JOURNAL GEOLOGICAL SOCIETY OF INDIA
Vol.84, August 2014, pp.227-238

Geotechnical Evaluation of Eastern Ghats Bauxite Deposits of India

P. G. Bhukte and M. J. Chaddha
Bauxite Alumina Division, Jawaharlal Nehru Aluminium Research Development and Design Centre (JNARDDC), Amravati Road, Wadi, Nagpur-440 023
Email: pg_bhukte@yahoo.com

Abstract: India is endowed with more than 3000 million tons of bauxite resources. Out of total India reserves, about 70% reserves are concentrated in Eastern Ghats (Odisha and Andhra Pradesh) region. Majority of the Eastern Ghat bauxite deposits are located at high altitude (high level type) and have been developed on khondalite and charnockite group of rocks with different geomorphological conditions. These are formed at an elevation of about 900- 1400 meter above mean sea level (msl). The physico-mechanical and technological properties of these bauxite vary widely depending upon the parent rock composition, mode of origin, geomorphological position, duration and age of bauxite formation. In the Bayer process the most important parameter that decides the economic importance is the quality of bauxite which again decides the digestion parameters for alumina extraction. Jawaharlal Nehru Aluminium Research Development and Design Centre (JNARRDC) is in process of evaluating the bauxite and laterite deposits of India for its suitability for commercial applications.

The present paper highlights the geological and geomorphological features of Eastern Ghats bauxite deposits and their technological characteristics. These studies are required to evaluate the bauxite in terms of their suitability for metallurgical and non metallurgical applications.

Keywords: Bauxite, Laterite, Geology, Evaluation, Gibbsite, Eastern Ghats.

INTRODUCTION

About two thirds of the Indian peninsula comprises Precambrian rocks. These rocks in parts are covered by Phanerozoic sedimentary suites and by the Deccan plateau basalts. The geology of India is presented in Fig.1A. Indian bauxite deposits are grouped into five major geological–geomorphological regions (Bardossy and Aleva 1990, Choudhary 1998; Mohamed Najar et al. 2009). These are (1) Eastern Ghats, (2) Central India, (3) Western Ghats and west coast, (4) Gujarat and (5) Jammu and Kashmir.

These are located in Odisha, Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Jharkhand, Maharashtra, Gujarat, Goa, Karnataka, Kerala, Tamil Nadu, Uttar Pradesh and Jammu and Kashmir. Bauxite deposits of first four areas are suitable for alumina production (Bhukte et al. 2008); however high grade bauxite deposits located in Gujarat and central India region are suitable for non-metallurgical applications (refractory, abrasive and chemical industry).

Jawaharlal Nehru Aluminium Research Development and Design Centre (JNARDDC) has carried out extensive survey on bauxite and laterite deposits of Eastern Ghats, Jharkhand and Gujarat during the year 2001-2005 under the Science and Technology, Ministry of Mines, Government of India project entitled "Bauxite technical data Bank". The various deposits/ areas evaluated under the project are delineated in Fig.1B (JNARDDC, 2005).

The main objective of the project was to prepare an information system for laterites and bauxite of the country, highlighting the main characteristics and technological features so that a ready reference is available to the industry. JNARDDC has evaluated the deposits during the phase-I of the studies which covered the areas of Madhya Pradesh, Chhattisgarh and Maharashtra during the year 1996-1999 in co-operation with Geological Survey of India (JNARDDC, 1999). Similarly in phase-II the bauxite and laterite deposits of Gujarat, Jharkhand and Eastern Ghats were evaluated (JNARDDC, 2005; Bhukte et. al. 2008).

In this paper an attempt has been made to summarize the salient characteristics of the work carried out in the project on geological and technological aspects of Eastern Ghats bauxite deposits. The geotechnical studies would be beneficial to existing alumina plants as well as for proposed Greenfield alumina plants viz. Vedanta Aluminium limited

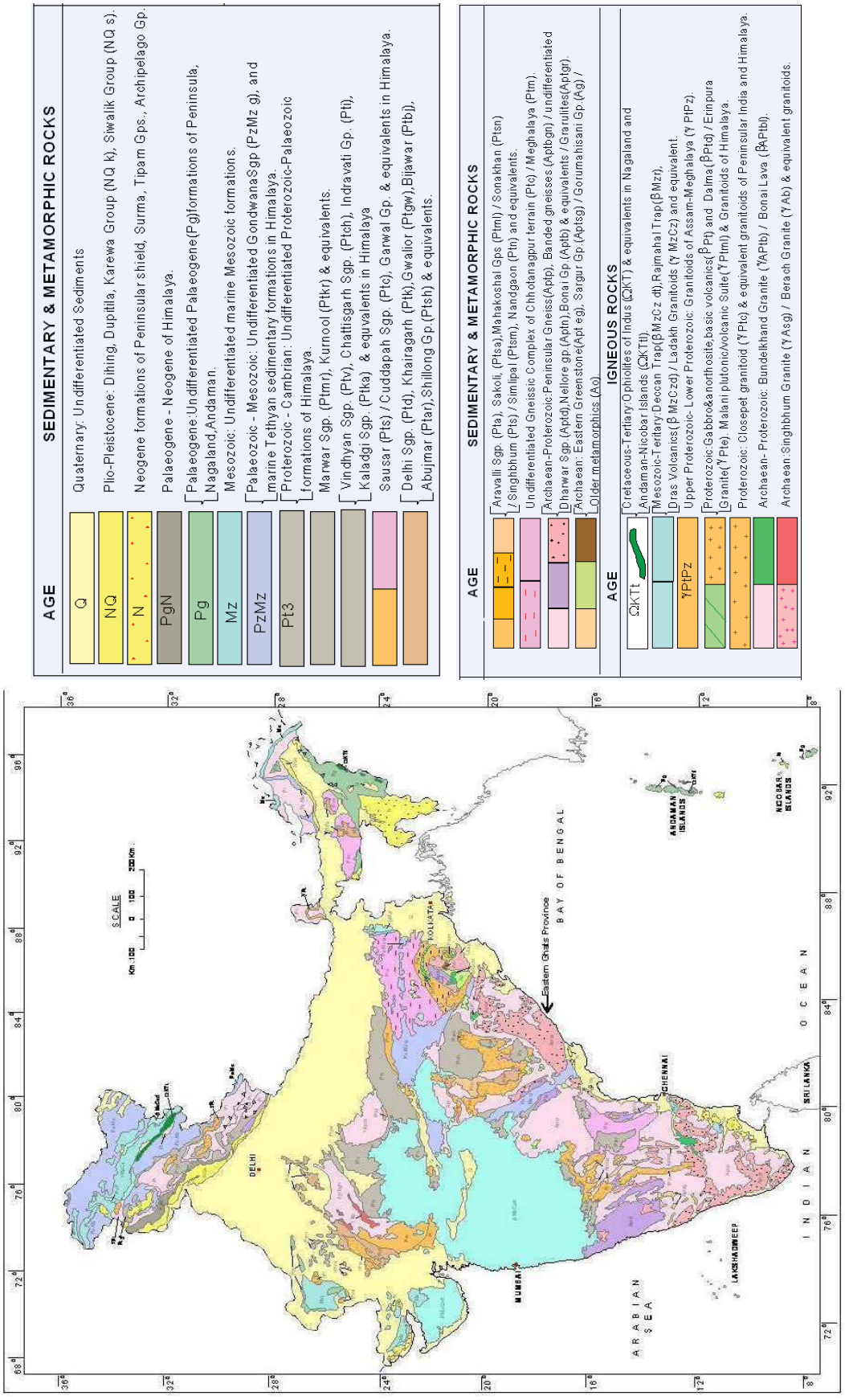

Fig.1A. Geological map of India

(VAL), Anrak Aluminium etc. coming up in the Eastern Ghats region.

