

Physico-chemical characterisation of lateritic nickel ores of Sukinda, Orissa

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ABSTRACT

The only nickel ore deposit of significance in India occurs in the chromiferous ultramafic complex of Sukinda, Orissa. It is a lateritic nickel ore deposit with a reserve of about 150 million tonne having cut-off grade of 0.05% Ni. The processing of this ore is difficult due to ultrafine nature of goethite, low content of nickel in the ore (max. 1.5% Ni), complex intergrowths of goethite with quartz, talc, kaolinite and magnetite and abrupt variation of nickel content in the ores in horizontal and vertical profiles. In this study the results of detailed investigations to characterise five bulk samples collected from different sectors of Sukinda-Kansa, TISCO and OMC are discussed. The techniques used for characterisation include granulometric study, optical microscopy, X-ray diffraction, thermal analysis, scanning electron microscopic, infrared studies, electron probe microanalysis, leaching experiments and chemical analyses. This study indicates that the nickel is not present as discrete minerals but mostly associated with goethite. Kansa ore has goethite as major mineral (90%) whereas the other samples contain significant amount of free quartz along with variable amount of chromite, hematite, magnetite, talc, serpentine and kaolin. The fine grained goethite is amorphous to quasi-amorphous in nature. Mineralogy and chemistry of the samples indicate that goethite, Fe and Ni are invariably enriched in the finer size fractions. Electron probe microanalyses indicate that nodular goethite and chromite are Ni-poor (<0.2% Ni) whereas lithiophorite and magnetite contain 11% and 0.9% Ni respectively. The results of the sequential leaching studies involving oxalic, sulphuric and hydrochloric acids indicate three types of association of nickel in goethite: a part with amorphous

goethite (ferrihydrite), a part in weakly bonded nature and a part as lattice bound state in goethite. The laterite ore is thus proved to be of complex in nature which creates problem for liberation of the constituent minerals based on the surface properties. Classification down to silt size fraction increases the Ni content to about 1.0% in the material. These ores have been successfully tested on pilot plant scale for extraction of nickel metal by reduction roasting followed by ammonium-ammoniacal leaching and electrowinning.

INTRODUCTION

Nickel is widely used in stainless steel, high temperature alloys, coins, electroplating, magnets, chemical industries and other products owing to its excellent physical and chemical properties. The demand for nickel has been increasing over the years with the development of economic and industrial progress. Most of the worlds, land based nickel resources are associated with iron-magnesium rich magmatic rocks. Nickel ore deposits associated with these rocks are found either as sulphides ores or in laterites which formed from secondary alteration of magnesium rich varieties. The worlds nickel sulphide ores are limited to a few countries viz., Canada, Australia, South Africa whereas the nickeliferous lateritic ores are abundant in the tropical and subtropical regions.

The annual demand of nickel in India is 10,000 tonnes/year and the entire quantity is being imported at a cost of about Rs. 230 crores. The demand is expected to rise to about 20,000 tonnes/year by the turn of this century. The nickeliferous laterite ores of Sukinda area ($21^{\circ}0' : 85^{\circ}45' - 21^{\circ}04' : 85^{\circ}52'$) of Orissa constitute the most important target deposit for large scale exploitation. This deposits was investigated in detail by Geological Survey of India during 1966-73 and was estimated to contain about 150 million tonnes of ores at 0.5% Ni cut-off grade ^[1].

The nickeliferous laterites of Sukinda is complex with respect to extreme variation in particle size, varied mineralogy and chemistry, overall low content of the metal and heterogenous distribution of precious elements in the ores. The method of processing such complex ores by physical beneficiation and chemical techniques involving hydro-and pyrometallurgical routes is greatly dependent on its detailed mineralogical and geochemical characterisation. In this paper the findings related to the complexity of mineralogy and chemistry of the nickeliferous laterites are enumerated. The approach encompasses the application granulometric study, microscope, XRD, DTA/TG, SEM-EDS, IR, EPMA, leaching experiments and chemical analyses.

MATERIALS AND METHODS

Indian Bureau of Mines, Nagpur in collaboration with Regional Research Laboratory (RRL), Bhubaneswar collected five bulk samples from different sectors of Sukinda area. These samples were collected from (a) Kansa Sector (sample No. Kansa), (b) two operating mines of OMC sector (sample No. OMC), (c) two operating mines of TISCO sector (sample No. TISCO) and (d) two number of samples collected from different dumps (sample Nos. Dump/9 and Dump/36).

Chemical analyses of the samples were done by XRF, wet chemical standard techniques and AAS. Sequential leaching experiments were performed by NH_4 -oxalate+oxalic acid, sulphuric and conc. HCl acids. In all cases standard methods have been used and salient description of each method is given in individual sections.

EXPERIMENTAL RESULTS

Granulometric Study

The samples are reddish to yellowish brown in colour. They have hard rock fragments as well as fine particles. The results of wet screening of five samples are given in Table 1. About 50% of the material of all the samples are below 63 micron size; the Kansa ore having the highest amount, about 88% (Fig. 1; Table 1). These data indicate that the samples are composed of considerable amount of clay and silt size fractions.

