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TECHNICAL PAPER

Mineralogical Studies of Low-Grade Iron Ore from Jharkhand–Orissa Region, India

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Abstract Due to increasing demand of steel in domestic market and depletion of high-grade iron ores day by day, industries as well as policy makers have started working on low-grade iron ores for iron and steel making industries. There are huge scopes for low-grade iron ores in iron and steel making. Aim of this study is to understand of morphology, texture, phase identification and properties of iron ore. Banded iron formation type low-grade iron ore is taken for the mineralogical studies. Characterizations of minerals are carried out by X-ray fluorescence spectroscopy, X-ray diffraction, scanning electron microscopy, energy dispersive analytical X-ray and optical microscopy techniques. Hematite is found as the dominant mineral; whereas quartz and kaolinite are as gangue minerals in low-grade iron ore. By this study, conventional liberation or beneficiation practice can be optimized for low-grade iron ore.

Keywords Low-grade iron ore · Mineralogy of ore · Characterization of ore · BIF

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1 Introduction

India is fortunate to have vast reserves of high-grade iron ores. Total reserve of the iron ore is about 28.52 billion tonnes (Bt), out of which about 17.88 Bt of hematite and 10.64 Bt of magnetite ore as estimated by Indian Bureau of Mines, Nagpur [1], India. There is tremendous increasing demand for steel due to rapid growth and development in recent past. The fast depletion of the high-grade iron ores and their increasing demand in steel industry, put pressure on assessing the exploitation of lean ores. Low-grade iron ore is beneficiated to enhance its iron content up to the desired level of industrial specification required for different end uses [2].

India has huge reserves of low-grade iron ore. Exploration and mining efforts of low-grade ores have not been adequate. Exploration strategy, to mine ores with +45 % $Fe_{(T)}$ grade as a target, is on the anvil. Given the current stage of economic development, the present need is not only to explore new deposits but also to make use of low-grade ores. Towards future availability of iron ore for the domestic iron and steel industries and also for global business; attention for potential use of low-grade iron ores, especially fines [3] are gaining momentum. About 30 % of the total reserve of low-grade iron ore (5.34 Bt) [1] is available to meet the demand of Indian iron and steel industries (as shown in Table 1).

Banded iron formation (BIF) rock of Pre-Cambrian age is responsible for the vast accumulations of commercial grade iron ore deposits in India, out of which more than 90 % of the iron ore is supplied to the industry [3]. The various physical types of iron ore, which are exploited commercially from BIFs, are massive, lateritic, laminated ore and blue dust. Ghosh et al. [4] have reported different types of low-grade of iron ores. They categorized the low-grade iron ores into three

Table 1 Resources of iron ore (hematite) [1]

Sr. No.	Grades	Amount of resources (Bt)	Low grade resources (Bt)	% low grade resources (w.r.t. total resources)
1	Fines	3.82	1.19	6.66
2	Lumps	9.93	1.62	9.06
3	Lumps and fines	2.33	0.73	4.08
4	Unclassified	1.80	1.80	10.07
	Total	17.88	5.34	29.87

types viz. Grade I, Grade II and Grade III which consist of <45 % $Fe_{(T)}$, 45–55 % $Fe_{(T)}$ and >55 % $Fe_{(T)}$ respectively. It has been observed that Grade I mainly consisted of Shale and BHJ, Grade II mainly of laterite, shaly flaky ore and Grade III mainly of laterite, shaly flaky ore, canga etc. They attempted to characterize the various low-grade iron ores from Jharkhand–Orissa region, India for the beneficiation assessment.

In this study, the main emphasis has been given on mineralogical characterization of iron ore to select the beneficiation process for recovering the iron value. The ore has been characterized by volumetric chemical analysis, X-ray fluorescence (XRF), X-ray diffraction (XRD), scanning electron microscopy (SEM), energy dispersive analytical X-ray (EDAX) as well as transmitted and polarized optical microscopy techniques.

