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# Field Relationship among the Three Iron Ore Groups of Iron Ore Super Group Encircling the North Odisha Iron Ore Craton, India: A Comparison Study

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**Abstract** Banded Iron Formation (BIF) and iron ore deposit occupy three distinct provinces surrounding the North Odisha Iron Ore Craton (NOIOC) located in eastern India. They are Bonai-Keonjhar belt in the western flank, Badampahar-Gorumahisani-Suleipat belt in the eastern flank and Daitari-Tomka belt in the southern side of the Craton. All these three belts having group status are the best preserved basins of the Precambrian period that form Iron Ore Super Group (IOSG) of Odisha. IOSG contains BIFs as enigmatic rock comprising alternate layers of iron bearing minerals and silica. Since long these belts have been undergone numerous investigations with regard to mineralogy, geochemistry, stratigraphy, structure etc. Opinions based on published literatures have still unclear about the status-occurrence of these BIFs. Irrespective of their similarity in many characteristic features, they differ with respect to stratigraphy, structure, mineralogy, metamorphism, intrusives, and thickness of iron formation. With the resemblance in the evolution of basins, their differences have been delineated in this paper.

***Keywords:*** *BIF, Iron Ore Super Group, NOIOC, Odisha*

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## 1. Introduction

Iron formations are economically important sedimentary rocks that are most common in Precambrian sedimentary successions. Iron formations host the majority of the world's economic Fe ore, which has fostered extensive research on their origin, depositional setting, and spatial and temporal distribution.

The supracrustal including banded iron formation and iron ore of Precambrian age constitute three discrete geographic segments along the periphery of the North Odisha Iron Ore Craton (NOIOC) (Figure 1). Among them the western flank of the craton is occupied by the Bonai-Keonjhar (BK) belt forming the U-shaped synclinorium, which is known as the Horseshoe belt [26]. In the north eastern boundary of the craton there exists the arcuate shaped Badampahar-Gorumahisani-Suleipat (BGS) belt. Daitari-Tomka (DT) belt constitutes the southern periphery of NOIOC. These three prominent belts of iron ore deposits along with associated litho-types have been designated as the Iron Ore Super Group (IOSG) of Odisha [2,6,18,25].

The Archaean-Proterozoic metasediments including the banded iron formation of the IOSG have been reviewed by Iyengare and Murty [25] and Acharya et al. [4]. The entire rock assemblages in Singhbhum-North Odisha Iron Ore Craton belong to single Iron Ore Group (IOG) (formed at about the same time) [37,38]. The litho sequences of IOSG have formed two separate Iron Ore Groups [11,12,24,25]. There are three or more Iron Ore Groups (IOG) existing in the IOSG [2,6,18,35]. Each BIF province has been assigned the Group status such as Badampahar Group [25], Noamundi Group [11,12], Koira Group [34]. As already mentioned, the three Iron Ore Groups are separated by unconformity, different metamorphic grade, distinct sedimentary and igneous assemblages and ore types [2,25,35].

The Mayurbhanj granite occurring along the eastern fringe of the Singhbhum granite was dated to be 3100 Ma [27]. The A-type Mayurbhanj Granite Pluton ( ~3.09 Ga), occurring along the eastern margin of the Singhbhum-Odisha Craton, eastern India, represents the final phase of acid plutonism in this crustal block of Archaean age [27,28].

While working on the three principal belts such as Noamundi-Jamda-Koira, Gorumahisani- Badampahar and Tomka-Daitari, Mukhopadhyay [31] proposed that there are some differences in the mineralogy, geochemistry and lithological association of BIFs in the these belts, particularly between the Noamundi-Jamda-Koira and Gorumahisani-Badampahar belts. He further mentioned that it is probable that they were deposited in separate basins, which had somewhat different depositional settings.

The rocks of IOG unconformably overlie the early phases of Singhbhum granite massifs and a late phase of Singhbhum granite intruded into the IOG group of rocks around 3120 ± 100 Ma [22]. According to Misra [29] there are two successive supracrustal–granite cycles in NOIOC. The first cycle included Older Metamorphic Group (OMG), Older Metamorphic Tonalitic Gneiss (OMTG) and Singhbhum Granite (SBG) phase-I and phase-II grew in sequence from ~3.55 to 3.30 Ga. The second cycle included IOG supracrustals followed by emplacement of Bonai granite and SBG phase-III ranging from ~ 3.30 to 3.16 Ga or upto ~ 3.12 Ga.

