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Morphology and Mineralogical Characteristics of Detrital Iron Deposit of North Odisha Iron Ore Craton, India

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Abstract

Objectives: North Odisha Iron Ore Craton (NOIOC) is a distinguished place for iron formation with Banded Iron Formation (BIF) as a common and abundant litho type. In few localities in Bonai-Keonjhar belt (BK belt) Channel Iron Deposits (CID) specifically detrital type of iron deposits occur along with BIF. Chamakpur-Inganjharan sector of BK belt located on both sides of bank of the River Baitarani is occupied by Detrital Iron Deposits (DID) with varying spatial horizon. A comprehensive study had been carried out on morphology and mineralogical characteristics of DID in the specified field area to locate new occurrences of iron ore. **Methods:** The morphology part of the study is primarily focused on field observations revealing depositional configuration with respect to size, sorting and orientation of clasts. Mineralogical studies have been carried out by using optical microscope with supported by X-ray Diffraction (XRD) instrumental technique. The bulk chemical analysis was carried out by employing X-ray Fluorescence (XRF) instrument. **Findings:** The DID mostly occurs as isolated bodies with limited extensions comprising predominantly of cobbles and pebbles of hematite with varying amounts of shale, BIF & quartz clasts. Mineralogical study reveals that DID of the study area mainly consist of hematite, goethite, quartz and clay. Hematite, goethite, silica and clay are common matrix that bind the clasts in DID. **Novelty:** DID occur as a type of iron formation next to Banded Iron Formation with regards to abundancy, which has not yet been focused for prospecting. Not much geological work has been done in the area to attain the commercial production of DID, even though they are available in suitable grades. So this paper discusses about the lithological and mineralogical characteristics of DID, which will help in mining of detrital Fe-ores to maintain the sustainable mineral development in a fast depleting BIF hosted Fe-ore scenario. We also discussed the possible mode of deposition of DID in form of alluvium and colluvium that have been supplied from bedded type of Fe deposits. It is evident from the studies that dominated by hematite fragments, DID can be the future source of iron production.

Keywords: Detrital Iron Deposit (DID); North Odisha Iron Ore Craton (NOIOC); Morphology; Mineralogy; BK belt

1 Introduction

Iron formations of Odisha are distributed in three groups encircling the North Odisha Iron Ore Craton (NOIOC), is designated as Iron Ore Super Group (IOSG) of Odisha [1–3]. Bonai-Keonjhar belt (BK belt), popularly known as Horseshoe belt [4,5] of Keonjhar district of Odisha, is one among the three iron ore groups (other two are Badampahar-Gorumahisani-Sulaipat & Daitari-Tomka belt) [3,5], which has highest reserve of iron ore to feed the iron and steel industries and export trade of the state. It is considered as the youngest iron ore group [1,3] comprising mainly of un-metamorphosed BIF of Precambrian age 2.47-2.32 Ga [1] that hosts the hematitic iron ore deposits throughout the belt. In some localities other than BIF there is occurrence of Detrital Iron Deposit (DID) belonging to the channel iron deposits (CID) [6,7].

DID described under different nomenclature has been reported from the Hamersley province of Pilbara Craton, Western Australia [7–9]. In this region DID occurs in association with the dominant BIF hosted bedded iron deposits and channel iron deposits. According to Kneeshaw and Morris [9], DID of Hamersley province comprises of hematite-goethite colluvial/alluvial deposits (~50-60 wt. % Fe), which have been derived largely from erosion of bedded iron ores hosted in the Achaean-Proterozoic Brockman iron formation. This depositional model of DID from the Hamersley province may be very much similar to DIDs of Chamakpur-Inganjharan area of BK belt. Apart from this formation, Solomon CID was discovered during late 2003 onwards which together with Robe and Marillana paleaeochannels contribute over 40% of the iron ore exported from the Province [10].