Fig. 1 As received low-grade iron ore sample

2 Experimental Work

For the present work, sample of low-grade iron ore is collected from Badjamada mine which is a part of Bonai ranges in Jharkhand–Orissa sector, India. As received, run of mine (ROM) ore samples are taken for mineralogical studies. In hand specimen mineralogy, the ore is reddish to steel gray in colour; having irregular and subangular shapes. Ore exhibits dull lustre, cavernous and friable in nature. Size of as received sample is −25 mm to +10 mm (as shown in Fig. 1). Specific gravity and bulk density of this ore are determined by standard procedures and these values are 3.84 and 1400 kg/m^3 respectively. Hardness (3–4 H) of the ore sample is determined by Mohs hardness.

The chemical analysis of the as received samples are carried out by wet volumetric method as well as bulk chemical analysis by using energy dispersive X-ray fluorescence analysis (EDXRF) 800 Shimadzu, Japan. X-ray diffraction pattern of ore is obtained by PANalytical XRD machine with Cu Kα radiation. A Jeol SEM (Model: JSM—5610 LV), which is coupled with Oxford EDAX system, is used to characterize the morphology of phases as well as chemical analysis of particular phase.

3 Results and Discussion

3.1 Chemical Properties

The chemical analysis of low-grade iron ore is shown in Table 2. Bulk analysis of low-grade iron ore is done by XRF, and also total iron is analyzed by the wet chemical method. The amounts of total iron from both analyses show nearly the same result. The low-grade iron ore contain ~53.6 wt% total iron, 8.5 wt% silicon oxide, 7.3 wt% aluminum oxide and others oxides. This analysis confirms the BIF sample, which is further categorized as low-grade iron ore. Significant amount of Titanium oxide is also recorded in the ore. Amount of harmful element like phosphorus is found to be low (0.02 wt%).

3.2 Mineralogical Studies

The mineralogy studies include ore mineralogy, mineral phase analysis, and texture studies. The texture studies of the as received sample under transmitted microscopy reveals dominantly black colour phase which for hematite and goethite; and whitish colour for different phases of quartz and kaolinite (Fig. 2). It shows inconsistency in

Table 2 Chemical analysis of low-grade iron ore by XRF analysis

Analyte	Fe_T	FeO	SiO_2	Al_2O_3	CaO	MgO	MnO	TiO_2	P	S	Na_2O	K_2O	ZnO	LOI
wt%	53.55	0.9	8.5	7.3	0.15	0.14	0.24	0.42	0.02	0.007	0.043	0.021	0.004	5.31

