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Mode of Occurrence of Phosphorus in Iron Ores of Eastern Limb, Bonai Synclinorium, Eastern India

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Abstract: The eastern limb of horse shoe shaped "Bonai Synclinorium" in India hosts Banded Iron Formations (BIFs), consisting of major high grade iron deposits. Phosphorus (P) gets adsorbed in the iron ore by way of ion exchange mechanism of clay minerals and hydrated secondary iron oxide minerals. Its concentration is lesser in hard ores and blue dust types of ores, while the highest in case of lateritic ores. P content reduces with increase in iron (Fe) content in individual ore types. Along the eastern limb, phosphorus content gradually reduces from north to south direction. Since phosphorus is mainly associated with secondary lateritization process, its concentration is very high in top weathered profile and along the weaker zones.

Keywords: Bonai Synclinorium, Phosphorus, Lateritization, Iron ore deposits, Orissa.

INTRODUCTION

World's 80% steel making is through the blast furnace method and hence the role of iron ore as a raw material and its quality becomes very critical to obtain the best quality steel. The east Indian iron ores consist of higher proportions of impurities in the form of alumina (Al_2O_3) and phosphorus (P). Their presence adversely affects the performance of blast furnaces and hence it is always preferred to maintain their level as low as possible (Majumder et al. 2005). Reduction of 1% alumina in iron ore improves blast furnace performance by 3%, reduction in reduction-degradation index (RDI) by 6 points, lowers the coke rate by 14 kg per tonne of hot metal and increases sinter productivity by 10-15%. The higher content of P increases surface cracking during steel making process at higher temperatures and also increases level of inclusions, which adversely affect the mechanical properties of finished steel (Upadhyay and Venkatesh, 2006; Upadhyay, 2008). Hence, it is important to restrict the alumina and phosphorus inputs in the furnace through raw materials (Upadhyay et al. 2009).

The eastern limb of "Bonai Synclinorium" hosts some of the major high grade iron deposits like, Noamundi, Thakurani, Joda, Joribahal, Jilling-langalata, Jajang, Khondbond etc while the western limb consists of Gua, Kiriburu, Bolani, Kalta, Barsua, Khandadhar etc. The Malangtoli and Mankarnacha deposits are located at the closure of this synclinorium. The present investigation attempts to unreveal mode of occurrence of P in some of the major high grade iron deposits located on the eastern limb (Majumder et al. 2005; Upadhyay, 2010; Upadhyay et al. 2010).

GEOLOGICAL SETUP

Singhbhum-Orissa-iron-ore-craton (Saha et al. 1988; Saha, 1994) or Singhbhum Orissa craton (Misra, 2006) consists of Iron Ore Group, which were deposited over Older Metamorphic Group. They occur in three basins along eastern, western and southern perimeters of Singhbhum granite batholithic complex, defined as Singhbhum-Keonjhar or Jamda-Koira Basin, Gorumahisani-Badampahar Basin and Daitari-Palalahara Basin respectively (Acharya, 1993; Misra, 2006). The western Singhbhum-Keonjhar or Jamda-Koira Basin extends over a strike length of 60-70 km in NNE-SSW direction from Chakradharpur to Malangtoli. The iron formations and associated rocks are found in horseshoe shaped, gently plunging, sharply bent synclinorium, known as "Bonai Horseshoe Synclinorium" (Fig. 1).

The country rock is least metamorphosed sedimentary formations consisting of Banded Iron Formations (BIFs) of Iron Ore Group (C.3100 Ma; Saha et al. 1988). They consist