Table 1 : Size analyses of five Ni-limonite ores of Sukinda

Size (mm)	Samples										
	KANSA			OMC		TISCO		DUMP/9		DUMP/36	
	Median	Wt%	Cum.	Wt.%	Cum.	Wt.%	Cum.	Wt%	Cum.	Wt%	Cum.
+2.0											
-2.0+1.0	1.500	9.1	9.1	22.0	22.0	24.0	24.0	16.9	16.9	12.4	12.4
-1.0+0.5	0.750	0.7	9.8	4.5	26.5	4.4	28.4	2.9	19.8	3.8	16.2
-0.50+0.355	0.428	0.2	10.0	2.4	28.9	2.4	30.8	1.6	21.4	2.6	18.8
-0.355+0.12	0.240	0.2	10.2	1.5	30.4	2.2	33.0	1.3	22.7	1.8	20.6
0.125+0.06	0.094	0.7	10.9	10.0	40.4	8.0	41.0	5.0	27.7	7.2	27.8
-0.063		0.9	11.8	8.7	49.1	6.4	47.4	4.9	32.6	6.6	34.4
		88.2	100.0	50.9	100.0	52.6	100.0	67.4	100.0	65.6	100.0

Mineralogy

The mineralogical study was undertaken by the combination of XRD, microscope, DTA/TG, Scanning Electron Microscope, and Infrared Spectroscopy.

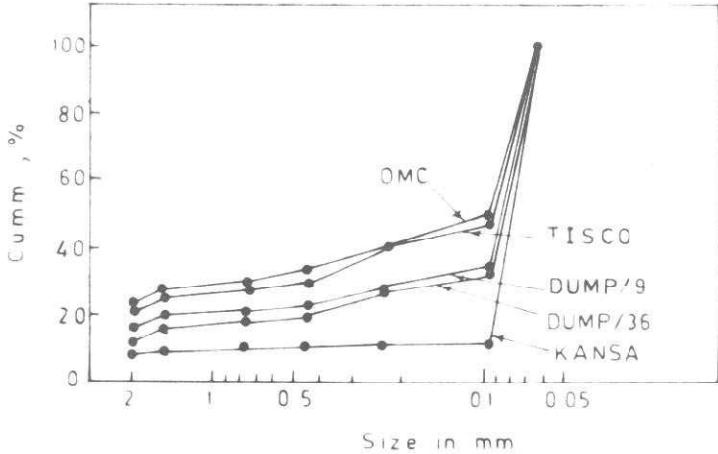


Fig. 1 : Size vs. cumulative wt. % (passing) plot of five samples.

- (a) *XRD Studies* : The XRD results (by Philips PW 1410 unit with Cu K_α radiation, 15mA and 25 KV) of the five bulk samples and their respective -63 micron size fractions are shown in Fig. 2. The minerals identified are : major minerals - goethite \pm quartz, minor minerals - magnetite, talc, kaolinite, hematite and chromite. Kansa sample has little amount of quartz whereas the other samples contain significant amount of free quartz (>50%) as revealed by their intense X-ray peaks. From XRD peak heights it is also clear that -63 micron samples contain more amount of goethite to the exclusion of quartz in the coarser size fractions. The d_{110} , d_{130} , d_{111} peaks of goethite varies between 4.1748 - 4.1836Å, 2.6907 - 2.976Å and 2.4435 - 2.4521Å respectively indicating low amount of Al^{3+} substitution for Fe^{3+} in goethite lattice (<3 mol% AlOOH). From XRD lithiophorite has also been indentified^[2].
- (b) *Microscopic Studies* : Hard and semifriable samples were selected for preparation of polished and thin sections by standard section preparation techniques. Goethite is the most abundant mineral which occurs as extremely fine grained (<1 micron size) to hard nodular concretions and massive body. The nodular goethite under ore microscope exhibits characteristic colloform bands and botroids suggesting formation from colloidal solutions. At places they occur as structureless mass and grade to fine grained limonite. In the hard silicified laterite, goethite and quartz are intimately associated with minor amount of relict chromite grains. The texture of the laterites duplicates the serpentine mesh texture indicating their formation from serpentinite. In the chert/birbirite cryptocrystalline quartz occur with minor hematite. The chert bands are