GEOLOGICAL SETTING

In general, the lateritic bauxite are formed by strong chemical weathering of aluminosilicate rocks (Xiluo Hao et. al. 2010; Bhukte, 2002). The Eastern Ghats bauxite is essentially formed from the khondalite, charnockite group of rocks and associated rocks of Archaean age (Singh et al. 2008). The bauxite deposits are formed by in-situ weathering and lateralization of the above parent rock. Lateritization can be considered as a process of re-equilibrium of mineral phases to the temperature, pressure and the other environmental conditions present at the surface and directly underlying the zone of weathering with variable thickness (Bardossy and Aleva, 1990; Bhukte, 2002). The lithostratigraphic succession of Eastern Ghats bauxite is as given below (Singh et al., 2008).

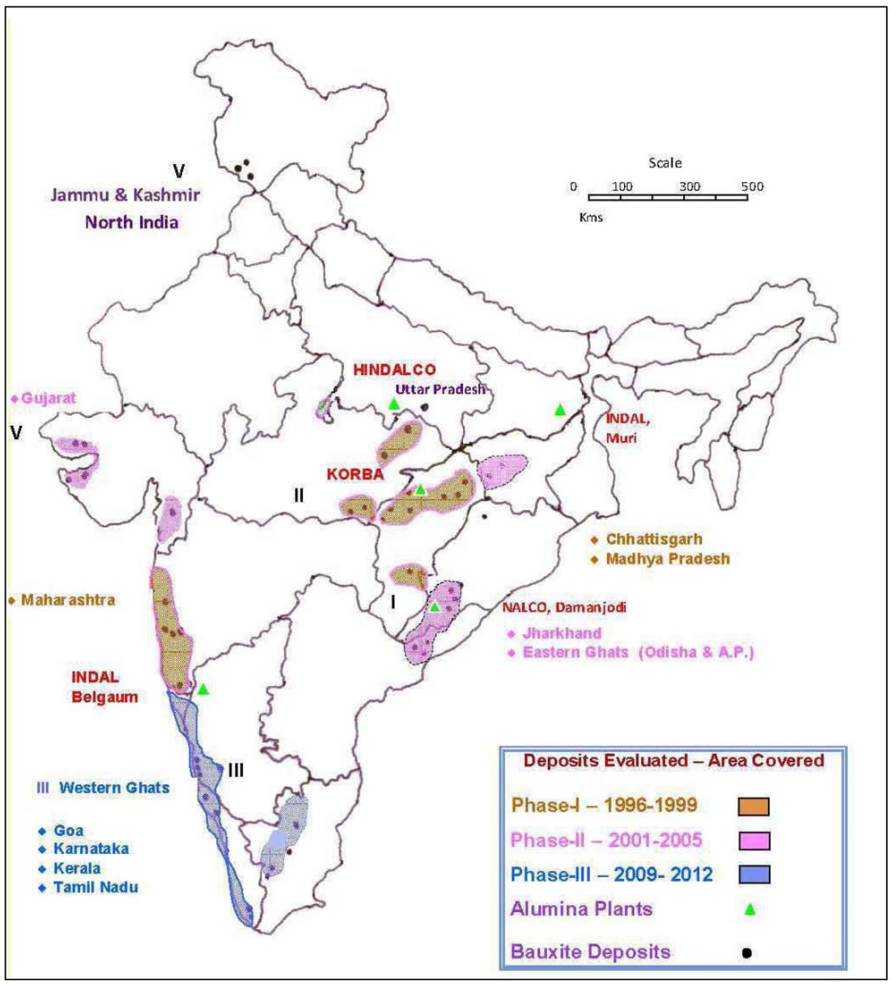

Fig.1B. Major bauxite deposits of India

Recent	Soil and Alluvium
Quaternary / Tertiary	Bauxite/ Laterite
Archean	Pegmatite & quartz veins, migmatites and gneisses, charnockite suite and khondalite

(Khondalite consists of Garnet- Sillimanite- Quartz-Feldspar- Graphite-Schists/ Gneisses with quartz and calc-granulites) (JNARDDC, 2005; Rao and Ramam, 1979).

The khondalite shows alternate bands or thin layers, rich in garnet and feldspar along with other minerals. The charnockites are represented by diopside-hypersthene-granulite and gneisses. These rocks contain about 15-20 % alumina, however, the major alumina bearing minerals in these rocks are feldspar, garnet, sillimanite etc. These rocks are highly metamorphosed and deformed. During the leaching process, the texture and structure of parent rock play a vital role. Texturally khondalite are porous and permeable and also contains weaker planes like foliations, joints, faults etc. thereby enhancing easy percolation of surface and sub-surface water for leaching (Chaudhuri and Chattopadhyay, 2005; Singh et. al. 2008).

Geomorphological Features

Eastern Ghats bauxite deposits are distributed between the north latitudes 17°47' and 19°45' and east longitudes 81°53 and 83°30' over a length of about 400 km and a maximum width of 30 km in parts of Andhra Pradesh and Odisha (Rao and Ramam, 1979; JNARDDC, 2005). The characteristics features of Eastern Ghats bauxite were described by Rao and Ramam (1979). Morphologically the east coast bauxite occurs on sloping landforms with uni-directional and /or polydirectional slopes unlike many other deposits. These geomorphic features have given rise to peculiar characteristics related to chemistry, mineralogy and thickness of bauxite occurrences (Bhukte, 2002). The Eastern Ghats bauxite deposits occur as a blanket over the

Archaean high grade metamorphics (khondalite and charnockite). It is characterized by low silica, moderate alumina, high iron and low titania (Rao, 1999; Bhukte, 2002).

On the basis of altitude, in eastern region, two types of deposits, high level and low level (coastal) deposits are located. The high level deposits are located at an elevation of about 900-1446 meter above mean sea level (Odisha, Andhra Pradesh) (Dutt, 1986) and on the other hand low level deposits are located at an altitude of about 50-350 meter above mean sea level (Coastal laterite deposits of Andhra Pradesh) (JNARDDC, 2005).

