



## Mineralogical and geochemical characterisation of iron ore deposit of Koira region of Sundargarh district of Odisha

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### Abstract

Koira region of Odisha is well known for mining and industrial activities. Mineralogical and geochemical studies of rocks of the area were carried out to assess the nature of the Iron Formation of the area. Mineral identification and their characterisation were done through optical microscopy and X-ray diffraction technique. Mineralogical study reveals that hematite is the predominant mineral phase. Other minerals associated are martite, specularite and goethite. Chert/silica, jasper, gibbsite and kaolinite form the gangue minerals. Cavity filling, replacement and colloidal textures are observed in the iron ores. Banding, micro-folding are common in iron ores. X-Ray Fluorescence Spectrometric analysis was carried out over samples of Iron ores. Range of values obtained for various oxides and element are: Fe<sub>2</sub>O<sub>3</sub> 67.24 % - 94.52 %, SiO<sub>2</sub> 1.11 - 14.21 %, Al<sub>2</sub>O<sub>3</sub> 1.05 - 8.20 %, Na<sub>2</sub>O 0.21 - 0.81 %, K<sub>2</sub>O 0.18 - 1.42 %, CaO 0.14 - 0.22 %, MgO 0.04 - 0.19 %, MnO 0.02 - 0.04 %, P 0.02 - 0.05 %, TiO<sub>2</sub> 0.13 - 0.43 %, V<sub>2</sub>O<sub>5</sub> 0.02 - 0.05 %, Cr<sub>2</sub>O<sub>3</sub> 0.02 - 0.06 %. Multivariate factor analysis was carried out on geochemical data for understanding the processes involved in the formation of these ores.

**Keywords:** mineralogy, geochemistry, factor analysis, iron ores

### Introduction

Iron industry has always remained as the backbone of country's development. As good quality steel is needed in various industries, extraction of iron ores has remained in the focus for many states. Fortunately, Odisha is endowed with rich resource of iron ores in the Joda-Barbil sector where mining is carried out since decades. However, exploration of good quality ores and their assessment is always a challenge.

### Geological set up

The study area fall under survey of India Toposheet No 73 G/5 around 21° 57' 49" - 21° 57' 25" N Latitude and 85° 15' 32" - 85° 16' 13" E Longitude in Bonai sub-division of Sundargarh district of Odisha (Fig.1). The study area is a part of a low NNE plunging synclinorium overturned towards southeast, which is commonly known as the horse-shoe synclinorium and belong to BIF-III (Acharya, 1984). The ores are associated with Banded Iron Formation (BIF). The BIF members include Banded Hematite Quartz (BHQ), Banded Hematite Jasper (BHJ), Banded Hematite Chert (BHC). The deposits occur near the closure part of the synclinorium which is also known as the Singhbhum-Keonjhar-Bonai iron ore belt extending up to 60 kms. The rocks of the belt belong to Precambrian which include schists, tuffs, phyllites, basic rocks and banded iron ore formation (Jones, 1934<sup>[8]</sup>).

The ores of these deposits include hard massive ore, soft laminated ore and blue dust. Soft laminated ores are associated with shales. The powdery ore and soft laminated

ores are observed underneath of hard ore and blue dust is found at the bottom of ore zone. Iron ores occur in the form of hard laminated ore, hard massive ore, soft laminated ore, lateritic ore and blue dust. The soft laminated ore and blue dust invariably contain shale occurring concordant to iron ore band. Limonitisation of iron ore is common along the fracture plane occurring across the ore body and also along the bedding plane and foliation plane (Chakraborty and Majumdar, 1986 and 2002)<sup>[2,3]</sup>.

### Materials and Methods

1. Representative samples of different iron ore types and associated rock typed were collected from different parts of the study area. Representative fractions of the samples were ground to below 200 mesh size by conventional grinding methods for geochemical and XRD studies.
2. Polished section of typical iron ore varieties were prepared for microscopic studies. The polished sections were examined under the microscope (Leica make). By this study the mineralogy, texture, microstructure, grain size distribution pattern in respect to various ore types were observed.
3. Mineral identification and their characterisation were done through X-ray diffraction technique. X-ray study was carried out by powder method. In this method, a mineral is ground up to a fine powder.
4. Powder mineral sample is placed on a sample stage so that it can be irradiated by the X-ray tube. To detect the

diffracted X-rays, an electronic detector is placed on the other side of the sample from the X-ray tube and is allowed to rotate to produce angles from 0° to 90°.