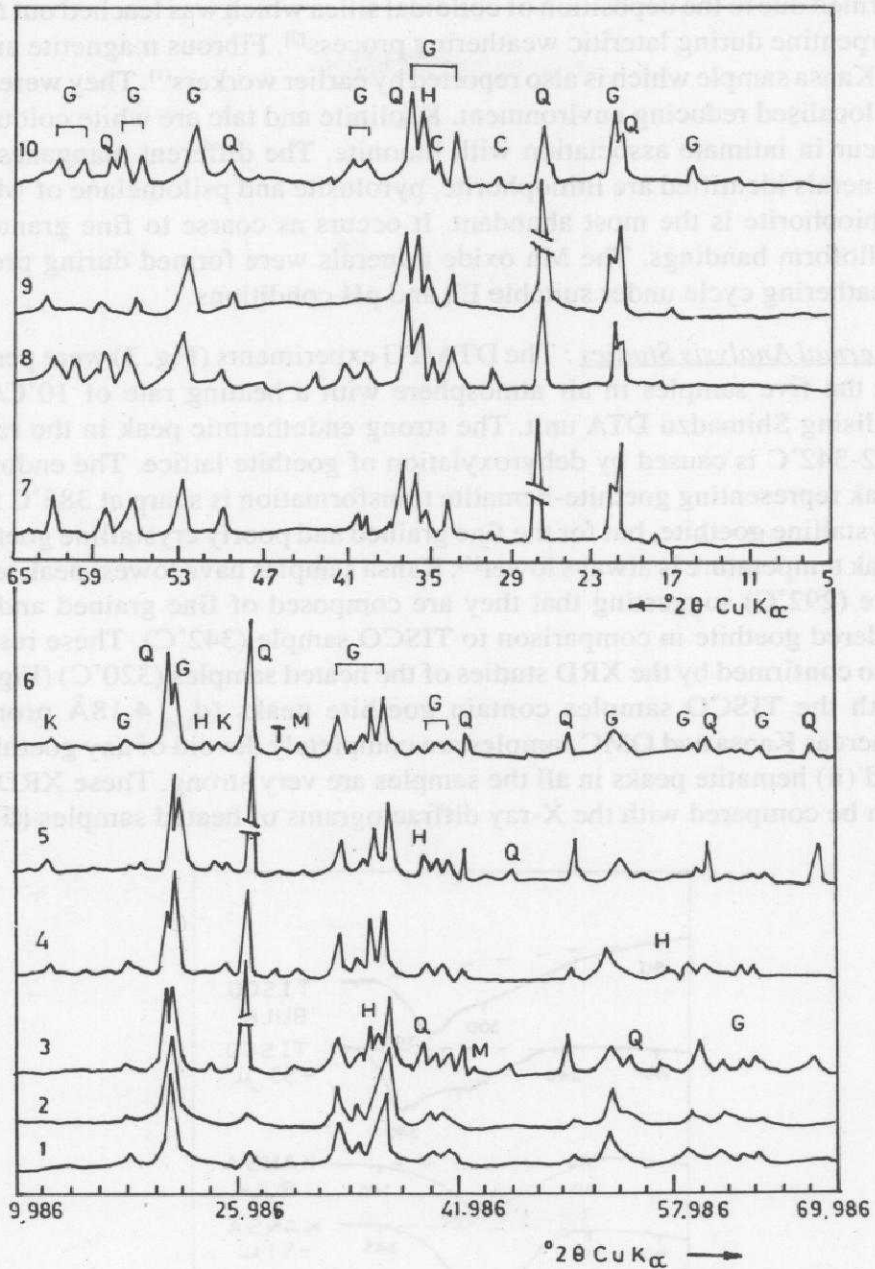


Fig. 2: X-ray diffractograms of the samples 1:-Kansa bulk; 2:-Kansa, -63 micron; 3:-TISCO bulk; 4:-TISCO, -63 micron; 5:-OMC bulk; 6:-OMC, -63 micron; 7:-Dump/9 bulk; 8:-Dump/9, -63 micron; 9:-Dump/36 bulk; 10:-Dump/36, -63 micron. Q-Quartz; G-Goethite; M-Magnetite; H-Hematite; K-Kaolinite; T-Talc, C-Chromite.

formed due to the deposition of colloidal silica which was leached out from the serpentine during lateritic weathering process^[3]. Fibrous magnetite are noted in Kansa sample which is also reported by earlier workers^[11]. They were formed in localised reducing environment. Kaolinite and talc are white coloured and occur in intimate association with limonite. The different manganese oxide minerals identified are lithiophorite, pyrolusite and psilomelane of which the lithiophorite is the most abundant. It occurs as coarse to fine granules and colloform bandings. The Mn oxide minerals were formed during prolonged weathering cycle under suitable Eh and pH conditions.

- (c) *Thermal Analysis Studies* : The DTA/TG experiments (Fig. 3) were performed on the five samples in air atmosphere with a heating rate of 10°C/min by utilising Shimadzu DTA unit. The strong endothermic peak in the region of 292-342°C is caused by dehydroxylation of goethite lattice. The endothermic peak representing goethite-hematite transformation is sharp at 385°C for well crystalline goethite, but for the fine grained and poorly crystalline goethite the peak temperature is always lower^[4]. Kansa samples have lowest peak temperature (292°C) suggesting that they are composed of fine grained and poorly ordered goethite in comparison to TISCO sample (342°C). These results are also confirmed by the XRD studies of the heated samples (320°C) (Fig. 9) : (i) both the TISCO samples contain goethite peaks (d_{110} 4.18Å prominent) whereas Kansa and OMC samples are completely devoid of any goethite peak and (ii) hematite peaks in all the samples are very strong. These XRD results can be compared with the X-ray diffractograms of heated samples (Fig. 4).