In the Andhra Pradesh sector, the Sileru river and its tributaries drain the Chintapalli area, whereas, the Sarada and Gosthani rivers form the main drainage systems for the area comprising the Anantagiri group of bauxite deposits.

In the Odisha sector, the Kolab and Machkund rivers form the main drainage for the southern group of deposits. The Machkund river flows westwards and then southwards before reaching the Godavari river basin (Rao and Ramam, 1979).

LATERITE AND BAUXITE OF EASTERN GHATS – ANDHRA PRADESH

The major bauxite deposits of Andhra Pradesh are located in Visakhapatnam and East Godavari districts however, major laterite spread is reported from coastal areas of Nellore, Prakasam, Ongole, Gudur and Hyderabad districts (JNARDDC, 2005).

The bauxite deposits of these areas occur as a blanket like capping over the top of hills comprising khondalite of Archaean age. However, in Hyderabad area, laterite occurs at high level and low level deposits over Deccan trap (Ramam, 1999). The khondalites and charnockites occurs, by and large as conformable bands with a regional NE-SW trend dipping at 50^0 to 85^0 towards southeast (Ramam and Vaidyanathan, 1981).The majority of laterite and bauxite occurrences of Visakhapatnam area are located in western and northern parts of the district (JNARDDC, 2005).

Bauxite forms four groups of high level flats on the Eastern Ghats at altitudes of 900-1420 m above mean sea level. These are formed due to geomorphological conditions and are situated in a belt 130 km long and 20 km wide and are devoid of intervening duricrusts (Dutt, 1986). These groups from SW to NE are the Gurtedu, Chintapalle, Paderu and Araku/ Anantagiri group (Table 1). Discontinuous and relatively small cappings (0.3 to1 sq.km. area) occur in the southwestern corner near Gurtedu in the East Godavari district are brought under Gurtedu group. Likewise, the duricrusts occurring in the vicinity of Chintapalle, Paderu and Anantagiri in Visakhapatnam district are termed as Chintapalle, Paderu and Anantgiri/Araku groups of deposits (Table 1).

Table 1. Location of bauxite and laterite deposits of Andhra Pradesh

Sl No.	Deposit No	District	Name of deposit
1.	1A	Visakhapatnam	Galikonda (Anantagiri Group)
2.	1B		Raktakonda (Anantagiri Group)
3.	1C		Katuki (Anantagiri Group)
4.	2		Minumuluru
5.	3		Sangudi
6.	4		Chittamgondi (Anantagiri Group)
7.	5		Gurugaru
8.	6		Araku
9.	7	Hyderabad	Vikarabad
10.	8	East Godavari	Dumkonda V.Ramavaram
11.	9		Chidipalem
12.	10		Sitapalli
13.	11		Addatigalu
14.	12	Nellore	Nellore
15.	13		Bitragunta
16.	14		Kavalli
17.	15	Ongole	Singaraukonda
18.	16		Ongole
19.	17	Visakhapatnam	Gudem (Chintappale Group)
20.	18		Sapparla (Chintappale Group)
21.	19		Jerrella (Chintappale Group)
22.	20		Katamrajkonda (Gurtedu Group)
23.	21		Sunkarimetta

The geological map showing location of laterite and bauxite deposits of Andhra Pradesh are presented in Fig. 2 and their relevant details are given in Table 1.

The areal extent of bauxite bearing lateritic plateau reported in Andhra Pradesh covers following districts as below

District	Area (sq km)
Visakhapatnam	24.65
East Godavari	9.00
Hyderabad and Ranga Reddy	109.00
Coastal laterite deposits	208.00
Nellore and Prakasam	70.00

(Ramam 1999, Roy Chowdhury 1965, GSI 2000, GSI 2001, JNARDDC, 2005)

Characteristics of Deposits

The thickness of bauxite in Visakhapatnam and East Godavari area is 3-14 m with an average 8 m. Bauxite occurs as blanket cover on khondalite and charnockite with the former being more prominent (Rao and Ramam, 1979). The average thickness of laterite in coastal deposits of Nellore,

Prakasam, Ongole and Gudur is about 2 m (JNARDDC, 2005). These deposits comprise the boulders and pebbles within the laterite horizon along with a few feet of soil overburden. The laterite horizon of coastal areas of Andhra Pradesh is presented in Fig. 3.

LATERITE AND BAUXITE OF EASTERN GHATS – ODISHA

The major bauxite deposits of Odisha are located in Koraput, Kalhandi and Sambalpur districts. The deposits in the Odisha sector are broadly described under the Southern, Central and Northern groups. The southern group of deposits includes Ballada, Maliparbat and Pottangi. The central group of deposits comprises Panchpatmali, Kodingamali and Karnapadikonda, however northern group of deposits are Baphlimali, Sijimali, Karlapat and Lanjigarh (Bhoskar 2005).

In the Odisha sector, there is a general fall in the altitude of cappings from south to north. The Pottangi, Ballada, Maliparbat, Karnapadikonda, Panchpatmali, Kondingmali and Lanjigarh cappings occur at altitudes of above 1300 m whereas, the Baphlimali and Karlapat cappings occur at altitudes of 1,000 m to 1,100 m. The Eastern Ghats bauxite contains a thick blanket of lateritic bauxite which directly rests above khondalite (Patnaik and Behra, 2005).

The geological map showing location of bauxite deposits of Odisha are presented in Fig. 4 and relevant details are given in Table 2.

The approximate areal extent of laterite bearing bauxite plateau reported for different districts of Odisha are given below (Roy Chowdhury 1965 and JNARDDC 2005).

District	Area (sq km)
Koraput	129
Kalahandi	93.74
Sambalpur and Bolangir	11.39
Ganjam	2.69
Phulbani	13.59

Characteristics of Deposits

Thick laterite cappings are observed on flat to gently sloping surfaces on hill tops. In Odisha, the thickness of bauxite on an average is 12 m overlain by ferruginous laterite of about 3 m. Below the bauxite zone, lies the partially lateritised khondalite (PLK) of about 10-50 m thick (Patnaik and Behera, 2005; Murthy and Patnaik, 2000). The partially lateritised khondalite and weathered khondalite rest on parent rock khondalite. This lithostratigraphic sequence is well observed in Panchpatmali deposit of National