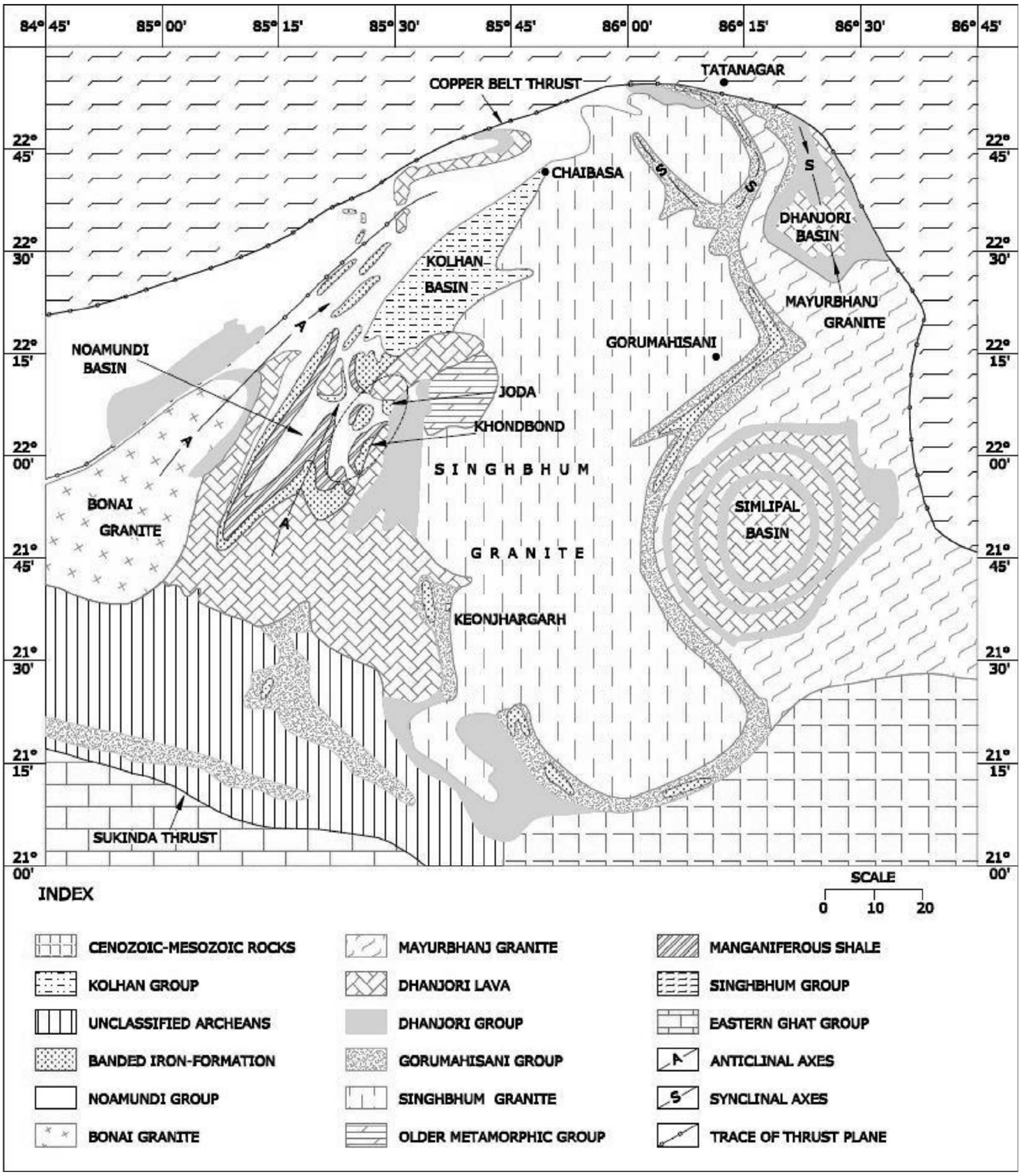
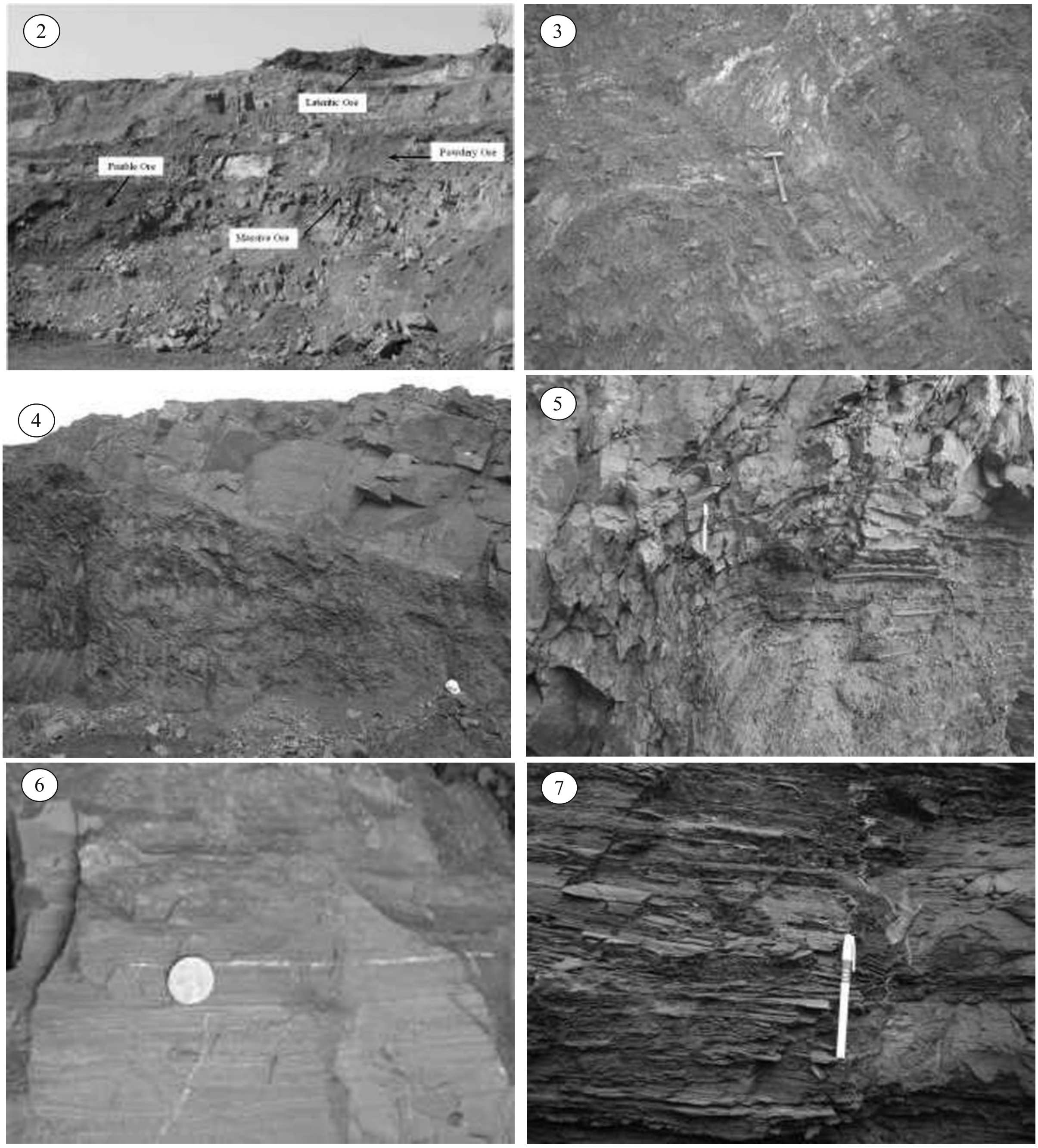