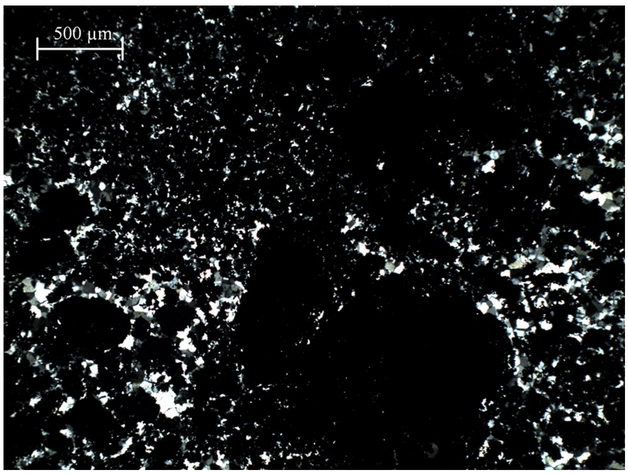

Fig. 2 Transmitted photomicrograph of low-grade iron ore

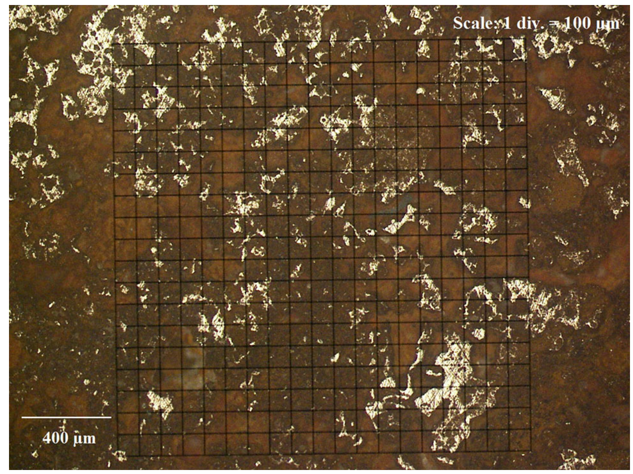

Fig. 3 Reflected photomicrograph of low-grade iron ore

distribution of the hematite phase which is attached with the gangue particles. Tiny gangue mineral phases are interlocked around the surface of ore mineral phases. Blackish colour in both hematite and goethite restricted a clear distinction between them. The gangue minerals consists approximately 60–70 % of hematite ore minerals by area of its distribution. Almost all hematite grains accommodate various size and shapes of gangue minerals.

Mineral phases (which are revealed in the reflected microscopy) are present in the as received sample; such as hematite (brownish colour), goethite, quartz (whitish matrix), and kaolinite (black colour). Gangue phases such as quartz and kaolinite are finely dispersed particles in few regions. Hematite phases are coated or enveloped by gangue phases. Kaolinite mostly coats the hematite grains at finer level. Size of hematite phase varies from few micron to 200 micron; whereas quartz having huge size range from few micron to 400 micron (as shown in Fig. 3). Liberation of ore mineral is difficult due to fine size of gangue mineral. Free grains (i.e. ore mineral) are enveloped/coated by the gangue mineral.

XRD analysis of low-grade iron ore sample is carried out and phase of minerals are identified by JCPDS Cards. Figure 4 shows that the peaks of major iron bearing minerals are hematite (Fe_2O_3, JCPDS Card No. 33-664) and goethite [FeO(OH), JCPDS Card No. 29-713]. The gangue minerals, quartz (SiO_2, JCPDS Card No. 33-1161) and kaolinite ($Al_2Si_2O_5(OH)_4$, JCPDS Card No. 89-6538) are also observed.

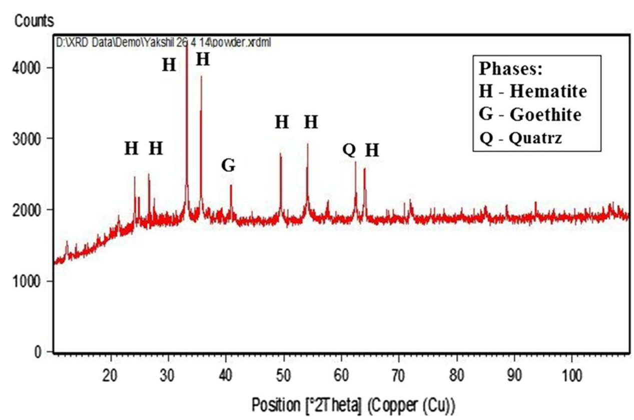

Fig. 4 XRD analysis of low-grade iron ore

SEM study is carried out to determine the textural relationship between mineral phases of low-grade iron ore. Phases are irregular in shape and size varies from very fine to coarse. Considerable amount of cavities are present at the surface. Phases of black colour (quartz) are not interlocked with adjacent phases. Whitish portion of the phases are highly interlocked with each other that are confirmed at higher magnification. White phases (hematite) are covered/coated with gangue phases (greyish in colour). Figure 5a, b show very fine particles combined within the regions at different locations. At the inner part of the cavity, tiny globular precipitates of iron bearing mineral