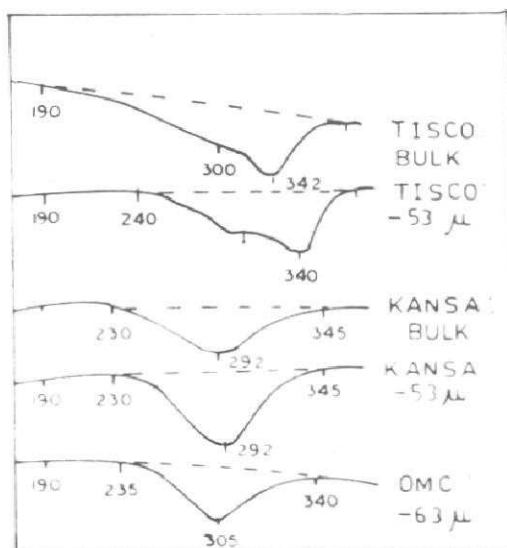


Fig. 3 : DTA curves for the samples.

The thermal gravimetric analyses (TGA) study gave loss of 5.66% (for OMC sample) and 8.58% (for Kansa sample) weight for the goethite-hematite transformation. Pure goethite is expected to show a weight loss of 10.11 percent. Smaller weight loss than the expected value for pure goethite shows that the ore contains some amount of other minerals.

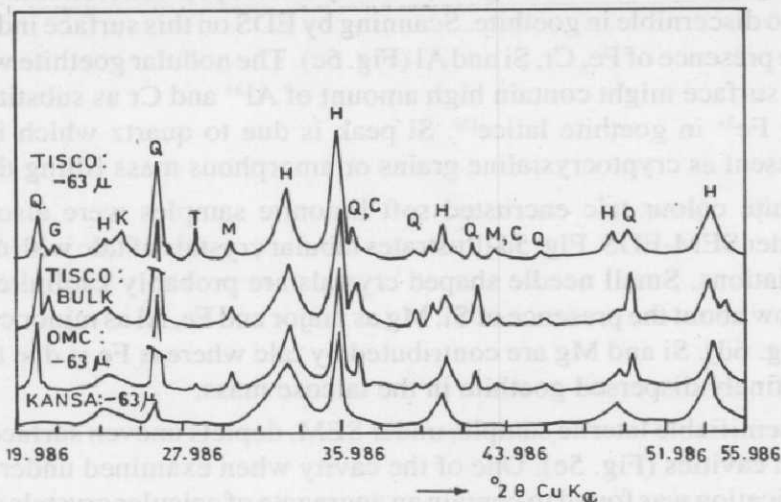


Fig. 4 : X-ray diffractograms of the heated samples (320°C) (Symbols as in Fig. 2).

(d) Scanning Electron Microscopic Studies : Scanning electron microscope with EDS attachment (SEM-EDS) can provide valuable information regarding micromorphology and chemical composition of the aggregates and/or particles, which in turn can be used to corroborate the minerals identified by XRD, optical microscopy etc., and infer the presence of small amount of additional minerals. SEM-EDS studies of the nickel laterite samples were undertaken at the institute fur Mineralogic und Lagerstättenlehre der RWTH, Aachen, Germany by utilising Zeiss SEM-EDS equipment. Some typical results are discussed in the following lines.

- i) The highly porous nature of the soft nickel limonite ores are depicted in Figs. 5 (a) and (b). The goethite grains are very fine and form spongy mass. This sponginess or fine scale mosaicism is due to ultrafine nature of goethite grains which have tendency to coagulate. Due to porous nature, as depicted in the figures the nickelferrous limonite ore have low bulk density ($\sim 1 \text{ gm cc}^{-3}$). The EDS of Ni-limonite samples shown in Figs. 5 (a) and (b) are illustrated in Figs. 6 (a) and (b) respectively. The results shown the presence of Fe, Al, Si and Cr in the ores. Fe is the major peak which is due to presence of large amount of goethite. Si and Al peaks are due to quartz and/or kaolinite which occur in fine scale intergrowth with limonite.

Chromite grains are also finely dispersed in limonitic mass. The presence of different minerals, viz., goethite, quartz, chromite and kaolinite in nickel limonite ores are also confirmed by XRD studies (Fig. 2).

- ii) The hard nodular goethite, under SEM, exhibits uneven surface and numerous pores and cracks (Fig. 5c). Poorly developed concretionary bands are also discernible in goethite. Scanning by EDS on this surface indicate about the presence of Fe, Cr, Si and Al (Fig. 6c). The nodular goethite which occur on surface might contain high amount of Al^{3+} and Cr as substitutional ion for Fe^{3+} in goethite lattice^[5]. Si peak is due to quartz which is probably present as cryptocrystalline grains or amorphous mass filling the cavities.
 - iii) White colour talc encrusted soft limonite samples were also examined under SEM-EDS. Fig. 5d illustrates tabular crystals of talc with distinct fine striations. Small needle shaped crystals are probably kaolinite. The EDS show about the presence of Si, Mg as major and Fe, Al as minor components (Fig. 6d). Si and Mg are contributed by talc whereas Fe is due to presence of finely dispersed goethite in the talcose mass.
 - iv) A semifiable laterite sample, under SEM, depicts uneven surface, fractures and cavities (Fig. 5e). One of the cavity when examined under high magnification was found to contain an aggregate of acicular crystals of kaolinite (Fig. 5f). The needles are diversely oriented. EDS data record that Si and Al are the two major elements with trace amount of Fe (Fig. 6e).
 - v) Fig. 5(g) shows well developed terminal faces of the juxtaposed quartz grains indicating their growth/nucleation in open space.
 - vi) The martitised magnetite sample exhibits rugged surface (Fig. 5h). EDS illustrate that the Fe is the major element with trace amount of Si, Al and Cr (Fig. 6f).
- e) *Infrared Spectroscopy*: The infrared spectra of the ores are given in Fig. 7. The ores contain OH band at 3400 cm^{-1} and hydrogen bridge bond at 1000 cm^{-1} and 1650 cm^{-1} . Small shoulders are due to impurities present in the ores. The peaks 800 cm^{-1} and 900 cm^{-1} are due to the OH bending mode. Typical Si-O-Si stretching vibration appears at 1000 cm^{-1} , 800 cm^{-1} and 700 cm^{-1} which indicate presence of large amount of quartz. The metal-oxygen vibration absorption as Fe-O comes up at about 450 cm^{-1} .