DID of Inganjharan-Chamakpur sector laying in the eastern limb of BK belt comes under the Survey of India Toposheet no. F45H8 (73 F/8) and bounded by the latitudes N 21°59′30″ to 22°01′00″and the longitudes E 85°27´30″ to 85°29′00″. DID in this area mainly comprise of pebbles and cobbles of hematite/goethite clasts cemented by fine matrix of lateritic and/or goethite/hematite masses. Morris and Ramanaidou suggested that DID in the Pilbara region, Western Australia differs from CID having iron rich talus that deposited in valley margins adjacent to BIF-hosted beddings, whereas CID is used to cover iron rich horizons of the channel deposits [8,9]. Colluvial and alluvial materials are derived primarily from the iron formation provenance to form the DID. Minable size of detrital iron deposits occur very prominently in Chamakpur and Inganjharan area on both sides of the river Baitarani. DID covering an area about ~2.5 km^2 (3×0.85 km) at Inganjharan and ~1.5 km^2 (1.5×1 km) at Chamakpur overlie the sandstone [11,12]. Mining of iron ores from DID horizons of Chamakpur area is carried out sporadically and in very limited extent even though it has great possibility of expansion. The depth of excavated area and morphological extension gives an impression that the DID occurs with considerable amount for future mining. Existing reserve of hematite ore account for around 28% of total iron resource of country [13,14] and it is fast depleting. So the left out DID resources can be converted into reserves in order to ensure an uninterrupted supply of iron. This paper briefly deals with the morphological and mineralogical characteristics of the detrital iron deposits of the study area to highlight its mode of formation and production suitability.

1.1 General geology of study area

The Chamakpur-Inganjharan detrital iron deposit is located at the north-eastern part of the eastern limb of Bonai-Keonjhar belt (Figure 1). The Bonai-Keonjhar belt is designated as BIF-III and it is the youngest Iron Ore Group amongst the three IOGs in the Iron Ore Super Group of Odisha[1,3]. Dhanjori Quartzite underlying this belt[11,12,15] contains BIF as the major supracrustal in addition to the other volcano-sedimentary rocks forming a significant portion of the Singhbhum-North Odisha Craton of eastern Indian shield. DID of Chamakpur-Inganjharan area lies in between Singbhum granite on the east and the Bonai granite on the west. The litho-associations of this area comprise of banded hematite jasper, banded hematite quartz/chert, banded shale, banded manganese formation and ferruginous shale. Apart from the BIF, there also occurs the small horizons of DID and Brecciated Iron Deposit (BID) in discontinuous manner. DID consisting of pebbles/cobbles of hard laminated hematitic ore, irregular fragments of BIF, shale, chert and jasper are cemented mostly by hematite/goethite. The matrices may also include fine to medium grained clastic quartz and silica. The disposition of DID masses in form of mounds and upheaval patches in the area remain aligned with the general trend of BK belt i.e. NNE-SSW[15]. A north-south fault along the course of Baitarani River has separated Chamakpur area from Inganjharan. Apart this several east-west aligned faults have also been noticed in this region (Figure 2).

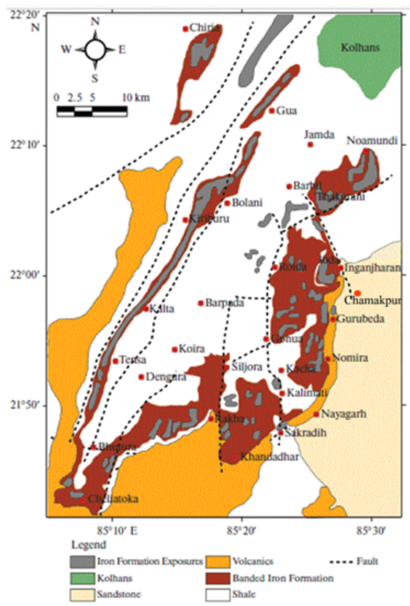

Fig 1. Generalized geological map of Bonai-Keonjhar belt (Modified after Jones; Nanda and Beura[1])