Table 2. Location of bauxite and laterite occurrences/ deposits of Odisha

Sl No.	Deposit No	District	Name of deposit/Occurrence
1.	1	Sambalpur-Bolangir	Borasambar (Gandhamardan Parbat)
2.	2.	Kalahandi	Kisanmali
3.	3.		Karlapat Hill
4.	4.		Siji Mali (TijiMali)
5.	5.		Manjimali
6.	6.		E of Lokharishi
7.	7.		Chandgiri
8.	8.		Taljhiri
9.	9.		Paphlimal Parbat
10.	10.		Kathakhal
11.	11.		Nagalbhata Mali
12.	12.		Dakapatna Parbat
13.	13.		Domb Mali
14.	14.		Sasbahu Mali
15.	15.		Near B. P. (Jeypore)
16.	16.		Tikri
17.	17.	Koraput	Girliguma plateau
18.	18.		Gusramali Parbat
19.	19.		Kodinga Mali
20.	20.		NE of Marubaruguda
21.	21.		E of Bandikuru
22.	22.		NW of Getchella
23.	23.		Panchpatmali
24.	24.		Chard
25.	25.		Domri Jola
26.	26.		Bijaghati
27.	27.		Karnapadi Konda
28.	28.		Mattalaputtu (Mali Parbat)
29.	29.		Kuntigam
30.	30.		Pottangi
31.	31.		Devmali Parbat
32.	32.		Poragar
33.	33.		Kailasakota
34.	34.		Kutrumali
35.	35.		Kalyansingapuram
36.	36.		Vatikirl Dongar
37.	37.		Gumma
38.	38.		Lanjigarh
39.	39.		Golagola
40.	40.		Manduru
41.	41.		Kotagad
42.	42.		Belagad
43.	43.		Gurulimaska
44.	44.		Parlakimidi
45.	45.		Ramagiri
46.	46.		Koipuram
47.	47.		Tdongiri
48.	48.		NNE of Koipuram
49.	49.		Mahendragiri
50.	50.		SE of Koipuram
51.	51		Maliparbat
52.	52		Ballada
53.	53		Baphlimali
54.	54		Pasangamali
55.	55		Korukonda
56.	56	Nupariia (Bastar and Nupariia-Orissa border)	Sainipara Hill
57.	57		Barapat Dongar
58.	58		Kondamai Hills
59.	59		Sandbahill

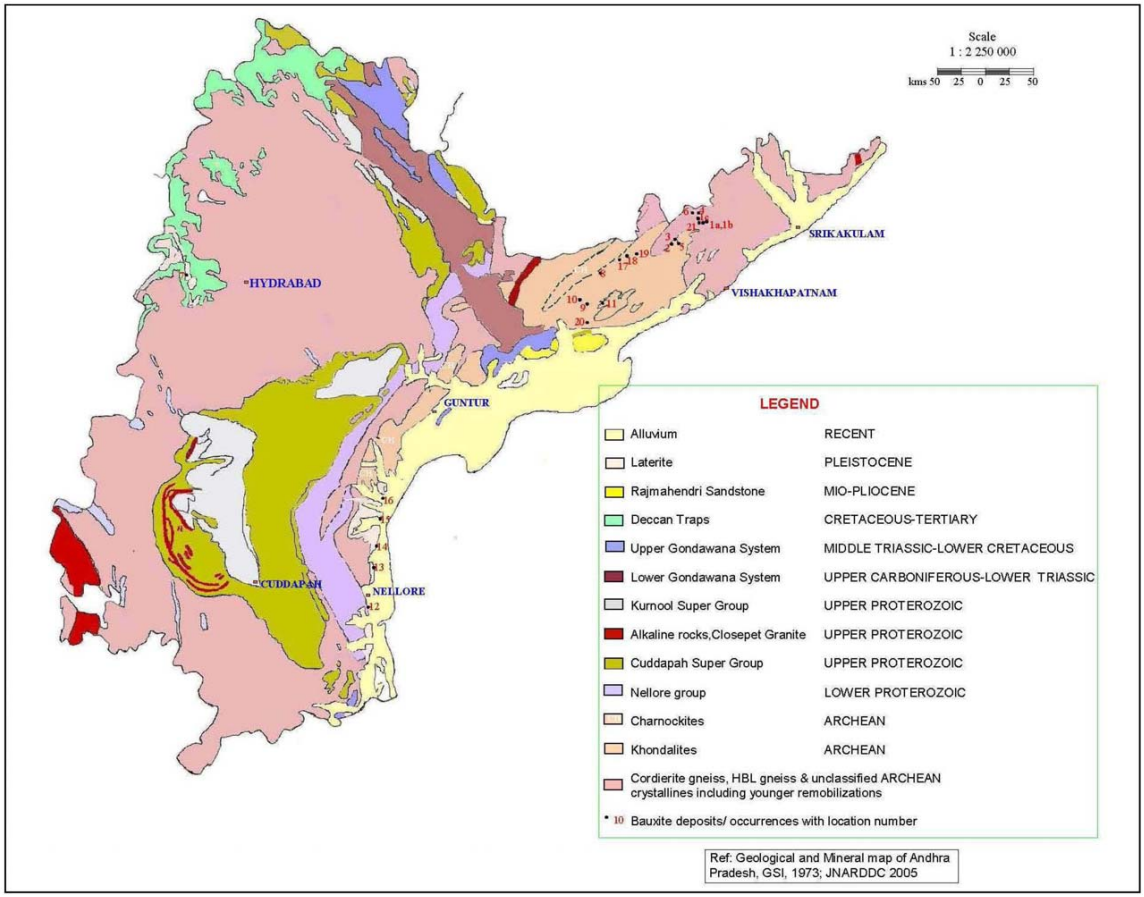

Fig.2. Geological map showing bauxite and laterite deposits of Andhra Pradesh

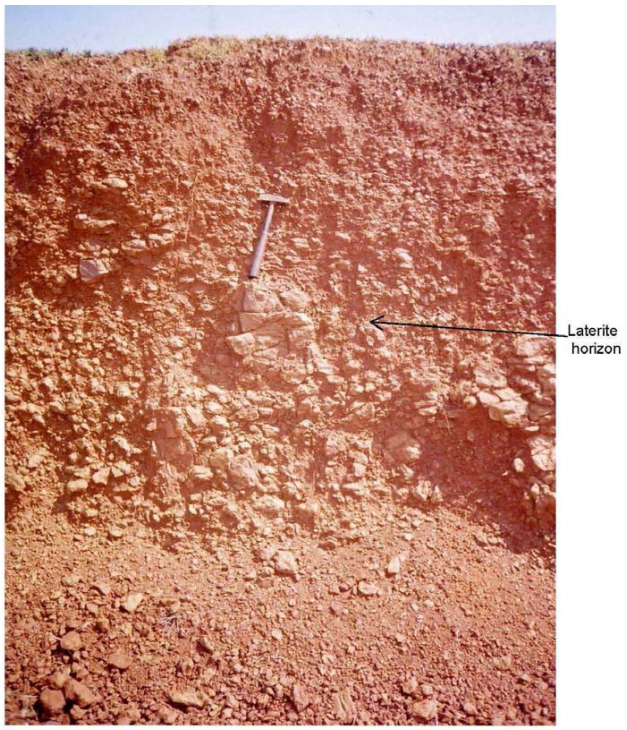

Fig.3. Coastal laterite deposit, Andhra Pradesh.

Aluminium Company Limited (NALCO) (Singh et. al. 2008). In general, the thickness of PLK varies from horizon to horizon. In exposed section it is around 15 m, however, as per some authors it is about 10-100 m (Mohanty and Patnaik, 2008).