Fig.1. Geological map of Singhbhum Orissa Iron Ore Craton showing lithological distributions and existence of three major iron ore basins (modified after Chakraborty and Majumder, 2002).

of alternate layers of iron oxide in the form of hematite and silica in the form of chert or jasper. The general strike direction of these formations is NNE-SSW, dipping mostly westerly with local contortions and folding.

NATURE OF MINERALIZATION

The iron ore profile commence with soil and lateritic cover at top, is followed by soft lateritic ores, hard massive or laminated ores, friable-powdery ores, blue dust ores, banded hematite jasper (BHJ) and shale at bottom. Lateritic ores, known as soft ores are the products of lateritization of primary ores and hence their composition varies widely depending upon the nature of primary ore and degree of lateritization. They are usually vesicular or porous and observed as capping over ore bodies. The steel grey coloured hard, massive, sometimes finely laminated ores found below lateritic ore, are characterised by their compact and



Figs.(2-7). (2) Lateritic, goethitic and hard massive ores observed on the upper part of the deposit, exposed in mining benches. **(3)** Flaky, friable ores often closely associated with ferruginous and shaly material. **(4)** Occurrence of blue dust, below hard massive ores exposed in mining benches. **(5)** Occurrence of blue dust in association with thinly laminated BHJ host rocks. **(6)** Hard, massive, BHJ rocks with macro to thin laminations of jasper and hematite. **(7)** Soft, weathered, BHJ rocks with thin laminations of jasper and hematite.

homogenous nature (Fig.2). Flaky-friable ores are brown to grey in colour and varies in characteristics from laminated, biscuity, flaky to friable, powdery in nature. Powdery ores are fine in nature and often closely associated with blue dust, ferruginous and shaly materials (Fig.3). Blue dust occurs as fine, steel grey coloured powder with a few flaky ore pieces and generally found below hard massive ores (Fig.4), in association with BHJ (Fig.5). It occurs in limited extent at deeper levels of the mineralized zones. BHJ consisting of laminations of fine grained hematite and jasper (Fig.6), vary in thickness from mere partings to a few centimetres (Fig.7).