The greenstone belts occur as three detached enclaves within Singhbhum granitoid. These referred to as the Western (Nuamundi-Joda-Koira-Malngtoli-Bursua-Chiria), Eastern (Gorumahisani-Badampahar) and Southern (Malaygiri-Tomka-Daitari) [32]. Mukhopadhyay et al. (2008b) have reported that the high grade magnetite ores occur as stratabound bodies hosted by BIF unit of the meso- Archaean iron ore group. They further suggested that the magmatic-hydrothermal fluids derived from mafic intrusives were instrumental in the formation of the magnetite ore bodies of the Gorumahisani deposits. While addressing the origin of BIF of BGS belt Beura and Singh [17] suggested genetic model on the basis of tectono-structural aspect.

Acharya [10] has discussed the relationship between the IOG and Singhbhum granite complex. He further mentioned that the BIF enclaves in granite have been derived from the oldest IOG (BIF-I), not from youngest IOG (BIF-III) (he opines three BIF exist in North Odisha). The emplacement of the third phase of the Singhbhum Granite possibly marks the closure of the Iron Ore basins. There was no further addition of juvenile crustal material to the Archaean nucleus of Singhbhum. Subsequent events were confined to the formation of intracratonic basins, and intrusion of mafic dyke swarms and of minor mafic-ultramafic bodies.

The iron ore basins have been better studied by Acharya and has unraveled the stratigraphy and structure of the basins [1,3,6,9] and their role in prospecting of the ore bodies. A good amount of details on the infra-, intra- and supra- BIF nature of ore deposits have been known [8]. BIF is considered as the litho-marker in all these three belts of IOSG. Irrespective of being the host rock of iron ore, the BIFs exhibit dissimilar characteristics among the three and have been named as BIF-I, BIF-II and BIF-III in space and time [2,6,14,18]. The rock assemblages of Badampahar-Gorumahisani-Suleipat belt, Daitari-Tomka belt and Bonai-Keonjhar belt have been assigned BIF-I, BIF-II and BIF-III respectively from old to young with respect to age. The three BIFs are allotted the stratigraphic status, which has been strengthened by differential characteristics in regards to mineralogy, metamorphism, structure, stratigraphy, litho-assemblages and intrusives.