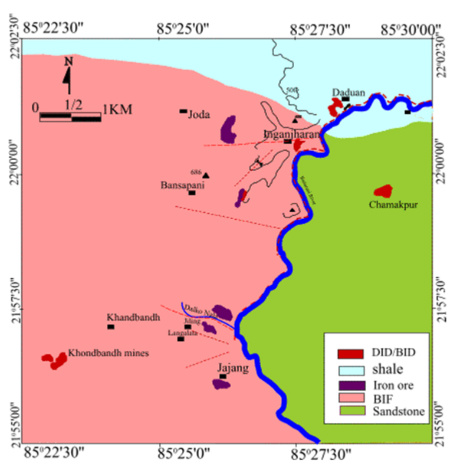

Fig 2. Geological map showing the DID deposits of Chamakpur-Inganjharan area of Bonai-Keonjhar belt

2 Methodology

Representative DID samples were collected from different outcrops of the Chamakpur -Inganjharan area of North Odisha Iron Ore Craton. The study includes morphological, mineralogical and chemical characterization of DID samples.

2.1 Collection of samples and characterization study

2.1.1 Field investigation

Geological field survey was carried out in detail to delineate the morphology and mode of occurrences of DID, and collection of representative samples from different outcrops of Chamakpur-Inganjharan area.

2.1.2 Mineralogical

The mineralogical study has been carried out by using optical microscope Leica DM-750P with supported by X-ray diffraction studies. A number of thin sections and polished sections were prepared from representative samples for microscopic studies under both transmitted and reflected light. The representative samples were crushed and pulverized to 74 micron size to obtain a homogeneous sample for X-ray diffraction study and geochemical analysis. X-Ray Diffraction (XRD) study was carried out by using PANalytical X-Pert PRO X-Ray diffractometer instrument. The characteristic X-ray data for the mineral phases present in the sample were obtained in the form of peaks with relative intensities, angles of the peaks in 2θ with their respective'd' values in Angstrom units. The X-ray data obtained on the sample was interpreted by using diagnostic patterns of standard minerals in (JCPDS, 1974)[(16)] diffraction file.

2.1.3 Chemical

Geochemical analysis was carried out by using X-Ray Fluorescence (XRF) instrumental technique. Major and minor oxides are analyzed by using X-Ray Fluorescence (XRF), PANalytical (PW-2403 Magixmodel). A rhodium target is used to generate X-ray which gives Fe (Kα) line at 6.375 keV. Loss on ignition (LOI) was determined by using weight difference after ignition at 1000°C.

3 Results

3.1 Morphology of Detrital Iron Deposit

Detrital Iron Deposit occurs as sizable stretch in Chamakpur-Inganjharan sector juxtaposed to the channel iron deposit running close to bank-side of River Baitarani. Formed by similar depositional mode, DID is discriminated from CID basing upon its physico-morphologoical characteristics. Shape, size, orientation of clasts and matrix types are some of the observed morphological characteristics describing the DID in the study area. In Chamakpur area, DID occurs as separate entity in form of segregated heaps and mounds with limited deep rooting of 3-4 meters [Figure 4 A]. Also, it extends as short ridges and elongated loads with irregular trends [Figure 4 B]. But the Inganjharan DID forms the terrain configuration of river bank with low relief [Figure 4 C]. The major mineral constituents of DID are hematite and goethite in form of clasts and matrix. The admixing of fragments of BHJ, jasper, quartz and shale are found in different proportion, which depends mainly on supply dynamics of provenance. Joda East being the nearest and potential iron formation at high altitude 675 meter above mean sea level [Figure 3] might have supplied the material to be deposited as alluvial/colluvial masses. Even though the supplier provenance is same i.e. Joda East iron formation, there is morphological variation between Chamakpur and Inganjharan DID. The DID of Chamakpur comprises clasts of banded hematite jasper/hard laminated ore of sizes ranging from pebble to boulder along with minor amount of quartz and shale, which are sub-rounded to angular in shape. DID comprising of more BHJ, jasper and shale fragments are the low grade ores [Figure 4 D] while the pieces of laminated iron ore constituting the DID are high grade in nature [Figure 4 E]. Numerous voids appear on external part of the DID due to dislodging of clasts from the matrix by leaching process [Figure 4 F]. DID of Inganjharan have been formed by gravel/cobble sized rounded clasts of hematite, which exhibits morphological similarity with canga ore [Figure 4 G]. In the foothill areas near to the provenance few isolated patches of DID are noticed where large pebbles of around 5-6 cm are arrested within the cementing masses [Figure 4 H].