ELECTRON PROBE MICRO-ANALYSES

This study was undertaken at the (a) Institute fur Mineralogie und Lagerstättenlehre der RWTH Aachen, Germany by utilising ARL-SEM-Q and (b) USIC, University of Roorkee, by operating JEOL-8600M Superprobe. The minerals taken for analyses are: lithiophorite, magnetite, goethite, hematite and

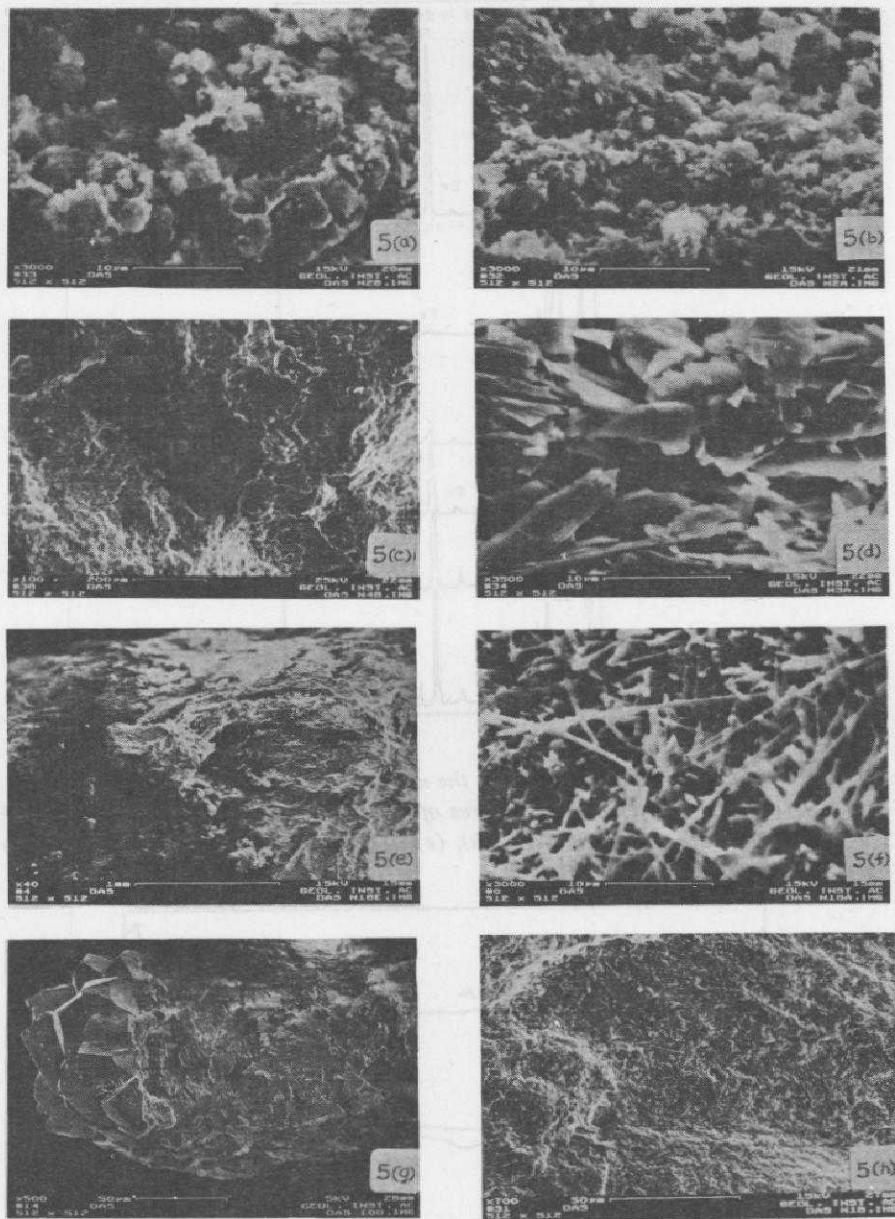


Fig. 5 : Scanning electron micrographs of some of the sampes, (a) Highly porous, soft and friable Ni-limonite ores. The goethite particles are very fine and globular and form spongy mass. The mosaicism develops dur to accretion of these ultrafine particles. Sample No. N2B. Kansa, (b) Ultrafine rounded goethite grains exhibit sponginess. Note the porous nature of this sample. Sample No. N23. Kansa, (c) Hard nodular goethite showing uneven surface and interconnecting fractures sample N4B. OMC, (d) Talc grains are tabular in nature. Sample No. N3, (e) A semifriable laterite showing the cavities and uneven surface. Sample No. N18, (f) The earlier feature at higher magnification reveals the acicular nature of the kaolinite grains (g) A piece of quartz grain shows the well developed terminal faces indicating its growth in open space in the laterite horizon Sample N10, and (h) Magnetite showing the uneven surface. Sample N1.