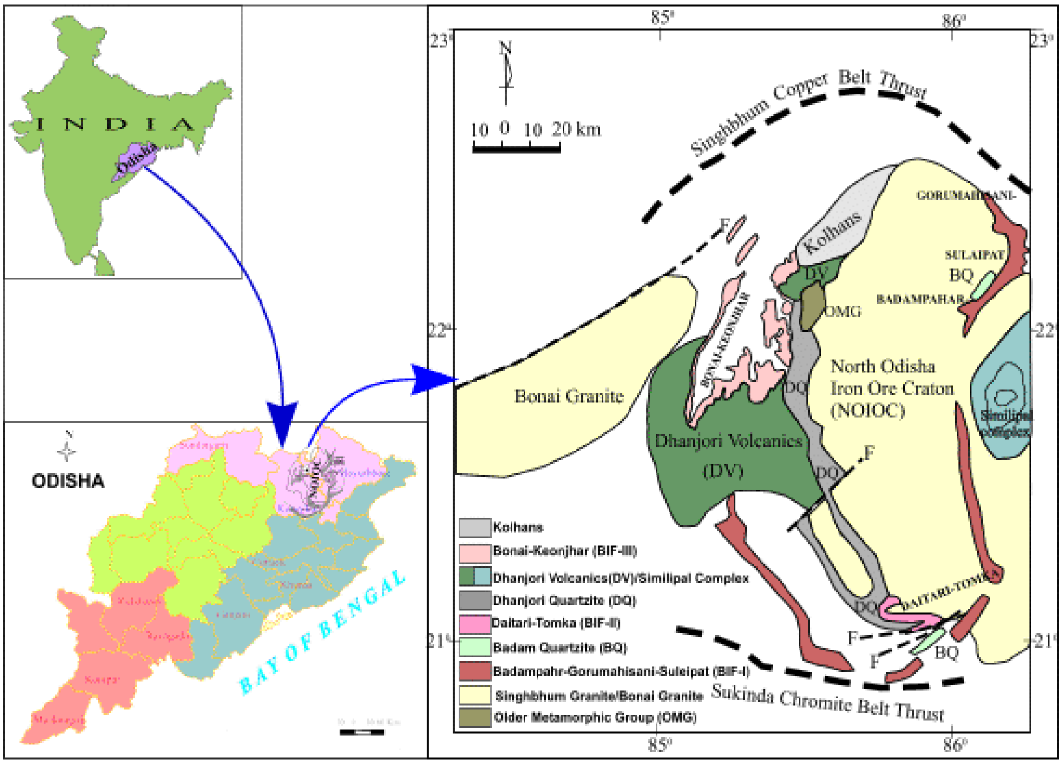


**Figure 1.** Generalised geological map showing BIF-I, BIF-II and BIF-III surrounding the North Odisha Iron Ore Craton (NOIOC) (Modified after [20,26])

## 2. Geological Setup

The Iron Ore formations, agglomerated in three BIFs occur along the periphery of Archaean continental nucleus i.e. the North Odisha Iron Ore Craton (NOIOC). This cratonic block in the Precambrian track of Odisha and Jharkhand is bounded by the arcuate copper belt thrust zone (Singhbhum shear zone) in the north and Sukinda chromite belt thrust zone in the south (Figure 1). The major part of it is occupied by Singhbhum granite complex. The Older Metamorphic Group (OMG) constitutes the oldest unit in the Archaean nucleus and consists of amphibolite facies pelitic schists, quartz-magnetite cummingtonite schists, quartzites, banded calc-gneiss, and para- and ortho-amphibolites. The OMG rocks are intruded by the Older Metamorphic Tonalitic Gneiss (OMTG).

In the southern part of the NOIOC, the BIF-II is overlain by Dhanjori quartzite that extends northward along the western periphery up to BIF-III and underlies it. A separate quartzite formation (may be part of Mahagiri quartzite) underlying the BIF-II runs northward along the eastern flank of NOIOC up to BIF-I and overlies it. This quartzite may have a separate stratigraphic entity, which differ from the Dhanjori quartzite and is named as Badam quartzite. The stratigraphic succession of IOSG constituting BIF-I, BIF-II and BIF-III has been established (Table 1).

There is extensive reactivation along its margins by rifting, local emplacement of mafic/ultramafic complexes and subsequently collision with the Iron Ore Group sequences along eastern, southern and western flank of the craton. lying to its north and west.

**Table 1. Stratigraphic succession of Iron Ore Super Group of Odisha [20]**

| | | | |
|---|---|---|---|
| | Kolhan Group | | Kolhan sediments ( Sandstone, Limestone, Shale) |
| | ----------------Unconformity---------------------- | | |
| IRON | Bonai-Keonjhar Group (BIF-III) | Upper Shale | Fe-shale<br>banded shales |
| | | BIF-III | Banded Hematite Chert/Jasper<br>and banded hematite shale |
| ORE | | Lower Shale | Banded shale<br>Banded Manganese Formations (B Mn F)<br>Variegated shales<br>Tuffs & Tuffaceous shale |
| SUPER | -----------------Unconformity ------------------------------ | | |
| | Dhanjori Group | | Dhanjori Volcanics<br>Dhanjori Quartzite |
| GROUP | ----------------- Unconformity--------------------------- --- | | |
| (NOIOC) | Daitari-Tomka Group | Upper Metapelites | Phyllites<br>Slate<br>Fe-Phyllites |
| | | BIF-II | Banded Chert<br>Banded Magnetite/Hematite Chert/Jasper<br>and Banded Magnetite/Hematite Quartzite |
| | | Lower Metapelites | Banded Phyllites<br>Quartz Schist<br>Chlorite schist |
| | --------------------Unconformity ---------------------------- | | |
| | Badamphar-<br>Gorumahisani-Suleipat Group | Upper Quartzite | Badam Quartzite<br>Micaceous Quartzite |
| | | BIF-I | Banded Magnetite/Martite Quartzite<br>Banded Magnetite/Grunerite Quartzite |
| | | Lower Quartzite | Banded black and green chert<br>Tremolite-actinolite schist<br>Fuchsite Quartzite |
| | -------------------Non- conformity------------------------------ | | |
| PRE-IOSG<br>PRE-CAMBRIAN | | | Singhbhum Granite≅Keonjhar granite ≅Bonai granite)<br>(older to BIF-I)<br>Tonalite gneiss (OMTG)<br>OMG ( Mica schist, fuchsite quartzite, Para-amphibolite,<br>Hornblende-schist etc. ) |