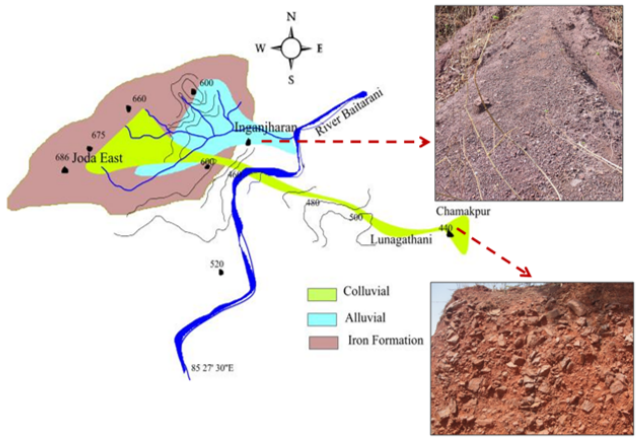

Fig 3. Schematic diagram of Chamakpur-Inganjharan colluvial/alluvial iron ore deposits

Fig 4. Field photographs showing (**A**) Segregated heaps and mound of DID of different dimensions in Chamakpur area. (**B**) Loose fragments of angular to sub-rounded iron ore and quartz forming short ridges and elongated loads in Chamakpur area. (**C**) DID occur as low relief and limited tabular extensions along river bank in Inganjharan area. (**D**) Hard and massive DID in Chamakpur area comprising clasts of BHJ, jasper and shale. (**E**) Soft and flaky laminated iron ore fragments dominate the constituents of DID in Chamakpur area. (**F**) Several voids appear in DID of Chamakpur area due to dislodging of clasts from bounded mass. (**G**) Gravels/cobbles of hematite are bounded by hematite/goethite matrix to form the DID in Inganjharan area. (**H**) Large pebbles of around 5-6 cm are arrested within the matrix in DID of Inganjharan area

3.2 Mineralogical Characteristics

Detrital Iron Deposits (DID) are colluvial/alluvial deposits mainly derived from the banded iron formations and iron ores. DID comprising of clasts of various compositions (banded hematite jasper/hard laminated ore/massive hematite), are embedded in fine grained iron mineral matrix admixed with clay and silt. Microscopic study reveals that DID of the study area exhibits irregular pattern of clast arrangement within matrix that predominantly contain iron oxides (hematite and goethite) with subordinate amounts of quartz and minor to very minor amounts of clay (kaolinite), and gibbsite.

Microscopic studies of DID samples in Chamakpur area shows fine to coarse grained and subhedral to anhedral hematite fragments constituting the major component [Figure 5 A]. Hematite also occurs as fine disseminated matrix binding both hematite and quartz grains [Figure 5 B]. Grain size of hematite ranges from 10 microns to 2500 micron. The variations in grain size distribution indicate that the hematite might have been developed during the recementation process followed by recrystallization [Figure 5 C]. At few places, randomly oriented micro platy hematite grains are noticed in some DID samples, which seems to be developed during the process of recrystallization [Figure 5 D]. At some places, fragmented banded hematite jasper (BHJ) clasts are cemented in the fine grained quartz and clay matrix [Figure 5 E]. Some of the hematite clasts are enveloped by goethite bands showing well developed colloform texture. Goethite occurs as crystalline as well as microcrystalline aggregates to amorphous patches. At some places, goethite occurs as cortices on hematite grains or as intergranular fillings in the matrix part [Figure 5 F].