Table 1. Mineralogical characteristic of different types of iron ores from Noamundi, Joda and Khondbond iron deposits

Ore types	Microscopic findings		XRD findings	
	Major Phase	Minor Phase	Major Phase	Minor Phase
Platy / Laminated ores	Hematite	-	Hematite	
Massive Hematite	Hematite	Clay	Hematite	
Biscuity type ores	Martite and Hematite	Magnetite, Maghemite and Goethite	Hematite and Goethite	Gibbsite
Massive Goethite	Goethite	Hematite	Goethite and Hematite	-
Transitional Ore – BHJ / BHQ	Hematite and Quartz	Clay	Hematite	Quartz and Kaolin

Ore Mineralogy

The ore microscopic study of polished thin sections of iron ore samples reveals that hematite, specular hematite, martite and goethite, are the main ore minerals with accessory association of kaolinite, gibbsite and limonite. A typical sample from Joda region revealed the presence of 70-75% hematite, 15-20% goethite and limonite, 3-7% gibbsite, 2-3% clay minerals, mainly kaolinite and maximum 2% other constituents like, mica, quartz, amphibole, etc (Upadhyay et al. 2009). The major contributions for higher Al_2O_3 and P are through intra lamellar and fracture filled kaolinite and gibbsite gangue minerals (Table 1).

Sources of Phosphorus

The chief sources of phosphorous in iron ores at Noamundi, Joda and Khondbond are kaolinous matter and hydrated iron oxide especially the goethite. Studies on BIF samples from these areas indicated that more than 50% P is contributed by the gangue minerals, filled up in voids, vug and fractures, intralamellar or fines disseminations. Rest of the P is contributed by weathered surface coatings, scales, free clay matters etc. (Upadhyay and Venkatesh, 2006). Laboratory experiments have indicated that around 30% of P is associated with secondary oxide minerals like goethite, limonite, ochre etc and aluminous minerals like clay, gibbsite etc can be reduced by removing these impurities through gravity separation, while remaining can be lowered through pyro-hydro metallurgical treatment only (Upadhyay et al. 2009).

Occurrence and Distribution

Iron ores contain P as apatite but in Bonai synclinorium, it has been observed through SEM studies that it occurs as filling of intralamellar, fracture, vug and voids spaces, surface scales, coatings (Table 2) or fine disseminations of clay minerals or in absorbed form with varied concentrations in different types of iron ores such as hard massive (Fig.8), friable (Fig.9) and lateritic/goethitic ores (Fig.10).

Ore-wise Distribution

It has been observed that P content is the least in BHJ formation while it is the highest in case of lateritic ores (Upadhyay, 2010). It is further revealed that it increases progressively from BHJ (0.028%) to hard massive ores (0.040%), blue dust (0.091%), friable flaky ores (0.100%) and lateritic ores (0.857%), as shown in Table 3. This variation is mainly attributed to the presence of goethite and clay minerals in varied proportions in these units.

Lateritic ores are low grade, where P ranges between 0.052 and 0.630%, averaging to 0.857%. In goethitic ores, Fe and P show weak negative correlation, Al_2O_3 and P show occasional weak positive correlation while SiO_2 and P exhibit negative correlation. Hard massive ores are high grade, low in alumina and P contents, averaging to 1.6% (0.8 to 8.9%) and 0.040% (0.016 to 0.161%) respectively. Alumina has the lowest co-efficient of variation which is indicative of

Table 2. Sources of phosphorus in different types of iron ores

Source	Ore Types			
	Hard ore	Flaky / powdery ores	Lateritic ores	Blue dust
	Phosphorus (P)%			
Surface coatings	2.8	12.9	12.1	7.8
Surface Scales	1.5	3.1	2.8	16.4
Void/Vug/Fractures fillers	24.6	7.1	33.0	18.9
Intralamellar/Fine disseminations	50.9	46.8	22.2	44.6
Free laterite/Kaolinite/ Clay	20.2	30.1	29.9	12.3
Total	100.0	100.0	100.0	100.0