## 2.1. BIF-I: Badampahar-Gorumahisani-Suleipat Belt

BIF-I comprising of iron formation and iron ore is well developed at BGS belt and part of it is discontinuously exposed along the southern hemisphere of the craton out skirting the BIF-II (Figure 1). The litho assemblages of this oldest Iron Ore Group under IOSG [6] consist of banded cherty quartzite, banded magnetite quartzite, banded magnetite grunerite quartzite, tremolite-actinolite schist and fuchsite quartzite.

The Badam quartzite is well exposed in the western side of the BGS belt, which overlies the BIF-I. The area witnesses presence of ultrabasics and numerous volcanic dykes. Banded magnetite quartzite is the dominant litho-unit in the BIF-I. BIF of this belt is characterised by oxide- and silicate- facies of minerals. The major mineral constituents are magnetite, martite, hematite, specularite, goethite, grunerite and quartz [15]. The BIF-I has suffered amphibolite facies of metamorphism.

The rocks of BIF-I have been suffered multiple episodes of deformation. The tight and isoclinal first folds ($F_1$) having NE-SW plunging axes is overprinted by co-axial, upright and tight to open second phase fold ($F_2$), and are parallel to the general trend (NE-SW) of the belt. The last phase of folding ($F_3$) is restricted to local domain and exists as gentle and broad warps. The $F_3$ fold is characterised by steep northeasterly dipping axial plane and moderately plunging axis towards NW direction. The geometrical analysis of folds of the area leads to establish relations among the three phases of folding as $F_1 // F_2 \wedge F_3$. Superposition of these folds is resulted in interference pattern as dome and basin structures, hook shaped patterns, eyed fold and mesoscopic folds of S, Z and M shapes (Beura and Singh, 2009).

### 2.2. BIF-II: Daitari-Tomka Belt

The BIF-II lying in the southern sector of the NOIOC is confined to Daitari-Tomka belt. It is underlain and overlain by Badam quartzite and Dhanjori quartzite respectively (Figure 2). The litho-assemblages of this middle aged belt among the three BIFs consist of banded magnetite/hematite quartzite, banded magnetite/hematite jasper, quartz sericite schist, phyllites, slate and banded chert. The dominant minerals of the area are magnetite, martite, hematite and goethite. The rocks of BIF-II attain green schist facies of metamorphism. Few ultrabasic intrusives are found in the area.

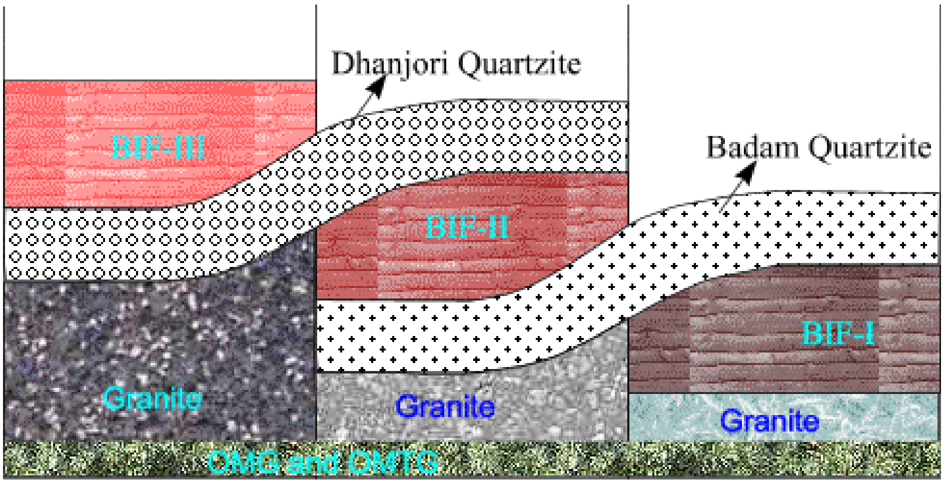


**Figure 2**. Schematic diagram shows stratigraphic setting of three BIFs of IOSG with respect to Badam and Dhanjori quartzite

The rocks of BIF-II have undergone polyphase deformations. The folds of different periods are co-axial and synchronously cross-folded having mutually perpendicular axial planes [7]. The area follows the regional trend of E-W direction and the plunge towards west.