**Mineralogical study of ores**

Field study confirmed the presence of iron oxide and silica as interbands known as Banded Iron Formation or BIF (James, 1983). Ore microscopic study was carried out to know the details of mineralogical variations in BIF and iron ores. Common primary minerals are hematite, martite, relict magnetite. The secondary phases are goethite and specularite. Small granules and skeletal of iron oxide are found in jasper matrix. Presence of magnetite as dusts, granules and in skeletal form in jasper and cryptocrystalline chert bands seemingly justify the assumption that it was the precursor of iron oxide minerals in BIF. Martite is commonly observed in the ores. These minerals occur as dusts (<0.01mm) or micro crystals (0.1mm) both individually and in aggregate. Martitization of magnetite is complete in smaller grains while in larger grains relict magnetite is commonly observed at the core. Diagenesis has favoured the development of hematite crystals from martites and is the most common mineral found in the ores. Diagenesis also favoured growth of secondary hematite, which differ from martite primarily by absence of relict magnetite in them and are generally found in the form of bladed crystals known as specularites. Goethite minerals are also secondary in nature and are formed due to remobilization of iron oxide along the cracks and cleavages of early formed minerals. Goethite is found replacing hematite along cleavage planes. Chert / Jasper and hematite are intimately existing as primary bands consisting of very fine crystallites (dust like) of hematite in chert matrix giving a “Pepper and salt” textural pattern. Jasper and chert form the gangue mineral in iron ores. Jasper is a cryptocrystalline variety of chert impregnated with fine/dusty hematite grains and is always found as bands in association with iron formations. Chert is also cryptocrystalline silica devoid of any impregnation of dusty hematite occurring as bands of varied dimensions in association with iron ores. The chert grains are usually bigger in size than those of jasper.

Evidence of diagenesis is seen with different size and shape of iron oxide (hematite) grains in jasper bands. Replacement textures are also observed with veins of goethite replacing chert and hematite.

**Geochemical study of ores**

Field study confirmed the presence of iron oxide and silica as interbands known as Banded Iron Formation or BIF (James, 1983) [7]. Ore microscopic study was carried out to know the details of mineralogical variations in BIF and iron ores. Common primary minerals are hematite, martite, relict magnetite. The secondary phases are goethite and specularite. Small granules and skeletal of iron oxide are found in jasper matrix. Presence of magnetite as dusts, granules and in skeletal form in jasper and cryptocrystalline chert bands seemingly justify the assumption that it was the precursor of iron oxide minerals in BIF.

Iron ores of Nadidih and Oraghat are found to contain variable quantity of Fe<sub>2</sub>O<sub>3</sub>. Fe<sub>2</sub>O<sub>3</sub> in iron ore samples varies from 67.24 % to 94.52 %. Al<sub>2</sub>O<sub>3</sub> content in iron ores varies from 1.05 to

8.20 %. SiO<sub>2</sub> in iron ores is very low and varies from 1.11 to 14.21 %. In massive iron ores and blue dusts SiO<sub>2</sub> is lower compared to other ore types. Na<sub>2</sub>O in iron ores varies from 0.21 to 0.81%. K<sub>2</sub>O in iron ores varies from 0.18 to 1.42 %. CaO in iron ores varies from 0.14 to 0.22%. MgO in iron ores varies from 0.04 to 0.19 %. P in iron ores varies from 0.02 to 0.05%. MnO in iron ores ranges from 0.02 to 0.04%. CuO in iron ores varies from 0.03 to 0.05%. TiO<sub>2</sub> in iron ores varies from 0.13 to 0.43%. V<sub>2</sub>O<sub>5</sub> content in iron ores varies from 0.02 to 0.05%. Cr<sub>2</sub>O<sub>3</sub> content varies from 0.02 to 0.06%.