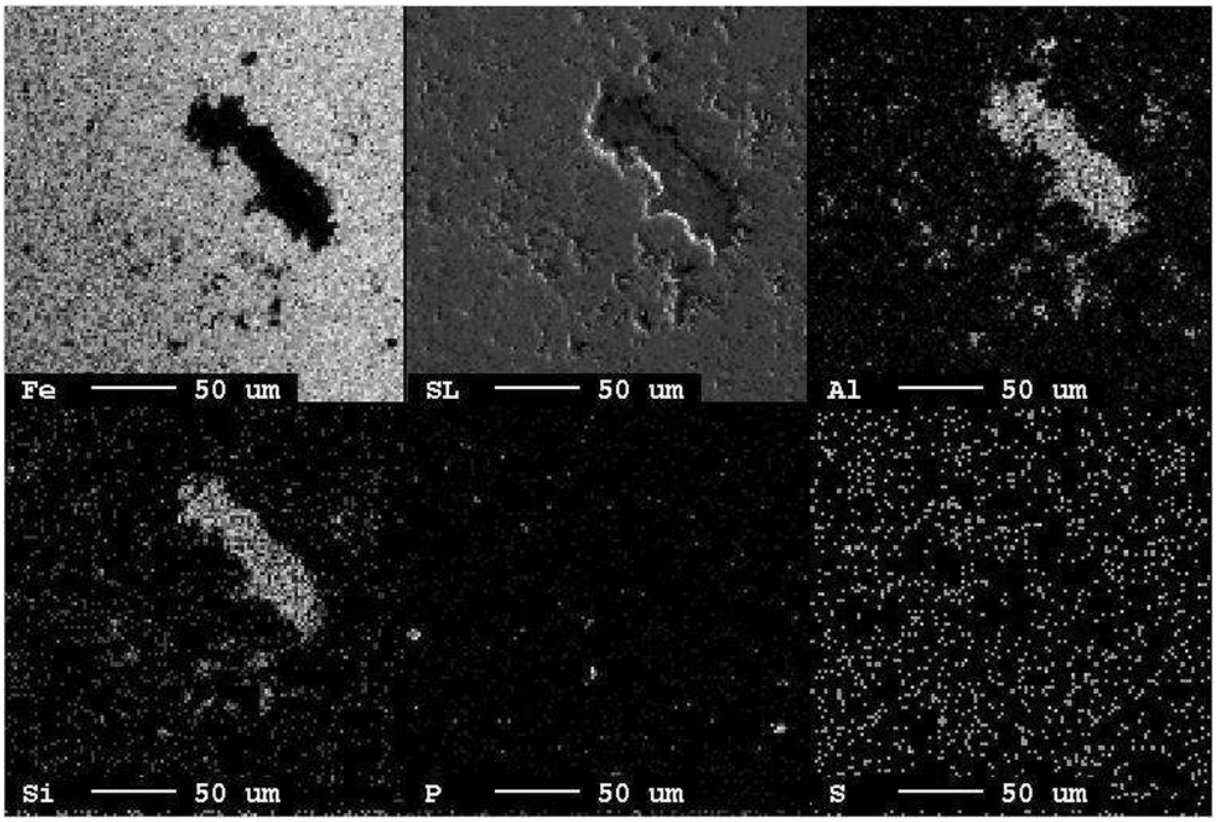


Fig.8. X- Ray image map of Fe, Al, Si, and P and S elements in hard massive iron ore.