The bauxite mine face of Panchpatmali deposit of central block is presented in Fig.5A. The generalized lithological sequence of Odisha bauxite deposits is given below.

top soil
laterite
bauxite
partially lateritised khondalite (PLK)
weathered khondalite
khondalite

MODE OF OCCURRENCE AND CONFIGURATION OF ORE BODY

There are distinct geological variations in the mode of occurrence and ore body configuration in various deposits, which largely influence the mining techniques to be adopted. Based on study of various Indian bauxites, three broad

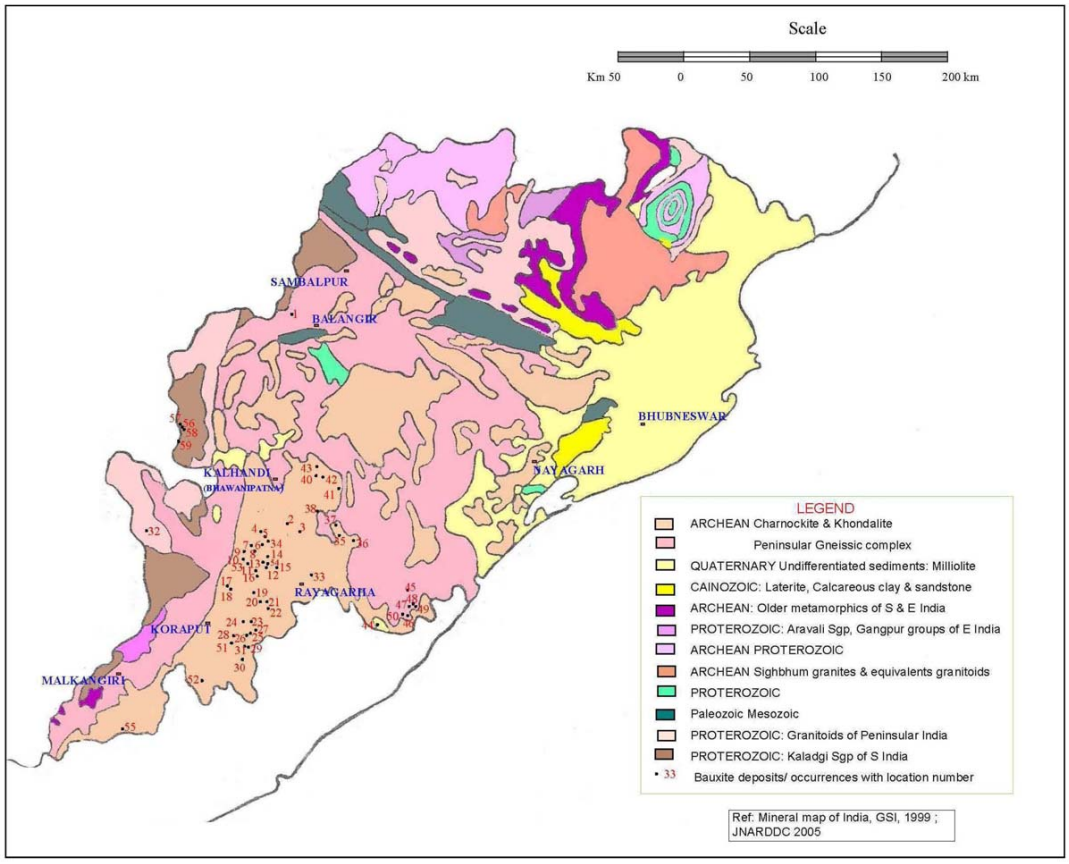

Fig.4. Geological map showing bauxite and laterite deposits of Odisha.

groups can be suggested (Nandi and Ramachandran, 1998). (1) Thick continuous ore body with undulating roof and floor: most of the bauxite deposits of Eastern Ghats. (2) Continuous with variable thickness and grade: selected Western Ghats and Gujarat bauxite deposits and (3) Pockety and discontinuous type of ore body: most of the central Indian and Gujarat deposits.

The areal extent of individual bauxite deposits varies from less than 1 sq.km to 15 sq. km along with variable thickness (Nandi and Ramachandran, 1998; JNARDDC, 2005). Depending on these two parameters, resources of bauxite are estimated. The bauxite are classified as small, moderate, large and very large depending on areal spread of cappings (Rao 1998).

Area (km^2)	Small Upto 1	Moderate 1 to 5	Large 5 to 10	Very Large 10 to 15
Resource of bauxite in million tons)	10 to 20	20 to 100	100 to 200	200 to 300
Bauxite deposits	*Galikonda and Rakta-konda (A.P.)*	*Chittamgondi Konda and Sapparla (A.P.) Kodingamali (Odisha)*	*Baphlimali (Odisha) (Odisha)*	*Panchpatmali, Sijimali*

COLLECTION OF SAMPLES

Based on the geological data of bauxite deposits, the deposits were identified for sampling. The field work was carried out in the areas of Odisha and Andhra Pradesh and thirteen representative samples of bauxite and laterite were collected from Panchpatmali and Pottangi deposits of Odisha. However 15 representative samples of laterite were also collected from various coastal deposits of Nellore, Ongole and Prakasam areas of Andhra Pradesh.

The representative samples were prepared in the laboratory for the characterization and technological studies.

Chemico-mineralogical Characteristics

The laboratory results indicate that costal laterite of Andhra Pradesh deposits is characteristics of high silica, high iron with low alumina content. Mineralogical studies by XRD reveal alumina present mainly in the form of kaolinite and alumo-goethite, whereas, gibbsite and