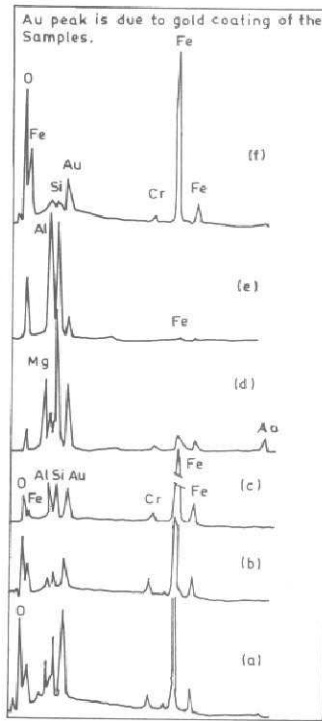


Fig. 6 : EDS of the different samples shown in the micrographs (Fig. 5). (a) EDS of nickel limonite ores of Fig. 5(a), (b) EDS of nickel limonite ores of Fig. 5(b), (c) EDS of hard laterite of Fig. 5(c), (d) EDS of talc + goethite matrix of Fig. 5(h), (e) EDS of kaolinite of Fig. 5(k) and (f) EDS of magnetite of Fig. 5(h).

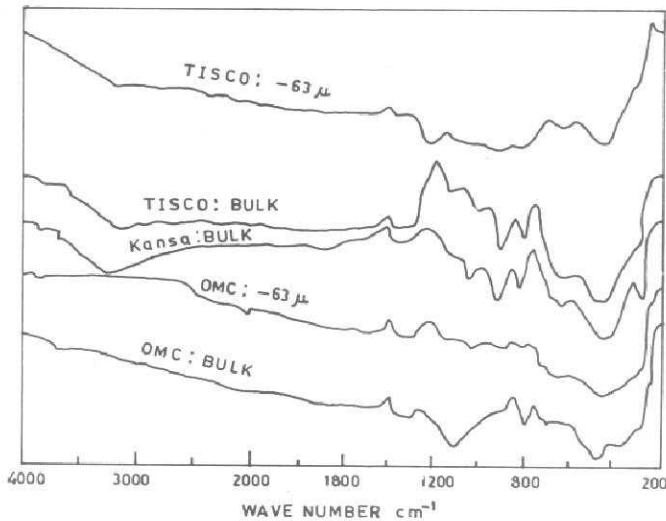


Fig. 7 : Infrared spectra of nickeliferous laterites.

chromite. The analytical data are presented in Table 2.

- a) The lithiophorite is highly enriched in Ni (Ni = 10.0%; NiO = 12.72%) and Co (Co = 11.24%; CoO = 14.29%) and also contain significant amount of alumina.
- b) The hematite associated with the lithiophorite is also Ni rich (max. Ni = 0.94; NiO = 1.19).
- c) The fibrous magnetite has 0.89% Ni (NiO = 1.13%). Ziauddin *et.al.*^[11] also reported the occurrence of fibrous nickeliferous magnetite with Ni content of 0.65% in the nickeliferous limonite ores of Saurabil area, Sukinda.
- d) The alumina content in the hard nodular goethite varies between 0.12% to 10.38% suggesting varying degree of Al³⁺ substitution for Fe³⁺ in goethite lattice. Cr³⁺ (max. Cr₂O₃ = 3.87%) and Mn³⁺ (max. MnO = 0.22) can also substitute Fe³⁺ to limited extent^[5]. The nodular goethite contains little amount of alumina, nickel (max. NiO = 0.22%) and Mn (max. MnO = 1.57%).
- e) The analytical results of chromite grains in goethite matrix has similarity with the results of clean chromite reported by Sahoo and Kaaden^[6]. Because of high stability nature, the chromite grains have survived large scale alteration.

LEACHING EXPERIMENTS

Goethite, the main nickel bearing mineral in laterite, occurs as amorphous, quasi-amorphous and well crystalline grains. Through XRD, microscopic and SEM-EDS analyses the exact nature of association of nickel in iron hydroxide has not been established. Therefore, stress was given on dissolution studies for understanding the mode of association of Ni in goethite such as (a) nickel associated with the amorphous iron hydroxide (possibly ferrihydrite), (b) nickel in chemisorption or weakly bonded in goethite and (c) lattice bound nickel in goethite. Sequential leaching experiments were performed on -63 micron size fraction samples by (i) 0.2 M NH₄ - oxalate + oxalic acid (shaking 2 hrs. in dark at pH 3) to remove amorphous iron^[5]; (ii) warm 0.1 N H₂SO₄ (shaking 2 hrs.) to remove weakly bonded nickel from goethite;^[7] and (iii) conc. HCL for removal of lattice bound nickel in goethite. The results are shown in Table 3. The maximum amount of Fe and Ni extracted by oxalic acid and sulphuric acids are 8210 and 490 ppm and 4400 and 130 ppm respectively. These data indicate the complex mode of association of nickel with iron hydroxides.