### 2.3. BIF-III: Bonai-Keonjhar Belt

BIF-III occupies a distinct 'U'-shaped pattern in the western flank of the NOIOC that rests over the Dhanjori Quartzite [5,16]. The litho-associations of this area form the youngest Iron Ore Group comprising of banded hematite jasper, banded hematite quartz/chert, banded shale, banded manganese formation and ferruginous shale. The banded iron-formation consists of predominantly iron oxide minerals such as hematite, martite, specularite and, magnetite and the silica as chert, jasper and quartz. The litho-assemblages of this youngest Iron ore belt are un-metamorphosed and lack of intrusives.

The general structural disposition of the rocks of the area shows a synclinorium trending NNE-SSE direction having low plunge towards NNE. The rocks of the area are experienced with three phases of folding. Successive phases of folding lead to plunge reversal that results in open cross folds.

## 3. Contrast Among the Three Iron Ore Belts

The BIF-I, BIF-II and BIF-III surrounding the NOIOC differ from each other on the basis of mineralogy, metamorphism and field relationship including stratigraphic sequence, structure, litho-assemblages and intrusives. The differential characteristics evolved through critical interpretation of field database led to distinguish the three BIFs with respect to age.

### 3.1. Stratigraphic Sequence

In BIF-I of Badampahar-Gorumahisani-Sulaipat belt the iron formation is overlain by Badam quartzite. A horizon of conglomerate striking N-S for about 1.5km has been noted at the eastern base of the Sulaipat hill across the river Khar Khari. In BIF-II of Daitari-Tomka belt quartz arenite underlies the BIF, which is the extension of the Badam quartzite (Figure 2). This quartzite lying below the BIF-II may be the part of Mahagiri Quartzite. A conglomerate zone is traced at the foothill of Daitari-Tomka belt. A coarse-grained sandstone zone (Dhanjori age) is overlying the southern part of Daitari-Tomka range. In Bonai-Keonjhar belt (BIF-III) BIF is underlain by lithic wacke at places. The BIF overlies the sandstones (Dhanjori age) and volcanics. The OMG unconformably underlies the IOG rocks and the granite lies in between them.

### 3.2. Intrusives

The BIF-I of Badampahar-Gorumahisani- Sulaipat belt is distinctly intruded by numerous dolerite and ultramafic dykes of younger age. One phase of Singhbhum granite maintains an intrusive contact with the BIF-I, which is considered as the Proterozoic mobilisate [15,30]. In Daitari-Tomka belt the BIF-II is intruded by chromiferrous ultramafic rocks and a few dolerite dykes. But in Bonai-Keonjhar belt the BIF-III has not at all intruded by any intrusives.

### 3.3. Metamorphism

In Badampahar-Gorumahisani-Sulaipat belt the BIF-I is characterised by banded magnetite grunerite quartzite rock (Figure 3a). Presence of amphiboles indicates a lower amphibolite facies of metamorphism. The BIF-II of Daitari-Tomka belt is metamorphosed up to green schist facies evidenced by banded phyllites and chlorite schists. Due to the effect of such metamorphism iron minerals exhibit elongate habit (Figure 3b). Where as the BIF-III of BK belt is not metamorphosed and iron minerals here have undergone diagenetic growth (Figure 3c).