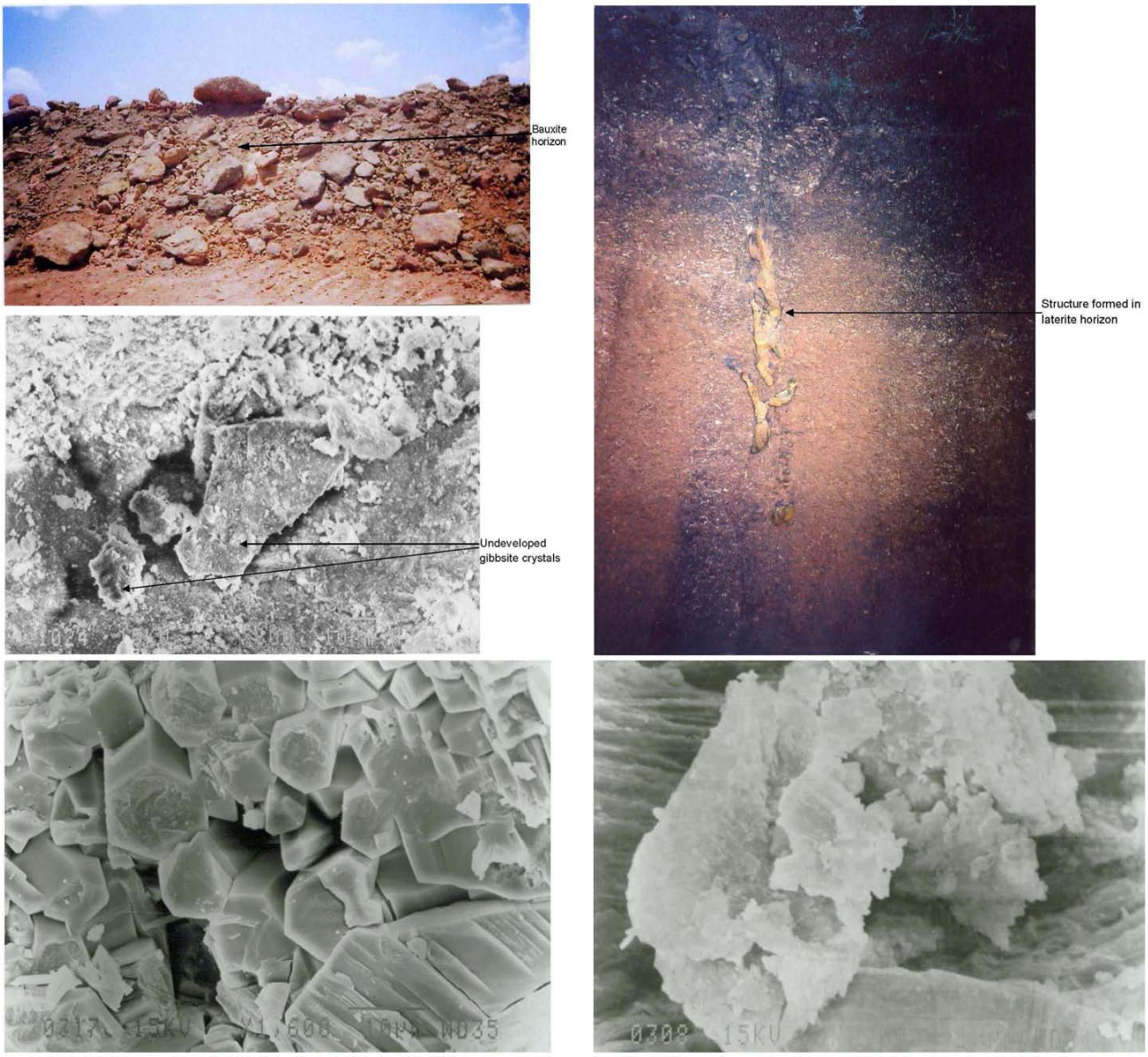

Fig.5. **(a)** Panchpatmali mine, Odisha. **(b)** Coastal laterite deposit, Andhra Pradesh. **(c)** Alumina mineral (gibbsite) in coastal laterite deposits of Andhra Pradesh. **(d)** Typical gibbsite in bauxite of Panchpatmali (Odisha) deposit. **(e)** Iron minerals in Pottangi bauxite deposit, Odisha.

boehmite as minor constituents which is unique of this laterite as compared to other Indian laterites (JNARDDC, 2005). These characteristics may be due to insufficient leaching of parent rock/ incomplete lateritisation and bauxitisation. Further these deposits are located at a low elevation (almost few meter above ground level) and above different parent rock types. The field photograph (Fig. 5B) indicates structure formed due to incipient lateritization within the laterite horizon in coastal deposits of Andhra Pradesh. The morphology studies by Scanning electron microscope (SEM) indicate undeveloped gibbsite crystals with ferruginous phase in laterite may be due to partial lateritization (Fig. 5C). In general, the bauxite comprises well developed hexagonal gibbsite crystals and may be due to complete bauxitization process (Fig. 5D).

The laboratory results shows that Eastern Ghats (Odisha) bauxite is characteristics of high iron, low to moderate alumina and low silica. It is found that the Panchpatmali bauxite contains alumina in the range of 42-48 % (Average 44 %). The north block contains quite high alumina as compared to Central block. The result shows that the laterite is siliceous in nature with high iron content. Mineralogically, the bauxite is gibbsitic in nature, however, it also contains minor amount of boehmite, diaspore, illmenite and siderite

(JNARDDC, 2005). The goethite is dominant as compared to hematite and silica is present mainly in the form of kaolinite.

Mineralogically, the east coast bauxite is very similar to that of Brazilian and Australian deposits except for the high content of iron oxides in the present bauxite (Singh et. al. 2008; Nandi and Ramachandran, 1999). However the Australian bauxite is characterized by high alumina content (Mahadevan and Ramachandran, 2000).These deposits are also high level, blanket type, however; the average thickness of bauxite is much less (3-6 m) as compared to Eastern Ghats bauxite.

TECHNOLOGICAL EVALUATION/STUDIES

The technological study of bauxite deposit is important for setting up a new alumina plant as well as utilization of particular bauxite for alumina production. For this purpose a number of technological studies have been carried out which includes

- Bond work index studies
- Determination of available alumina and reactive silica
- Digestion studies – Optimization of digestion parameters such as temperature, caustic concentrations, residence time, liquor to bauxite ratio for techno-economical extraction of alumina
- Settling studies – determination of settling characteristics

Bond Work Index (Grindability) Studies

The bond work index or grindability indicate hardness of the mineral which gives an idea about how much energy is required to grind the ore and hence it is important from plant point of view (Bhukte et. al, 2008). The bond work index of various bauxite samples of Odisha deposits have been carried out by bond work index mill. The result shows that the bond work index of Eastern Ghats bauxite is in the range of 10-12 KWh/mt. The bond work index values of various bauxite of Eastern Ghats deposits are given below (JNARDDC, 2005).

Sl. No.	Deposit/Bauxite	Bond work Index (KWh/mt)
1	Pottangi	10.53
2	Kutrumali	12.07
3	Panchpatmali	10.50
4	Lanjigarh	11.80

The bond work index of Eastern Ghats bauxite is very low as compared to Gujarat, Jharkhand and Maharashtra bauxite which is in the range of 15-18 KWh/mt. It indicates

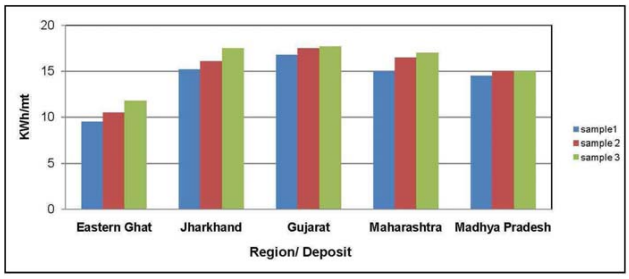

Fig.6. Bond work index of bauxite.

that Eastern Ghats bauxite require less energy for grinding of ore for alumina production because the ore is gibbsitic in nature and very soft (10-11 KWh/mt). The bond work index of various bauxite deposits of India (JNARDDC 1999, Ramana Rao et. al. 2000, Bhukte et. al. 2008) is presented in Fig. 6.