Microscopic studies of DID samples from Inganjharan area confirm different shape and size of clasts in comparison to Chamakpur area. Rounded to sub rounded grains of hematite and quartz are embedded within siliceous and clay matrices in DID of Inganjharan area [Figure 5 G and H]. Rounded grain contents in large proportion suggest that iron ores and quartz in form of alluvium have formed the DID in Inganjharan area. Development of goethite is noticed along the margins of hematite grain evidenced by colloform texture [Figure 5 I]. Abundant goethitisation process during the formation of DID might have lowered its grade. Some of the DID patches in Inganjharan show less amount of detrital than matrix [Figure 5 J]. BHJ, hematite and quartz fragments altogether exist in the DID indicate the erosion has taken place in broad area with diverse lithosome. Continuous alteration process in hematite grains to form goethite has left behind the skeletons of hematite at different phases [Figure 5 J].

3.2.1 Modal Analysis

Modal distribution of minerals in Chamakpur and Inganjharan area suggests that DID of Chamakpur area have more concentration of hematite in comparison to DID of Inganjharan area. Moreover, it is also observed that the goethite and clay mineral concentration drastically increased in the Inganjharan area. The approximate modal distribution of minerals in the DIDs of Chamakpur and Inganjharan area are presented in below [Table 1]

Table 1. Modal Distribution of Minerals in DID of Chamakpur and Inganjharan Area

Minerals	Approximate (%)	
	Chamakpur	**Inganjharan**
Hematite	70-75	45-50
Goethite	10-15	35-40
Quartz	7-10	3-5
Clay (kaolinite)	5-7	10-15

3.2.2 X-Ray Diffraction (XRD Studies

XRD study shows that DID samples consist of hematite, goethite, quartz, kaolinite and gibbsite [Figures 6 and 7]. The identified mineral phases of DID in Chamakpur and Inganjharan area are presented in [Table 2]

Table 2. XRD study of DID samples of Chamakpur and Inganjharan area

Sl. No.	Sample	Mineral Phases Identified
01	DID- Chamakpur	Hematite (Hem.), Quartz (Qtz.), Goethite (Gth.),
02	DID- Inganjharan	Hematite (Hem.), Goethite (Gth.), Quartz (Qtz.), Kaolinite (Kao.), Gibbsite (Gibb.)

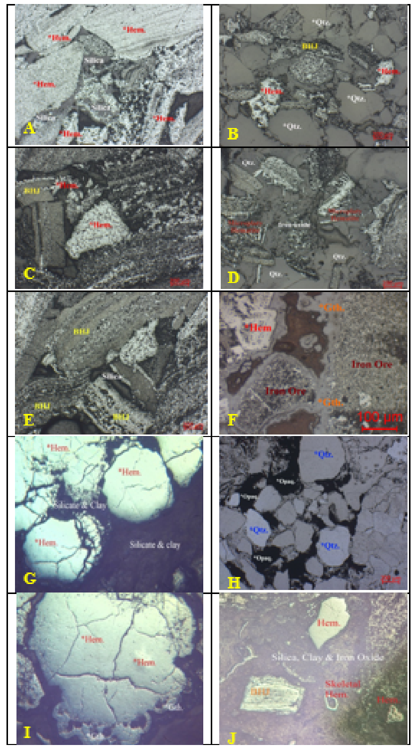

Fig 5. Photomicrographs of DID of Chamakpur area underreflected light showing (A) Subhedral to anhedral hematite fragments asmajor constituents of DID (X 200). (B) Quartzis dominating over iron ore fragment cemented mostly by Fe masses. (C) Variation in grain size indicatesrecrystallisation of hematite. (D) Presence of micro platy hematite grains inDID indicate that either they are transported or developed by the process ofrecrystallisation. (E) Banded hematite jasper (BHJ) clasts asdominating constituents in DID cemented in the fine grained silica matrix. (F)Goethite develops along the external borders of iron ore and hematite grains bygoethitisation process. Photomicrographs of DID of Inganjharan area showing (G)Rounded hematite clasts bounded by silicate and clay matrices (Reflected lightX100). (H)Rounded to sub-rounded quartz grains cemented in the fine grained iron oxidematrix (opaque) (Trans. light). (I) Development of goethite around the hematitegrain exhibited by colloform texture. Fractures on hematite grain may bedeveloped by abrasion (Reflected light X100) (J) Concentration of clasts inDID is less as compared to matrix amount. Varieties of clasts like BHJ,hematite, skeletal hematite are present in the matrix comprising of iron oxide,silica and clay (Reflected light X100)