**Table 1:** Range, minimum, maximum and average of major and minor Oxides in % of Iron ore samples of Koira region.

Descriptive Statistics				
	Range	Minimum	Maximum	Mean
Fe	19	47	66	62.08
Fe <sub>2</sub> O <sub>3</sub>	27.28	67.24	94.52	88.6175
Al <sub>2</sub> O <sub>3</sub>	7.15	1.05	8.20	2.1555
SiO <sub>2</sub>	13.10	1.11	14.21	3.3295
LOI	4.59	1.85	6.44	3.6863
Na <sub>2</sub> O	.60	.21	.81	.5059
K <sub>2</sub> O	1.24	.18	1.42	.4264
CaO	.08	.14	.22	.1635
MgO	.16	.04	.19	.0642
P	.03	.02	.05	.0379
MnO	.02	.02	.04	.0295
CuO	.02	.03	.05	.0366
TiO <sub>2</sub>	.30	.13	.43	.2478
V <sub>2</sub> O <sub>5</sub>	.03	.02	.05	.0296
Cr <sub>2</sub> O <sub>3</sub>	.04	.02	.06	.0309

**Multivariate factor analysis**

Multivariate geostatistical technique such as factor analysis was applied to the geochemical data to understand the processes of ore formation (Davis, 1973 and 1986) [4, 5].

The general purpose of factor analytic technique is to find a way of condensing the information contained in a number of original variables into a smaller set of new composite dimensions with minimum loss of information (Davis, 1986; Ratha and Sahu, 1993; Ratha *et al.*, 1994; Ratha, 1997) [5, 13, 13, 11]. The R-mode factor analysis with rotation was applied to normalized major and trace element data of iron ores and BIF (Kaiser, 1958; Kumru and Bakac, 2003) [9, 10].

The general form of function is:

$$Z_j = a_{j1}f_1 + a_{j2}f_2 + \dots + a_{jm}f_m + d_ju_j$$

Where, Z<sub>j</sub>= variable j in standardized form; f<sub>m</sub> = hypothetical factors;

u<sub>j</sub> = unique factor for variable j; a<sub>j1</sub> = relative importance of the common factor 1 and d<sub>j</sub> = standardised regression coefficient of variable j on unique factor j.

Prior to the statistical analysis the data were normalized by the transform log[C/(1-C)] for major elements and log C for trace elements, where C is the weight fraction of the elements (Davis, 1973 & 1986; Ratha and Sahu, 1994) [4, 5, 13].

An important concept in factor analysis is rotation of factors. The main aim of rotation is to find new directions so that loadings on few variables tend to 1 and on others tend to 0.

This reduction of ambiguities that accompany the initial unrotated factor loadings improves the interpretation. For this Varimax rotation has proved very successful as an analytical approach (Kaiser, 1958) [9].

Factor analysis with varimax rotation on the geochemical data of iron ores brought out four common factors. They are as follows:

**Factor 1:** The first rotated factor explaining 48.043 % of the total variance is strongly loaded on SiO<sub>2</sub> (+ve), Al<sub>2</sub>O<sub>3</sub> (+ve), K<sub>2</sub>O (+ve), P<sub>2</sub>O<sub>5</sub> (+ve), LOI (+ve), MnO (+ve), CaO (+ve), MgO (+ve), Fe<sub>2</sub>O<sub>3</sub> (-ve) and CuO (-ve). Since there are very strong loading on SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub> and LOI with strong -ve loading on Fe<sub>2</sub>O<sub>3</sub> this factor may be interpreted as ore formation factor revealing the formation of Iron Ores of different types such as Hard Massive Ore, Lateritic Ore, Blue dust in association with Quartz and clay. In this process predominately silica has been leached out from the original matrix by the process of weathering with the enrichment of Iron.

**Factor 2:** The second rotated factor explaining 23.159 % of the total variance is strongly loaded on V<sub>2</sub>O<sub>5</sub> (+ve), CuO (+ve), Cr<sub>2</sub>O<sub>3</sub> (+ve), CaO (+ve), MgO (+ve) and MnO (-ve). Since strong loadings are observed on V<sub>2</sub>O<sub>5</sub>, Cr<sub>2</sub>O<sub>3</sub> and CuO, which are refractory elements this factor may be interpreted as

refractory elements factor revealing the occurrence of these elements in iron ores which are residual accumulations. The negative loading on MnO indicates depletion of Mn from refractory accumulation.