Determination of Available Alumina and Reactive Silica

Maximum extractable alumina (MEA) or available alumina is determined to know the correct picture about the quality of ore. The quality of bauxite is most important parameter in the Bayer process which decides the digestion parameters of an alumina plant (JNARDDC, 2002).

In bauxite the alumina is distributed in different mineralogical phases such as gibbsite, boehmite, diaspore, kaolinte, and alumo-goethite. The crystal habit of natural gibbsite is usually pseudohexagonal tubular. The typical hexagonal well developed gibbsite crystals recorded in Panchpatmali bauxite and mineralogical study also reveal that the bauxite is gibbsitic in nature (Fig. 5d). The Pottangi bauxite shows puff shaped minerals of alumogoethite. It is one of the typical iron mineral and commonly occurs in Indian bauxite. In general the alumogoethite is derived from the garnet which is a constituent of khondalite rock (Fig. 5e) (JNARDDC, 2005). The technology for suitable extraction is decided on the mineralogy of the bauxite and the maximum extractable alumina, that can be extracted under the prevalent temperature and caustic concentration. The same is true for silica bearing minerals which is distributed in two mineralogical phases namely kaolinite and quartz. Higher the kaolinitic silica content of the bauxite less will be the extractability of alumina due to formation of sodalite complex. Hence it is very much important to determine both the available alumina as well as reactive silica (JNARDDC, 2002). The "Digestion Characteristics" for different bauxite vary widely and sometimes even the bauxite from the same deposit might behave very differently (Mahadevan, 2000). The chemico-mineralogical characteristics of bauxite might change within the bauxite deposit. The gibbsitic bauxite is easy to digest as compared

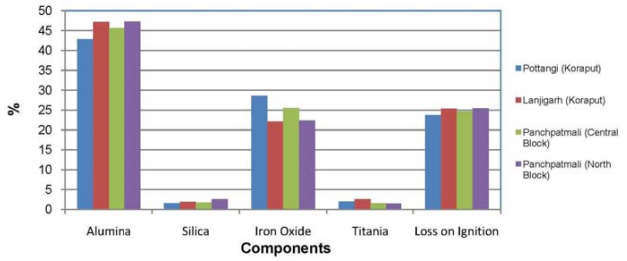

Fig.7a. Chemical composition of bauxite.

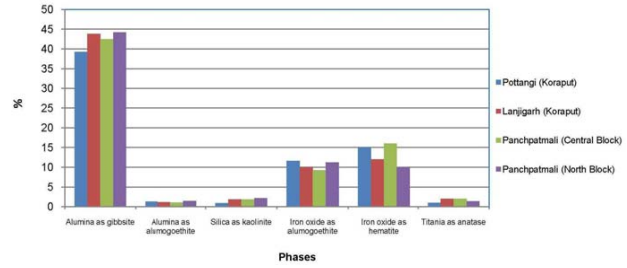

Fig.7b. Mineralogy of bauxite.

to boehmitic and diasporic bauxite.

The chemical composition of bauxite samples by wet chemical method is presented in Fig.7a and the various mineralogical phases present in bauxite are depicted in Fig.7b. The available alumina of bauxite was determined at JNARDDC laboratory by autoclave at temperature of 145^{0}C. The results show that gibbsitic bauxite of Odisha has available alumina in the range of 40-45%. The selected bauxite of north block of Panchpatmali contains high available alumina due to the presence high alumina in bauxite (Fig. 8A). The estimate of reactive silica was carried out at temperature of 145^{0}C with 30 minute time. The trend of reactive silica is also proportional to gibbsitic bauxite having lower reactive silica content (Fig. 8B).

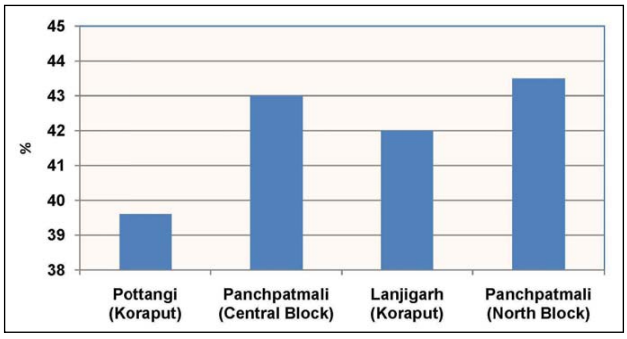

Fig.8a. Available alumina present in bauxite.

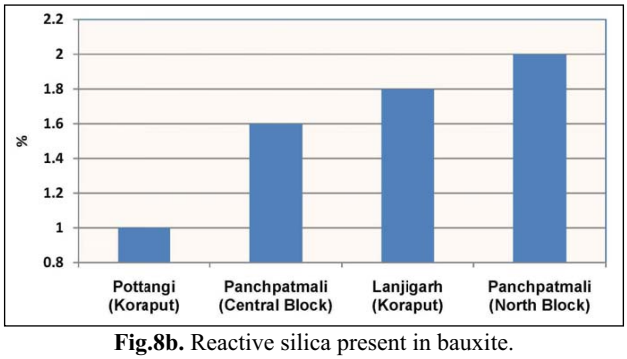

Fig.8b. Reactive silica present in bauxite.

Digestion Studies

The objective of carrying out digestibility test is to ascertain the suitability of a new bauxite deposit for its processing in the plant and to optimize the digestion parameters for increasing extractability of alumina from bauxite.

In general, the deposits particularly those located in the Eastern Ghats (Odisha and Andhra Pradesh) are suitable for alumina production, however, there are limited resources of high grade bauxite, suitable for refractory and abrasive industries (Bhukte et.al. 2012). The specifications for suitability of bauxite grade for metallurgy are Al_2O_3 40-52% SiO_2 1.5-15 % Fe_2O_3 5-30 % and TiO_2 1-6 % (Nandi et. al.1999).

The digestion studies were carried out on different bauxite samples of Odisha deposits by bomb digester.

The procedure adopted for digestion tests is as follows

- Experiment was conducted in a 10 liters autoclave with agitation and temperature control.
- Digestion temperature 145°C for 30 min
- The particle size of bauxite used in the experiment was -100 mesh

The digestion efficiency at 145^{0}C of Pottangi, Panchpatmali and Lanjigarh bauxite having gibbsitic mineralogy is in the range of 90-93%. The results are tabulated in Table 3

CONCLUSIONS

Field assessment of Eastern Ghats bauxite has been

Table 3. Digestion parameters and Results

Parameters	Pottangi	Panchpatmali	Lanjigarh
Digestion Liquor Na_2Oc gpl	172.83	180.57	175.93
Al_2O_3 gpl	88.74	109.58	89.76
Initial Liquor RP	0.513	0.606	0.510
Target RP	1.20	1.23	1.23
Bauxite charge, gpl	300	286.74	270
Results Liquor analysis after digestion			
Digested liquor Na_2Oc gpl	157.325	164.30	154.75
Al_2O_3 gpl	168.19	195.51	189.74
RP (achieved)	1.20	1.21	1.23
Mud Load	0.396	0.401	0.335
Digestion efficiency %	92.33	91.56	91.51

carried out by collecting representative samples. Subsequently, the samples were homogenized by standard sampling procedure and subjected for characterization and technological studies. The details of these studies are summarized below.

