology of Singhbhum-Keonjhar-Mayurbhanj region, Eastern India. Ind. Jour. East. Sc. S. Ran. Vol. pp 37-43.

Swain ,B.B. and Jena,P.K, Jena,S.K., Misra,A.P.(2011).-Geology and stratigraphy of north east extension of Tomka-Daitari Iron Ore Belt, Kendujhar district,Orissa in Seminar Vol.-I , OMEGA, Geol.Surv.Ind.,pp-34-41