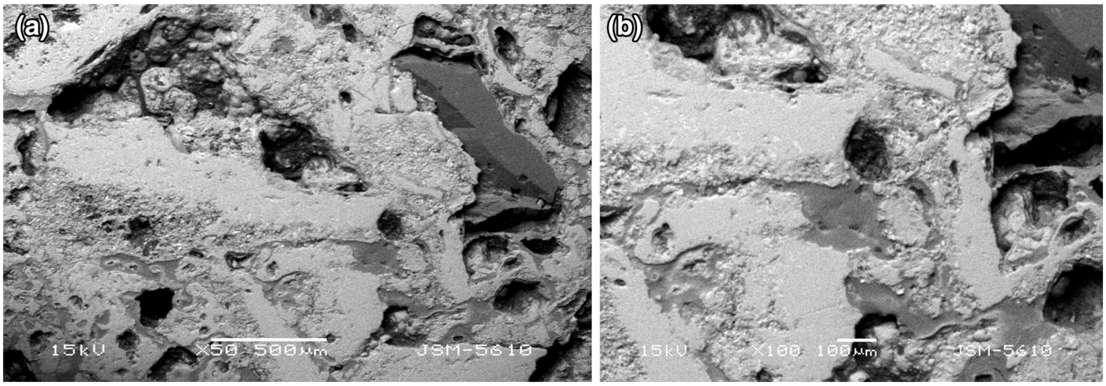

Fig. 5 SEM image of low-grade iron ore sample in as-received state. **a** magnification 50X, **b** magnification 100X

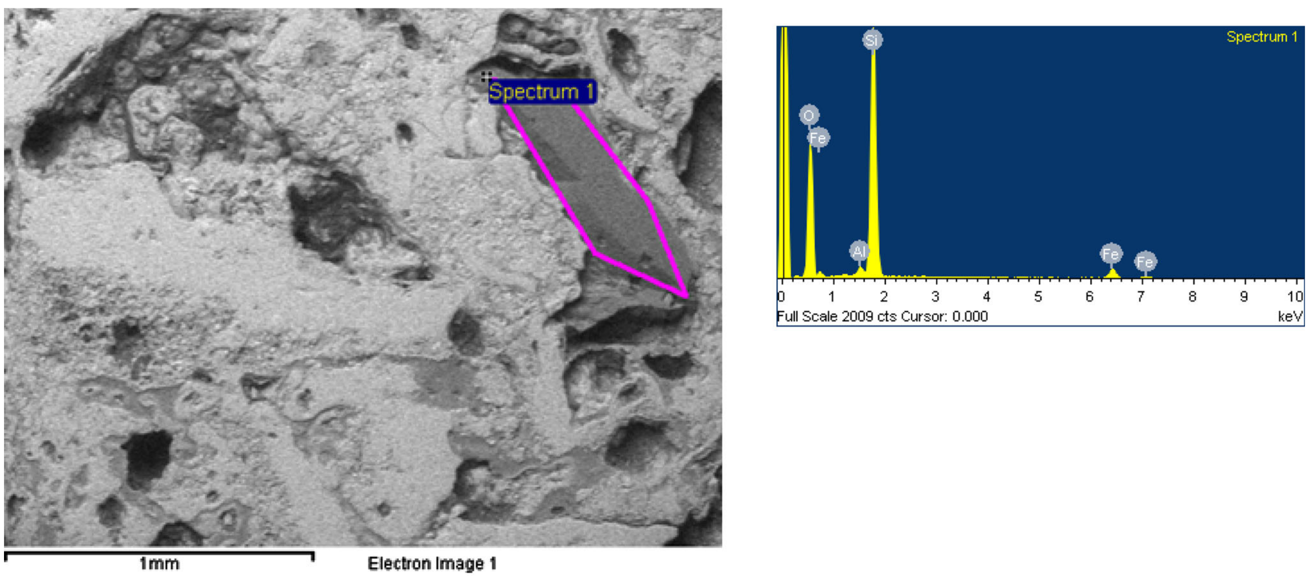

Fig. 6 EDX analysis of sample (*black region*)

are also observed as shown in Fig. 5b. Mostly cavities are observed in gangue minerals region or at the interface of gangue-iron bearing minerals.

For EDX analysis, several spots are targeted for chemical assay (as shown in Figs. 6 and 7). From this characterization, black coloured region is spotted as quartz mineral whereas whitish region is analyzed as iron based mineral. EDX analysis does not give information about the chemical formulae of phases.