**Table 2:** Rotated Component Matrix<sup>a</sup>

	Component		
	1	2	3
SiO <sub>2</sub>	.934	.078	.202
Fe <sub>2</sub> O <sub>3</sub>	-.933	-.015	-.281
Al <sub>2</sub> O <sub>3</sub>	.923	.076	.203
K <sub>2</sub> O	.900	.146	-.044
P <sub>2</sub> O <sub>5</sub>	.827	-.188	.260
LOI	.740	-.221	.491
V <sub>2</sub> O <sub>5</sub>	.177	.829	.084
MnO	.472	-.767	.047
CuO	-.471	.749	.091
Cr <sub>2</sub> O <sub>3</sub>	.121	.655	-.477
CaO	.445	.640	.361
MgO	.583	.635	.471
TiO <sub>2</sub>	.299	.208	.862
Na <sub>2</sub> O	-.190	.003	-.796

**Extraction Method:** Principal Component Analysis.  
**Rotation Method:** Varimax with Kaiser Normalization  
 a. Rotation converged in 5 iterations.  
 Rotation method: Varimax with Kaiser normalisation.

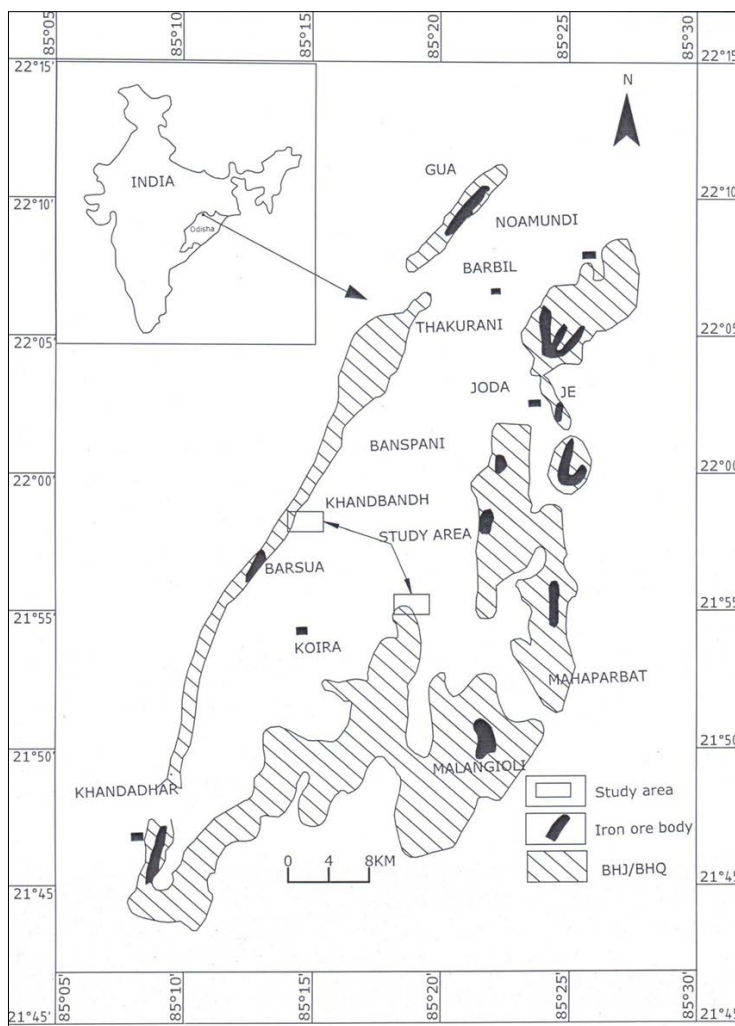


Fig 1: Location map of study area showing iron ore and BIF (modified after Jones, 1934) [8]

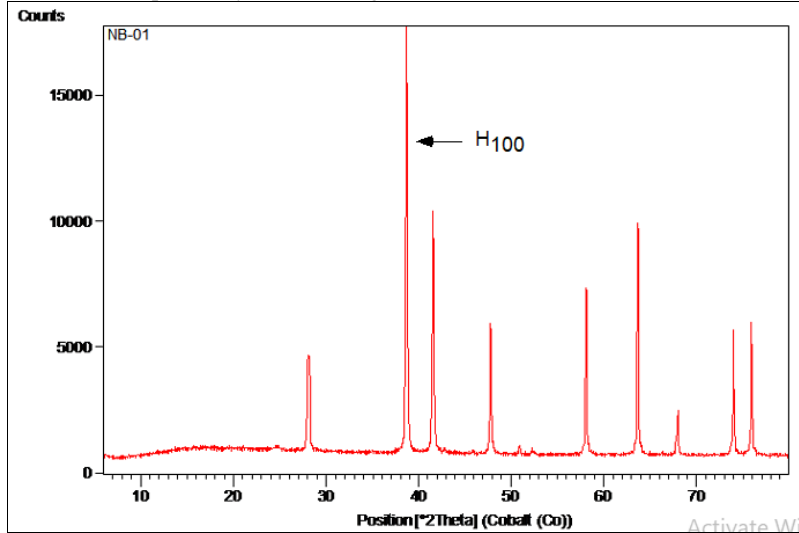


Fig 2: Hard massive ore of Hematite consisting of only Hematite (H<sub>100</sub>)