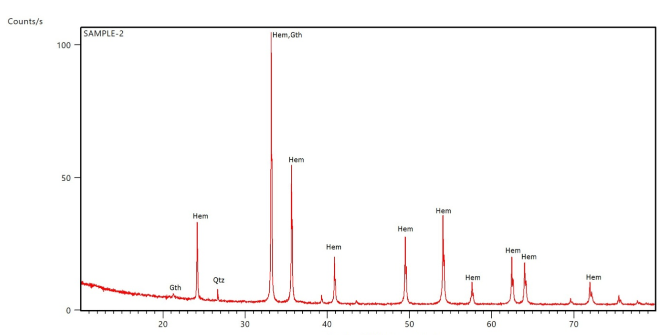

Fig 6. X-Ray Diffraction graph showing different mineral phases present in Detrital Iron Deposit ofChamakpur area

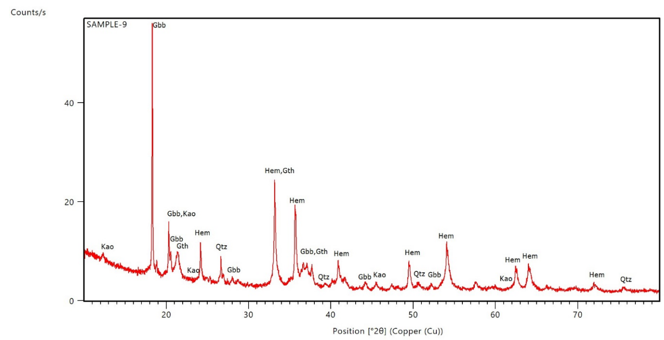

Fig 7. X-Ray Diffraction graph showing different mineral phases present in Detrital Iron Deposit of Inganjharan area

3.2.3 Chemical Analysis

The bulk chemical analysis (major and minor oxides) of representative DID samples [Table 3] revealed that the$Fe_2O_{3(T)}$ content in DID varies from 71.10% to 90.78%, SiO_2 content ranges from 5.19 to 14.45% and concentration of Al_2O_3 ranges from 1.56% to 7.86%. The other minor oxides have relatively low contents of Na_2O (0.01%-0.07%), K_2O (0.01%-0.11%), CaO (0.01%-0.07%) and MgO (0.02%-0.13%) in the studied samples. It is observed that the Al_2O_3, and LOI are comparatively higher in the DID samples of the Inganjharan area, whereas Fe_2O_3 and SiO_2concentration increases in the DID of the Chamakpur area.

Table 3. Major and minor oxides (wt. %) in detrital iron deposit of study area

Sample	Fe_2O_3	MnO_2	SiO_2	Al_2O_3	Na_2O	K_2O	CaO	MgO	TiO_2	P_2O_5	LOI	Total
Chamakpur Area												
DID-1	89.92	0.05	6.87	1.56	0.03	0.02	0.03	0.04	0.02	0.01	1.43	99.98
DID-2	90.78	0.09	5.19	1.78	0.02	0.03	0.03	0.06	0.07	0.02	1.72	99.79
DID-3	79.75	0.07	14.45	2.28	0.05	0.03	0.04	0.05	0.09	0.01	2.76	99.58
DID-4	82.91	0.12	12.17	2.13	0.04	0.03	0.01	0.04	0.07	0.02	2.46	100.00
DID-5	80.90	0.06	12.96	2.89	0.07	0.05	0.03	0.06	0.04	0.01	2.75	99.82
Average	84.85	0.08	10.33	2.13	0.04	0.03	0.03	0.05	0.06	0.01	2.22	99.83
Inganjharan Area												
DID-6	82.24	0.03	9.83	4.06	0.01	0.01	0.04	0.06	0.21	0.01	3.49	99.99
DID-7	79.44	0.18	7.27	5.97	0.04	0.02	0.04	0.04	0.32	0.22	6.43	99.97
DID-8	71.81	0.09	12.07	7.57	0.01	0.11	0.07	0.13	0.27	0.03	7.83	99.99
DID-9	85.49	0.07	6.89	3.87	0.02	0.11	0.05	0.07	0.13	0.02	3.27	99.99
DID-10	71.10	0.01	12.62	7.86	0.03	0.06	0.03	0.02	0.09	0.05	8.11	99.98
Average	78.02	0.08	9.74	5.87	0.02	0.06	0.05	0.06	0.20	0.07	5.83	99.99