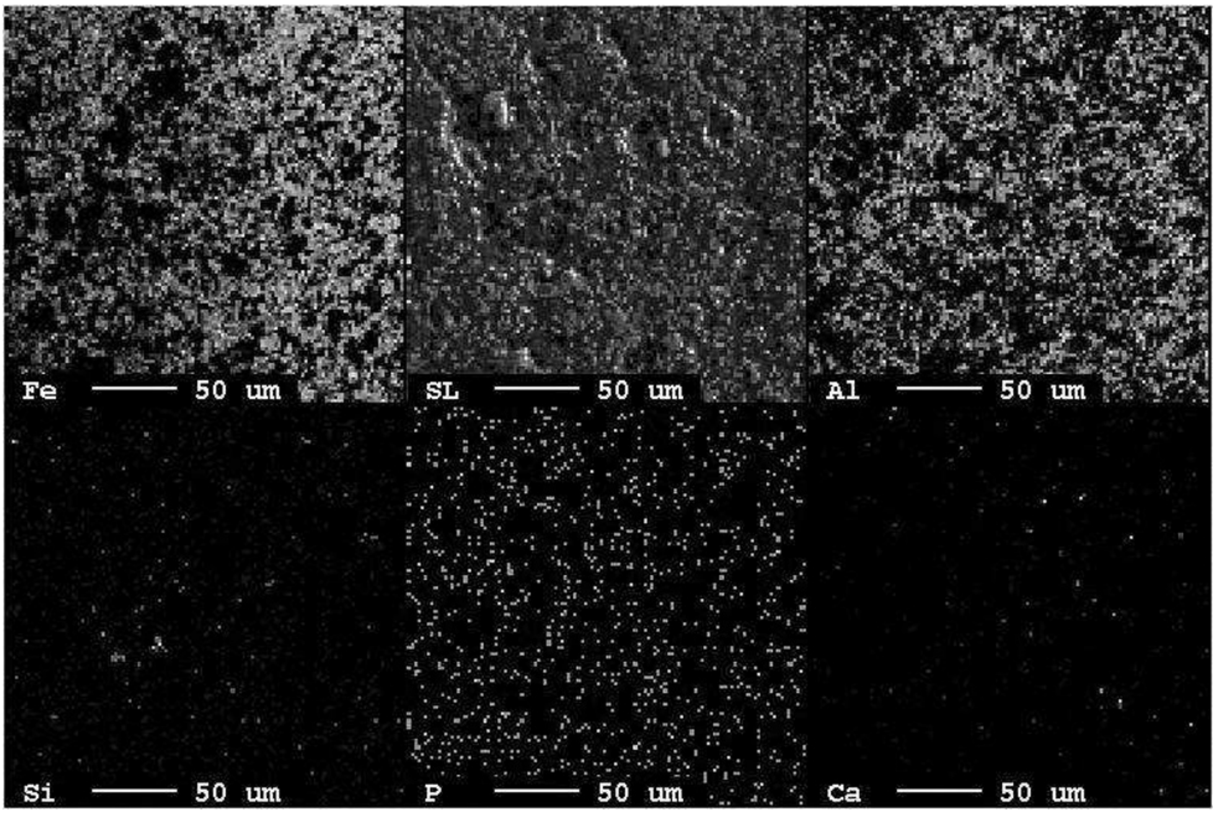


Fig.9. X Ray image map of Fe, Al, Si and P elements in flaky - friable iron ore.