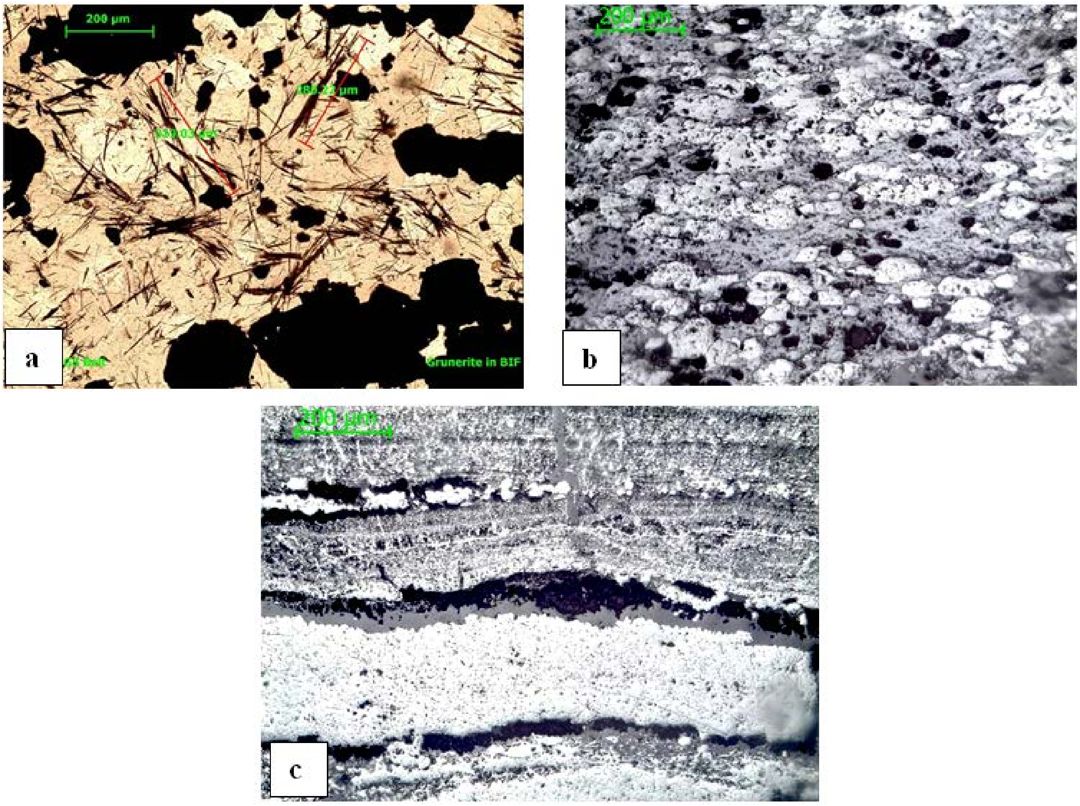


**Figure 3.** Photomicrographs showing (a) Grunerite with magnetite in BIF-I, (b) magnetite and martite in elongated form in BIF-II, (c) Hematite diagenetically grows in bands of BIF-III (Leica DM 2500 P)