CHEMICAL ANALYSES

The chemical analyses of the samples were undertaken partly by XRF, partly by wet chemical standard techniques and AAS. The data are presented in Table 4. Of all the bulk samples Kansa has the lowest amount of silica. In all the cases, Fe and Ni increase sharply in the -63 micron size fractions. This confirms the previ-

Table 2 : Electron probe microanalyses of the minerals

	Lithiophorite		Magnetite		Hematite		Goethite		L1		Goethite		Hematite		Chrom N36	
	N39A Av.(5)	N23A Av.(3)	N39A Range	N39A Av.(4)	N71 Range	N71 Av.(4)	N71 Range	N71 Av.(3)	N71 Range	N71 Av.(3)	N71 Range	N71 Av.(2)	N71 Range	N71 Av.(3)		N71 Range
MnO ₂ *	41.01	0.03	39.36 42.45	0.10 0.05	0.09	0.05	0.06	0.09	0.05	0.00	0.00	0.09	0.00	0.75	0.17	0.69
Cr ₂ O ₃	n.d.	n.d.	n.d.	0.21	0.05	1.83	0.16	2.54	1.20	0.12	0.02	0.42	0.10	0.10	1.57	60.00
Al ₂ O ₃	11.66	n.d.	9.66	0.01	0.50	3.42	0.50	3.87	3.87	0.41	0.15	7.33	0.12	1.14	0.24	11.92
TiO ₂	n.d.	n.d.	16.85	0.01	0.00	10.38	0.04	7.14	7.14	0.02	0.59	7.44	0.00	0.02	1.77	0.12
					0.00	0.00	0.11	0.06	0.06	0.02	0.00	0.00	0.00	0.00	0.00	0.00
CoO	14.29	n.d.	13.57 14.58	0.00	0.02	0.05	0.02	0.00	0.16	n.d.	0.05	—	0.05	0.00	0.05	0.00
NiO	12.72	1.13	7.67 14.54	1.15	1.09	0.19	0.29	0.84	0.76	0.12	0.11	0.18	0.13	0.16	0.10	0.01
ZnO	n.d.	—	—	—	1.19	0.49	—	—	0.91	n.d.	0.13	0.23	—	—	0.22	—
FeO	—	28.06	—	—	—	—	—	—	—	—	—	—	—	—	0.36	16.89
Fe ₂ O ₃	—	68.0	—	96.16	95.74	77.51	76.00	82.51	79.53	88.17	86.42	78.17	86.42	95.69	93.02	—
V ₂ O ₅	—	—	—	—	96.70	—	78.00	0.03	83.49	n.d.	88.47	78.47	88.47	0.01	96.58	0.28
MgO	—	—	—	—	—	—	—	—	0.01	n.d.	—	—	—	—	0.00	0.03
Total	79.68	97.23	—	97.65	—	88.37	—	88.95	—	88.84	—	86.26	—	97.87	—	98.59

Note : *MnO in all other analyses except lithiophorite n.d. - not determined.

ous observations that goethite is concentrated in the silt size fractions. Silica in the finest size fractions vary between 5.23% to 21.78% (Table 4). This silica is mostly contributed by free quartz and to a lesser extent by talc and kaolinite which are intimately intergrown with goethite. Very often the quartz grains are also fine and cryptocrystalline in nature. Because of the complex intergrowths beneficiation to separate the silicate minerals particularly quartz will involve several steps.

Table 3 : Sequential leaching of Fe and Ni to illustrate their association with goethite

Samples	Treatment	Fe, ppm	Ni, ppm
Kansa	I	8210	340
	II	4400	130
	III	48.63%	11530
	Total conc.	51.86%	12500
OMC	I	2810	490
	II	1359	130
	III	40.57%	8700
	Total conc.	44.06%	9822
TISCO	I	2340	290
	II	575	40
	III	42.89%	8450
	Total conc.	45.15%	8722
DUMP/9	I	2320	220
	II	3612	40
	III	41.45%	6630
	Total conc.		
DUMP/36	I	3400	320
	II	1162	70
	III	41.89%	7900
	Total conc.	43.9 %	8650

Note : I. NH_4 - oxalate + oxalic acid, II. Residue of $1+0.1\text{MH}_2\text{SiO}_4$; III. Residue of II+Conc. HCl. I. removes ferrihydrite, II. removes weakly bonded nickel, and III, extracts lattice bound nioethite in goethite.

Table 4 : Partial chemical analyses of the bulk samples and their size fractions

Sample : KANSA					
Wt%	Fe_2O_3	LOI	SiO_2	NiO	Ni
Bulk	73.36	12.4	4.88	1.55	1.22

Contd.....