4 Discussion

High grade iron ores including massive, hard & soft laminated and powdery varieties are mostly BIF hosted which are common worldwide [11,17]. Channel iron ore deposits including detrital iron ore deposits are though uncommon but occur in good quantities in and around the iron ore craton of Odisha. While the BIF hosted iron ores are produced by epigenetic process through leaching, the DID are formed from the clasts derived from BIF. Low relief topography near by the BIF mounts of Joda East act as the trap for DID formation [12].

The morphological and mineralogical study indicate that the DIDs of Chamakpur–Inganjharan area are of allochthonous in nature and are mainly formed from banded iron formations (BIF) derived from Joda East area. The iron ore fragments of varying sizes produced from the sources through weathering, erosion process were transported by different means to be deposited at the suitable milieu. Morphology of DID shows difference in clasts size, shape and matrix content between Chamakpur and Inganjharan area. Small and rounded clasts with matrix composition in DID of Inganjharan reveal alluvial type of deposits. But in Chamakpur the constituent fragments are bigger in size and angular in shape which infers that they have undergone quick transport through mass wasting or creep and thus of colluvial type of deposit [Figure 3]. Means of deposit of DID in both the areas are also evidenced by topographic configuration, drainage pattern and altitude difference between provenance and site of deposition.

Detrital iron ore deposits comprise mainly of hematite, goethite, quartz, BHJ and shale as clasts, and hematite/goethite, silica and clay minerals as matrix. Goethite is the next abundant constituents after hematite to appear as clasts and matrix in DID. Colloform goethite bands are developed enveloping the hematite crystals, which are prominent in both Chamakpur and Inganjharan area. Modal distribution of minerals shows that the percentage of goethite and clay in DID of Inganjharan area is high, while in DID of Chamakpur area the percentage of hematite and quartz are more in concentration. Goethitic dominance in DID of Inganjharan area might have lowered its ore grade than Chamakpur area. Micro platy hematite grains found as arbitrarily oriented individuals or as bunch suggesting the recrystallization of hematite within DID. X-ray diffraction study shows that hematite, quartz and goethite are major phases found in DIDs of Chamakpur area while DIDs of Inganjharan area has hematite, goethite, quartz phases along with kaolinite and gibbsite. XRF data supports the modal distribution for minerals in DIDs of the study area showing more LOI and Al_2O_3 in Inganjharan area while less LOI, Al_2O_3 and comparatively more SiO_2 wt. % are shown by DID of Chamakpur area. From these observation we can conclude both the DIDs are formed from the action of weathering, erosion of BIFs in Joda East followed by different mode of deposition i.e. colluvial and alluvial in Chamakpur and Inganjharan area respectively.

5 Conclusion

The DID of BK belt has enough scope to take the place of rapidly consuming BIF hosted iron formation. At present the detrital iron resource may not be economically sustainable. But In due course of time, the technological development may reduce the cut-off grade of Fe and at that point these low grade iron ore resources may be used as suitable raw material for iron and steel industries. The clasts including pebble and cobbles may be segregated from the DID and upgraded to fit for the industries. The geological in-put in terms of lithology and mineralogy of DID may help to determine the occurrence, depth and stretch for the reserve evaluations of Fe.

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