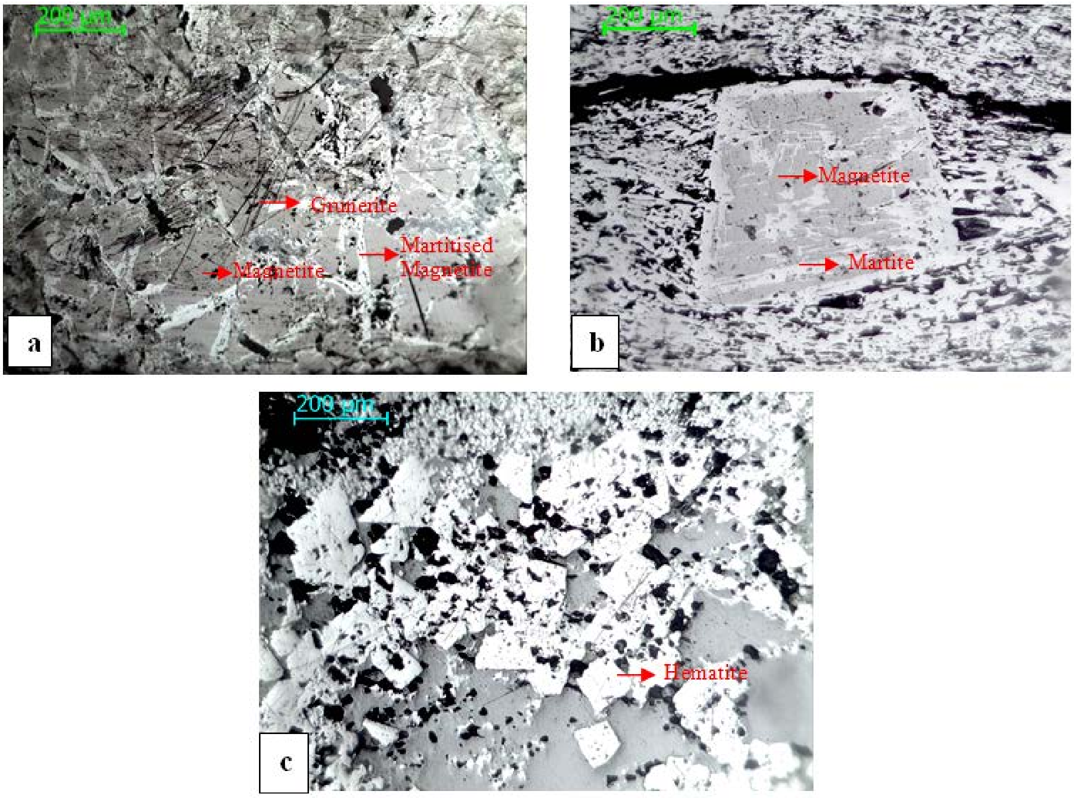


**Figure 4.** Photomicrographs showing (a) Grunerite, magnetite (primary) and martitised magnetite in BIF-I, (b) Magnetite and martite in BIF-II, (c) Hematite in BIF-III

### 3.4. Mineralogy

The BIF-I of Badampahar-Gorumahisani - Sulaipat belt comprises of iron -oxide and -silicate minerals predominantly magnetite (primary) and grunerite respectively (Figure 4a). Manganese ore deposit is scarcely observed. Only on the top of the Suleipat hill a pocket deposit of manganese is traced. In Daitari-Tomka belt magnetite and hematite (martite) co-exist in the BIF-II. Martitised magnetite is the predominant mineral in the belt (Figure 4b). Negligible amount of manganese ore is found as pocket deposits. Hematite and jasper constitute the primary minerals in the BIF-III of the BK belt (Figure 4c). Manganese ore deposit is predominant economic mineral next to iron ore.

### 3.5. Lithoassemblages

The BIF-I consists of fuchsite quartzite, tremolite-actinolite schist, banded chert, banded magnetite/martite quartzite and banded magnetite grunerite quartzite. The iron formation is intercalated with black chert and altered volcanic tuffs. The BIF-II includes chlorite schist, banded phyllite, banded magnetite/hematite quartzite and banded magnetite/hematite jasper/chert. Banded hematite chert and banded hematite jasper are the main litho types of the BIF-III along with banded hematite shale, banded shale and banded manganese formation.

### 3.6. Structure

The BIF-I of the BSG belt has suffered three and more episodes of deformations, which is resulted in intricate interference pattern through successive superimposition in the longest range of time [21]. Interference fold patterns like dome and basin structures, hook shaped patterns, eyed fold and mesoscopic folds of S, Z and M shapes are the illustrating structural features of the belt (Figure 5a). At least three phases of deformation are observed producing co-axial and synchronous cross folds in the BIF-II of DT belt (Figure 5b). The BIF-III of the BK belt has undergone at best three phases of deformation, which results in more open type cross folding (Figure 5c).