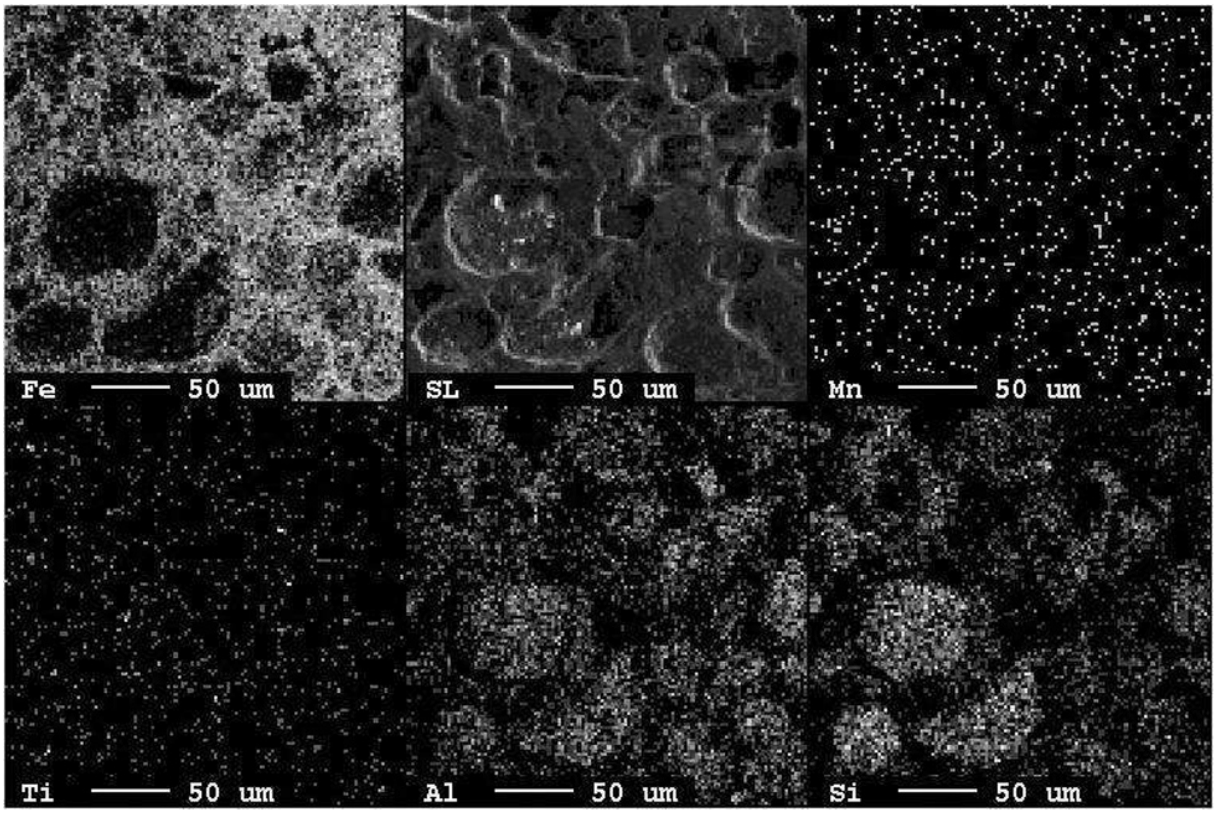


Fig.10. X Ray image map of Fe, Al, Si and P elements in Lateritic / goethitic iron ore.

uniform distribution. There exists a strong negative correlation between Fe and P while positive correlation between Al_2O_3 and P, indicating that alumina and phosphorus decreases with increase in iron content. The flaky-friable ores have Fe, ranging between 57.0 to 68.7%, Al_2O_3 from 0.6 to 6.25%, SiO_2 from 0.7 to 11.8% and P between 0.022 to 0.216%. There exists very poor, negative correlation between Fe and P and SiO_2 and P while poor positive correlation between Al_2O_3 and P. Blue dust, particularly from Joda region is rich in iron and low in alumina and phosphorus (Table 4). Blue dust is the only ore type where all the radicals having low variance and co-efficient of variation. There exists poor negative correlation between Fe and P and SiO_2 and P, while poor positive correlation between Al_2O_3 and P.

Table 3. Chemical composition of different iron ores from Joda-Khondbond region

Ore Type	Parameter	Fe%	Al_2O_3%	SiO_2%	P%
BHJ	Minimum	28.64	0.72	41.20	0.012
	Maximum	34.64	1.03	53.10	0.043
	Wt. Average	30.28	0.93	48.44	0.028
Massive-Hard ores	Minimum	61.20	0.84	0.40	0.016
	Maximum	68.06	8.88	2.80	0.161
	Wt. Average	65.01	1.59	1.30	0.040
Blue dust	Minimum	59.60	0.80	0.57	0.030
	Maximum	68.60	3.24	7.22	0.168
	Wt. Average	65.06	1.84	2.19	0.091
Flaky ores	Minimum	57.00	0.60	0.69	0.022
	Maximum	68.67	6.25	11.82	0.216
	Wt. Average	63.79	1.75	3.05	0.100
Lateritic/ goethitic ore	Minimum	58.20	2.56	2.07	0.052
	Maximum	65.70	6.32	5.87	0.630
	Wt. Average	62.26	4.35	3.62	0.857

In hard ores and blue dust, P shows negative correlation with Fe while positive correlation with alumina. It indicates that P content increases with increase in Al_2O_3 and decreases with increase of Fe contents. Similar trend has been observed in case of flaky-friable ores and lateritic ores also. With silica, it shows a weak negative correlation in flaky-friable ores.