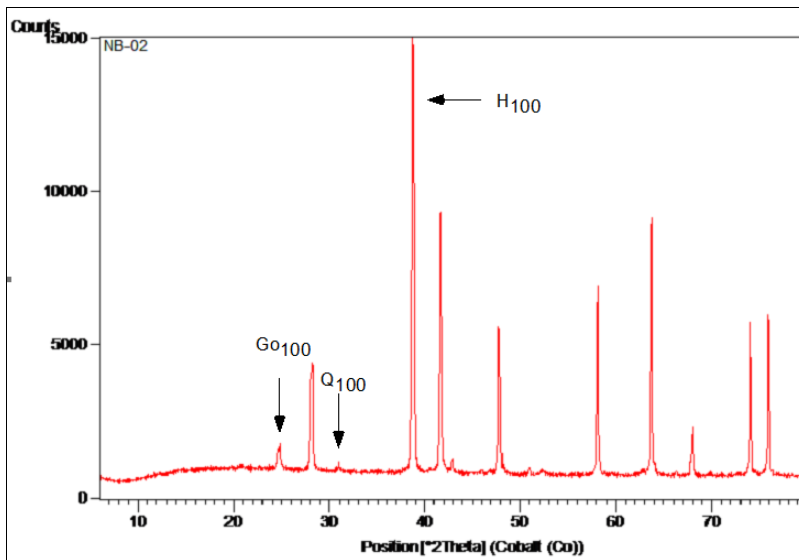


Fig 3: Hard massive ore having predominant Hematite(H<sub>100</sub>) with trace of Goethite(Go<sub>100</sub>) and Quartz (Q<sub>100</sub>)

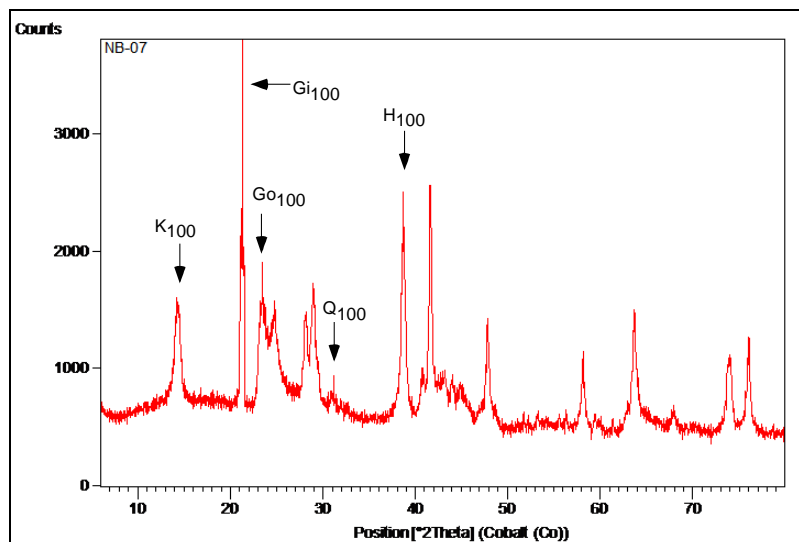
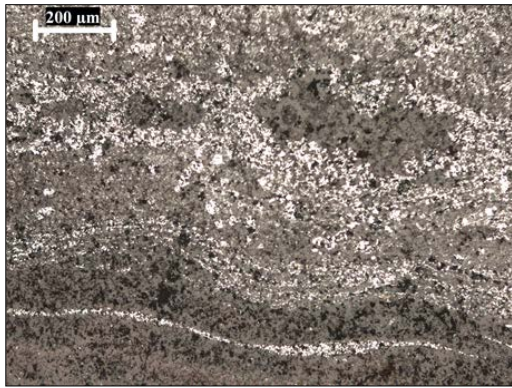
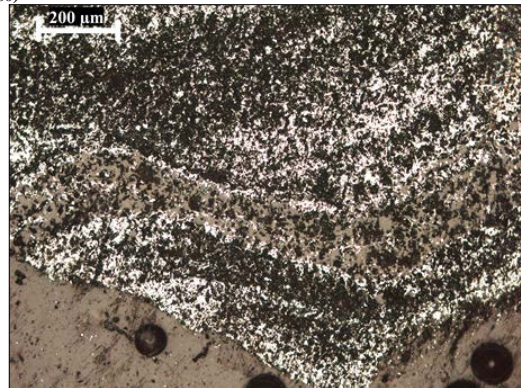