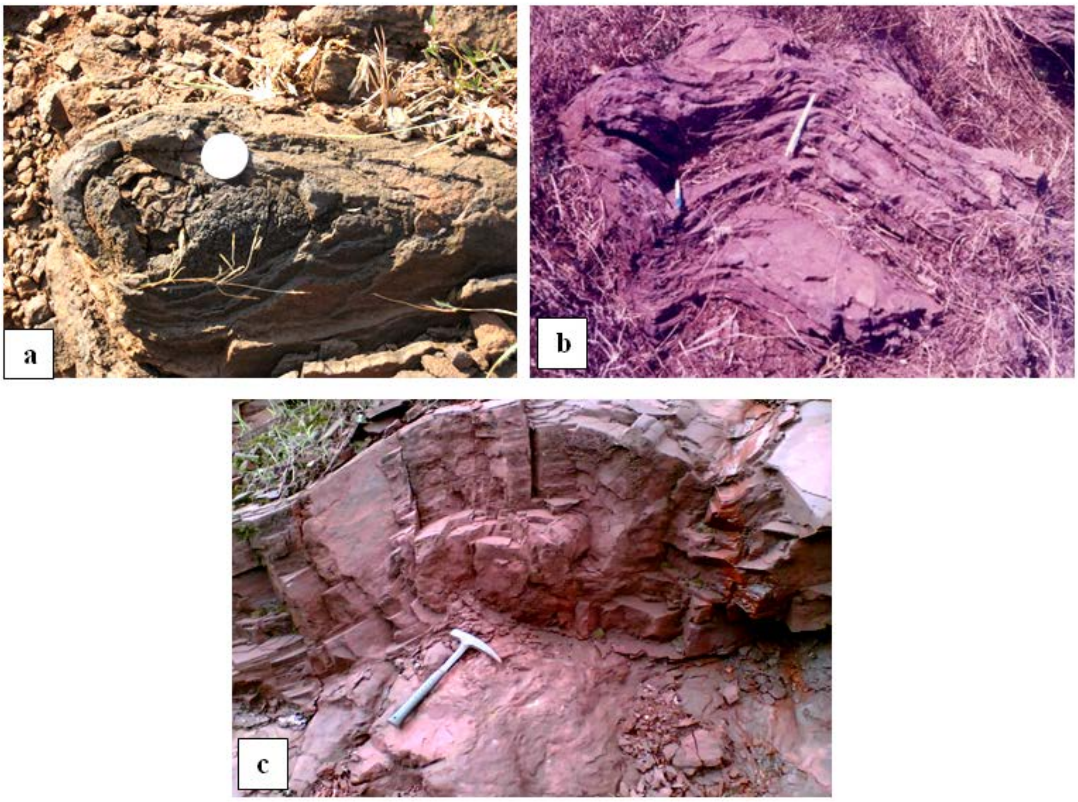


**Figure 5.** Photographs showing (a) Eye shaped fold in BIF-I, (b) Co-axial cross fold in BIF-II, (c) Open cross folds in BIF-III

## 4. Discussion and Conclusion

Iron formations around the NOIOC occupy different stratigraphic levels in the Precambrian. The grade of metamorphism decreases from bottom to top. The BIF-I of the BSG belt has attained higher grade i.e. amphibolite facies of metamorphism. At DT belt the BIF-II has undergone lower grade i.e. green schist facies of metamorphism, while there is lack of metamorphism in the BIF-III of BK belt. This indicates that the BSG belt is disposed at the bottom most, the DT belt overlies it and the BK belt is at the top of the regional sequence of the Iron Ore Super Group. The spatial disposition of these BIFs in space and time implies that the BIF-I, BIF-II and BIF-III should be assigned an age status from old to young respectively.

Structural geometry became simpler with advancement of time i.e. from BIF-I to BIF-III. BIF-I being the oldest among the three has conceived intricate interference fold patterns. BIF-III attains the most simplified structural deformation with open cross folds. Whereas the BIF-II has undergone a deformative episode, which is suitably fit in between above two having co-axial and synchronous cross folds.

The field observation shows that the thickness of iron formations vary and it increases from BIF-I to BIF-III. The BIF-I, the oldest iron formation has passed through a long period of erosive episode and there by has attained less thickness in due course. The other two, BIF-II and BIF-III have probably obeyed the same principle to arrive at their present thickness. Inter basinal transfer of iron materials from BIF-I to both BIF-II and BIF-III might have caused the later two to achieve more thickness [18,19].

During the Precambrian time, the depositional environment for iron formation has produced a range from magnetite to hematite predominant BIFs suggesting increasing level of oxygen. According to thermodynamic principles and the Precambrian environment for deposition, magnetite might have been formed in a less oxidized environment of early Precambrian, which suggests that the BIF-I containing magnetite is the oldest iron ore group. Hematite was formed in a highly oxidized environment of later Precambrian and therefore the BIF-III of BK belt comprising it represents the youngest iron ore group. However, the BIF-II of DT belt stands in between these two having Martitised magnetite (hematite) is the predominant mineral here. This may be formed due to incompletion of chemical equilibrium reaction in an environment of midway oxygen level [14,23].

The three BIFs of IOSG encircling the NOIOC differ from each other with respect to stratigraphy, intrusives, metamorphism, mineralogy, lithoassemblages and structure. Comparisons on the basis differences in characteristics of iron formations have been done among the three BIFs. The points of comparisons studied are certainly valid among them and a three fold classification as BIF-I, BIF-II and BIF-III of IOSG so adopted holds good with its general applicability.

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