Lateral Distribution

The P content in iron ores of eastern limb is found to be lower compared to western limb (Sarkar and Gupta, 2005). It is observed that in eastern limb, it gradually reduces from north to south (viz. from Noamundi deposit to Khondbond deposit) in most of the hard massive, flaky-friable, powdery and blue dust ores. However, lateritic ores do not show consistency due to varied extent of weathering

Table 4. Occurrence of Phosphorus in different iron ore deposits

Deposit and location on the eastern limb	Massive Ore	Flaky Ore	Blue Dust	Mixed ores	Lateritic Ore	Total
			Phosphorus%			
Noamundi (in North)	0.069	0.085	0.046	-	0.137	0.077
Katamati (bBetween north and central portion)	0.077	0.066	0.048	0.074	0.101	0.070
Joda East (in central portion)	0.041	0.059	0.029	0.084	0.146	0.066
Banspani (between central and southern portion)	0.037	0.059	-	-	0.129	0.049
Khondbond (in southern portion)	0.018	0.027	-	-	0.050	0.030

Table 5. Depth (level) wise P, Fe and Al_2O_3 contents in different types of iron ores in Noamundi region

Level	Phosphorus (P)%		Iron (Fe) %		Alumina (Al_2O_3) %	
RL in m.	Avg. (analysis range)	Std. Dev.	Avg.	Std. Dev.	Avg.	Std. Dev.
			Hard Ores			
672	0.115 (0.060-0.248)	0.043	65.58	1.655	2.33	0.936
660	0.082 (0.032-0.188)	0.039	66.91	1.287	1.66	0.733
588	0.077 (0.036-0.184)	0.035	64.68	1.425	3.28	1.0.53
576	0.071 (0.028-0.156)	0.034	65.41	1.256	2.33	0.673
			Flaky Ores			
684	0.120 (0.060-0.196)	0.046	61.96	3.685	4.57	1.912
672	0.160 (0.092-0.220)	0.042	63.81	1.169	4.05	0.096
660	0.152 (0.092-0.316)	0.052	64.52	0.847	4.13	0.611
576	0.120 (0.080-0.168)	0.030	63.45	1.379	3.24	0.94
570	0.108 (0.076-0.144)	0.072	63.63	1.984	3.13	0.077
			Lateritic Ores			
672	0.235 (0.156-0.328)	0.053	60.83	0.893	4.64	0.703
660	0.170 (0.060-0.284)	0.056	63.14	1.532	4.48	1.122
600	0.137 (0.080-0.232)	0.039	62.39	1.979	3.7	0.911
588	0.098 (0.056-0.0156)	0.035	61.12	2.321	4.61	13.41
			Blue dust			
588	0.079 (0.032-0.176)	0.040	67.17	0.491	1.63	0.301
570	0.075 (0.024-0.104)	0.022	67.39	1.053	0.96	0.59

at places.

The average P in Noamundi deposit is 0.077%, while at Katamati, it is 0.070%. In Joda east iron deposit, it is 0.066%. At Banspani deposit and at Khondbond deposit, it is 0.049 and 0.030% respectively (Table 4).

Depth-wise Distribution

In general, based on exploration data, it is observed that P content in all types of ores, reduces with the depth, as the effect of weathering decreases. A study of level wise variation of P content in different ore types in Noamundi region indicated that it is low at the deeper levels compared to upper levels but no significant correlation could be established with respect to individual ore categories (Table 5 and Fig. 11) (Upadhyay et al. 2010).

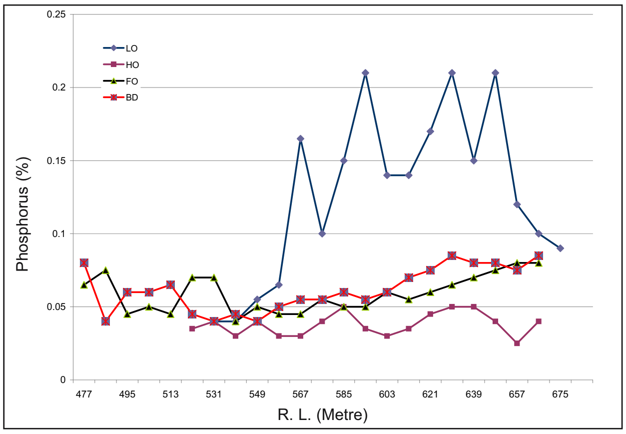


Fig.11. Occurrences of phosphorus in lateritic (LTO), hard (HO), flaky (FO), and blue dust ore at different depths (levels) in Joda region.

CONCLUSIONS

Phosphorus (P) occurs in kaolinitic gangue in the form of cavity and vein fillings. It is comparatively low in massive hard ores and blue dust while highest in goethitic-lateritic type of ores. It is concentrated in the top weathered profile and along the weaker and altered zones in the BIFs. Exploration data reveal that the phosphorus content in all types of iron ores reduces with depth as the weathering profile diminishes. In the eastern limb, there is a gradual phosphorus reduction from north to south.

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