4 Conclusions

Indian iron ores have major constraints due to the presence of high amount of kaolinite and quartz which causes the degradation of ore that results in low-grade iron ore. ~53 wt% total Fe is present in low-grade iron ore (by chemical analysis). From mineralogy observation, it is evident that hematite, goethite, quartz, kaolinite and Al–Fe siliceous phases are present in the low-grade iron ore. By microscopic studies, texture and nature of interlocking are observed. Hematite phases are interlocked by fine gangue grains, and also they are covered by gangue grains at finer scale. Most of the hematite grains are highly altered and the mineral alteration zones are clearly visible. All these attributes are also observed in SEM analysis. In SEM analysis, cavities are observed which have the weathered products such as goethite and kaolinite.

By EDX analysis, phases are spot analyzed and elemental information is collected. From mineralogical and characterization analyses, it may be observed that liberation of the ore minerals from the gangue minerals are difficult. It is suggested that a washing treatment be employed after each mineral dressing operation. So, quartz

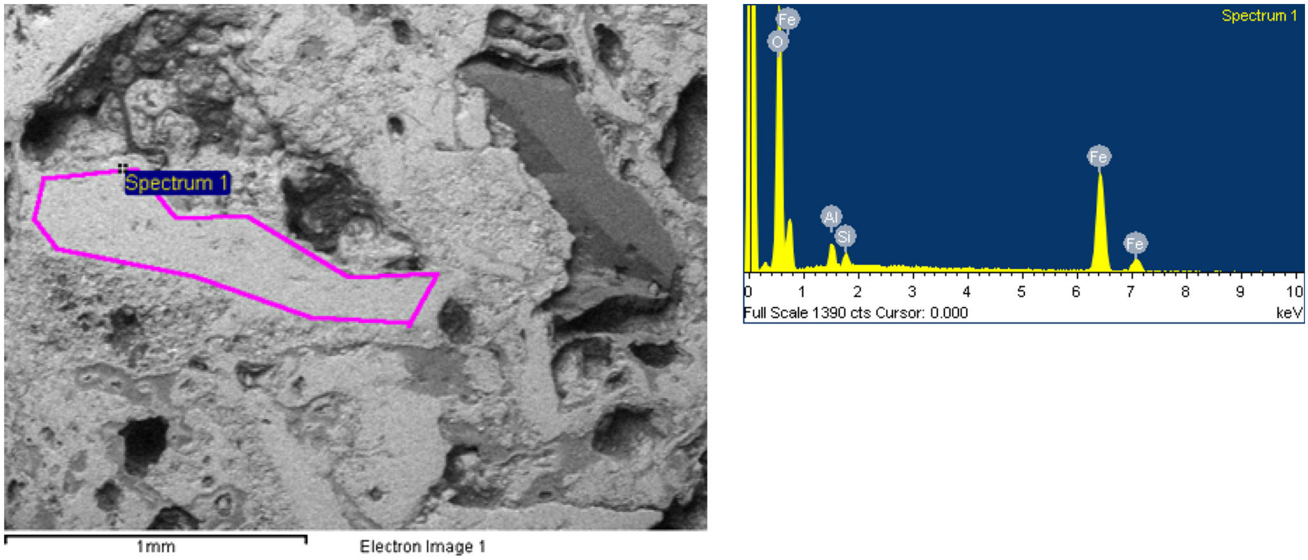

Fig. 7 EDX analysis of sample (*white region*)

and clay mineral separate progressively from the ore minerals. For liberation of ore minerals, especially wet concentration and/or wet classification techniques are essential.

References

1. Indian Bureau of Mines (IBM), Nagpur, India (2010). www.ibm.nic.in/imyb2010_ironore.pdf.
2. Lal S M, Mohan R, and Gundewar C S, *Beneficiation of a Low-Grade Magnetite Ore from Jharkhand Area*, Mineral Processing Technology (MPT-2010), NML Jamshedpur, (2010), p 559.
3. *Iron & Steel—Vision 2020*; Ore Dressing Division, Controller General, Indian Bureau of Mines, Nagpur (2011), p 45.
4. Ghosh T K, Biswas N and Rao S M, *Characterization and Assessment of Low-Grade Iron Ores for Their Beneficiation from Jharkhand–Orissa Region, India*, XXVI International Mineral Processing Congress (IMPC) 2012 Proceedings, New Delhi (2012), p 1842.