	(Size in mm)							Contd.....
	+2.0	-2.0+1.0	-1.0+0.5	0.50+0.355	-0.355+0.125	0.125+0.063	-0.063	
Fe ₂ O ₃	66.08	69.75	71.19	67.39	70.75	72.19	74.14	
LOI	12.5	13.01	13.05	12.7	12.89	12.98	12.57	
SiO ₂	5.01	3.96	1.98	6.10	7.31	6.88	5.23	
NiO	1.01	1.13	1.12	1.15	1.34	1.28	1.59	
Ni	0.8	0.89	0.88	0.91	1.05	1.01	1.25	

Sample : OMC

Wt%	Fe ₂ O ₃	LOI	SiO ₂	NiO	Ni
Bulk	41.17	6.07	43.23	0.82	0.64

(Size in mm)

	+2.0	-2.0+1.0	-1.0+0.5	0.50+0.355	-0.355+0.125	0.125+0.063	-0.063
Fe ₂ O ₃	28.28	24.66	24.55	22.1	16.99	18.26	59.81
LOI	4.38	5.69	5.66	3.62	3.12	3.37	8.53
SiO ₂	57.79	82.51	60.00	58.8	72.67	64.01	21.78
NiO	0.41	0.46	0.52	0.49	0.35	0.42	1.25
Ni	0.32	0.36	0.41	0.38	0.27	0.33	0.98

Sample : TISCO

Wt%	Fe ₂ O ₃	LOI	SiO ₂	NiO	Ni
Bulk	47.65	5.2	37.1	0.83	0.65

(Size in mm)

	+2.0	-2.0+1.0	-1.0+0.5	0.50+0.355	-0.355+0.125	0.125+0.063	-0.063
Fe ₂ O ₃	21.56	18.90	2.61	18.86	18.71	20.62	64.55
LOI	3.84	3.83	4.52	4.25	2.87	2.73	8.62
SiO ₂	66.07	72.36	68.08	70.25	66.54	63.21	16.16
NiO	0.24	0.32	0.33	0.31	0.22	0.26	1.21
Ni	0.19	0.25	0.26	0.24	0.17	0.21	0.95

Sample : DUMP/9

Wt%	Fe ₂ O ₃	LOI	SiO ₂	NiO	Ni
Bulk	56.61	10.5	20.01	0.82	0.64

(Size in mm)

	+2.0	-2.0+1.0	-1.0+0.5	0.50+0.355	-0.355+0.125	0.125+0.063	-0.063
Fe ₂ O ₃	50.55	34.89	42.55	43.9	34.34	32.58	63.94
LOI	9.81	6.08	9.52	8.77	6.32	5.48	12.04
SiO ₂	25.19	46.2	35.29	37.44	38.58	46.15	15.04
NiO	0.89	0.27	0.42	0.46	0.33	0.41	1.2
Ni	0.7	0.21	0.33	0.36	0.26	0.32	0.94

Contd.....

Sample : DUMP/36

Contd.....

Wt%	Fe ₂ O ₃	LOI	SiO ₂	NiO	Ni		
Bulk	52.91	10.58	21.15	0.85	0.67		
(Size in mm)							
	+2.0	-2.0+1.0	-1.0+0.5	0.50+0.355	-0.355+0.125	0.125+0.063	-0.063
Fe ₂ O ₃	47.28	50.17	38.25	37.52	30.09	35.71	61.9
LOI	9.77	9.48	7.61	8.01	5.82	5.74	11.9
SiO ₂	31.78	27.38	43.65	43.91	48.33	44.58	19.88
NiO	0.24	0.34	0.42		0.31	0.4	1.22
Ni	0.19	0.27	0.33	0.36	0.24	0.31	0.96

CONCLUSIONS

At Sukinda a thick profile of nickeliferous laterite overlies the serpentinised ultrabasics. The characteristics of five lateritic nickel ores of Sukinda were investigated by various physico-chemical techniques. Granulometric study, mineralogy and chemistry reveal that goethite is concentrated in the -63 micron size fraction indicating its fine grained nature. XRD, and DTA/TGA techniques have been useful to identify the different mineral constituents and their physical properties. Goethite → hematite transformation temperature varies between 292°C to 342°C which indicate that goethite is poorly crystalline in nature. SEM-EDS studies reveal high porosity of the Ni-limonite ores and complex intergrowth of quartz, kaolinite and talc with goethite. EPMA results show that the lithiophorite is the highest nickel bearing mineral. Sequential leaching experiments establish the polymodal association of nickel with goethite. The different studies indicate that the ore does not contain any discrete nickel bearing mineral and that the metal is distributed in the fine grained goethite. Secondary silicification adds considerable amount of silica to the nickel limonite ores which persists even in the finest size fractions. Elaborate beneficiation techniques are warranted for effective separation of micron sized silicate minerals particularly quartz from the limonite matrix. The lateritic nickel ores of Kansa sector are high grade and can be used directly for extraction of nickel by reduction roasting followed by ammonium-ammonical leaching and electrowinning.

ACKNOWLEDGEMENTS

The authors are thankful to the Director, Regional Research Laboratory, Bhubaneswar for kind permission to present this paper. The authors are also grateful to Prof. G. Friedrich, Institut für Mineralogie und Lagerstättenlehre der RWTH, Aachen, Germany for kind permission to undertake various experiments during one of the author's (S.K. Das) stay under CSIR-GTZ programme. We also extend our thanks to the authorities of IBM (Indian Bureau of Mines), Nagpur,

OMC (Orissa Mining Corporation, Orissa) and TISCO (Tata Iron and Steel Company Ltd.) for allowing to collect the samples.

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