Fig 4: Hard massive ore with shale composed of predominantly Hematite(H<sub>100</sub>), Gibbsite(Gi<sub>100</sub>), Goethite (Go<sub>100</sub>) and Kaolinite (K<sub>100</sub>) and minor

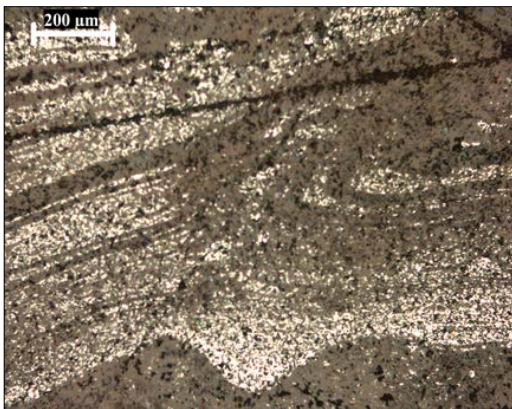
amounts of Quartz ( $Q_{100}$ )



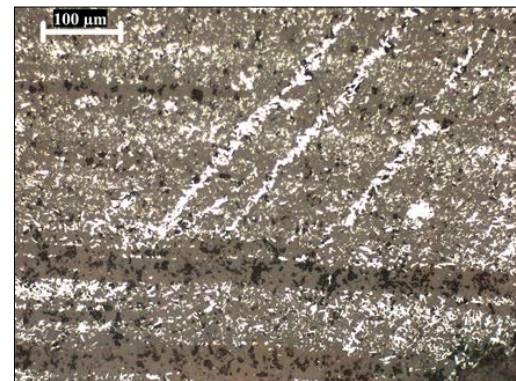
**Fig 5A:** Microfolding in BHQ with pinch and swell texture



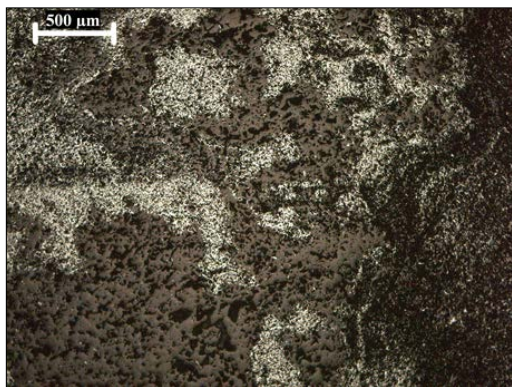
**Fig 5E:** BHQ folding with slump texture



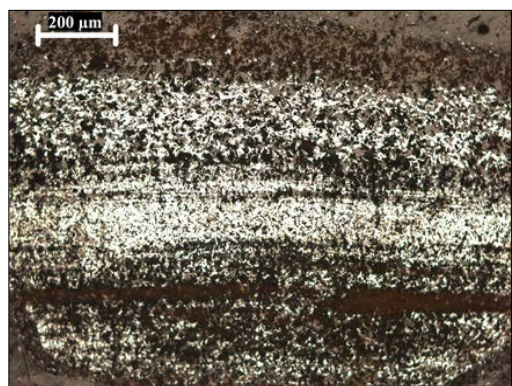
**Fig 5B:** Microfolding and faulting in BHQ



**Fig 5F:** Cross cutting Hematite veins showing secondary Hematites (Two generation of Hematite)



**Fig 5C:** Multi generation microfolding in BHQ



**Fig 5D:** BHJ showing banding

### Conclusion

Fields study, ore microscopic and XRD study of iron ores and BIF indicates sedimentary origin of iron ores. Geochemical studies and factor analysis of chemical data reveal weathering and secondary enrichment of primary ores of the ore deposits. Also, diagenesis and recrystallisation process has played a significant role in enriching ore formation.

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