- The Eastern Ghats bauxite has developed on khondalite and charnockite. The deposits are blanket type with average bauxite thickness of about 10 m.
- The bauxite is characterized by moderate alumina, high iron and low silica content. Mineralogically it is completely gibbsitic in nature.
- Our re-evaluation study of laterite deposits of Andhra Pradesh shows that the laterite contains high iron, high silica, and low alumina. These vast spread of laterites are found promising and suitable from industrial point of view (cement, emery etc.)
- The Eastern Ghats bauxite is very soft as compared to other bauxite (Jharkhand, Gujarat, Maharashtra etc.) of India because it is gibbsitic in nature and originated from khondalite.
- In Eastern Ghats (Odisha) region there are selected deposits whose reserves are in the order of 15-40 million tonnes can be best suitable for setting up of alumina plant because of gibbsitic nature of bauxite. The technological studies (available alumina, reactive silica, digestion) also show that the bauxite is suitable for alumina production.
- The gibbsitic nature of bauxite with digestion efficiency of about 91% is ideal for production of alumina by Bayer process. Further the reactive silica is also low.
- The laterite of Panchpatmali (Odisha) and coastal Andhra Pradesh areas are found amenable to simple beneficiation by crushing and dry screening and the grade can be appreciably improved by rejecting selected fractions based on the economics of mining and processing.

Acknowledgements: Authors are grateful to Shri C S Gundewar, Director, JNARDDC for granting permission to publish this paper. We take this opportunity to respectfully acknowledge Science and Technology Wing, Ministry of Mines, Government of India for sponsoring and financial support to the project entitled 'Bauxite technical data bank'. Authors are thankful to Dr. J Mukhopadhyay, Ex. Director, JNARDDC for guidance during the above work. We wish to express our sincere gratitude to the Directorate of Geology and Mining (DGM), Geology and Mining Department NALCO and Geological Survey of India (GSI) for their co-operation in literature survey and sampling. Authors wish to thank the staff of bauxite alumina, wet chemical and SEM lab for carrying out the laboratory work.

References

Bardossy, G. and Aleva, G.J.J. (1990) Lateritic Bauxite: developments in economic geology. 27, ELSEVIER, Amsterdam-Oxford-New York-Tokyo, pp 369-395

Bhukte, P.G. (2002) Geological and geomorphological features of bauxite deposits of western and Coastal Maharashtra, their chemico-mineralogical characteristics and possible utilization: Unpublished Ph.D. thesis, Nagpur University, Nagpur, pp.7-12

Bhukte P.G., Chaddha M.J. and Mukhopadhyay, J. (2008) Bauxite technical data bank of India-Its significance for the Country. Proc. ICSOBA-2008, pp.24-29

Bhukte P. G., Chaddha M. J., Puttewar S.P., Najar M. and Nandi A.K. (2012) Indian Calcined Bauxite –Status and future prospects: Internat. Symp. (IBAAS) Binder Vol. I, pp 90-101

Choudhary, N.K. (1998) Bauxite mining in India. Proc. BAUXMET-1998, pp.65-80.

Chaudhuri, B.K. and Chattopadhyay, S. (2005) The geology of East Coast bauxites of Orissa –A review with special reference to its morphology and petrological characters. Proc. ICSOBA, pp.190-199.

Dutt, N.V.B.S. (1986) Geology and Mineral Resources of Andhra Pradesh. NRDCS, Hyderabad, pp.156-190.

GSI (2000) District resource map of East Godavari district, Andhra Pradesh

GSI (2001) District resource map of Rangareddy and Hyderabad district, Andhra Pradesh

GSI (2001) District resource map of Nellore district, Andhra Pradesh

Jadhav, G.N., Sharma, N. and Sen Priyanka (2012): Characterization of Bauxite deposits from Kachchh area, Gujarat. Jour. Geol. Soc. India, v.80, pp.351-362.

JNARDDC (1999) Report on 'Bauxite Technical Data and Information Bank (Madhya Pradesh and Maharashtra)' Vol. I & II, Jawaharlal Nehru Aluminium Research Development and Design Centre (JNARDDC) and GSI (Central Region), Nagpur, pp.1-25

JNARDDC (2002) 'Short term course on 'Alumina Technology' (SAT 2002), pp.22-71

JNARDDC (2005) Report on 'Compilation of Bauxite Technical Data Bank (Gujarat, Jharkhand and eastern Ghats), JNARDDC, Nagpur, pp.1-206

JNARDDC (2012) Report on 'Bauxite Technical Data Bank-Phase-III (Western Ghats deposits), JNARDDC, Nagpur, pp.1-182

Mahadevan, H. (2000) Alumina Extraction - Dependency on Bauxite and Process Parameters. Proc. BAUXMET-2000, CD Vol-I

Mahadevan, H. and Ramachandran, T.R. (2000) Competitiveness of Indian East Coast Bauxite for Alumina Production. Proc.

BAUXMET-2000, CD Vol-I

Mohamed Najar, P. A., Janbandhu, K.R., Bhukte P.G. and Mishra, R.S. (2009) Thin layer chromatographic study of Indian bauxites: Indian Jour. Chem. Tech., v.16, pp.65-75

Mohanty, D.K. and Patnaik, S.K. (2008) Environment management in large scale mechanized open cast mine: A case study of Panchpatmali bauxite mine: Proceedings ICSOBA 2008, pp 30-34

Murthy, C.M.D. and Patnaik, S.K. (2000) Major challenges in exploiting East coast bauxite reserves: Proc. BAUXMET-2000, CD Vol 1.

Nandi, A.K. and Ramachandran T. R. (1998) Criteria for setting up greenfield alumina plant in India; Proc. BAUXMET-98, pp.319-330

Nandi A.K. and Ramachandran T.R. (1999) Optimum utilization of Indian bauxite for alumina production. Proc. Bauxite Vision-2050, pp 4-13

Nandi A. K., Bhukte P., Muthuraman K., Iyer R.V., Bhatia S. K., Prem Babu and Srinivasachari, K. (1999) Re-examination of bauxite occurrences of Maharashtra -Proposal for industrial use; Proc. Nat. Sem. Bauxite Vision – 2050, pp.44-54

Patnaik, S.K. and Behera, B.L. (2005) Exploitation of East coast bauxite reserves: A case study from Nalco's Panchpatmali bauxite Mines: TRAVAUX ICSOBA, v.32(36), pp.154-162

Ramam, P.K. and Vaidyanathan, R. (1981) Laterites and lateritisation over Eastern Ghats and coastal plains in North coastal Andhra Pradesh India: Lateritisation Process, Oxford and IBH Co, New Delhi, pp.295-301.

Ramam, P.K. (1999) Mineral Resources of Andhra Pradesh. Geological Society of India, Bangalore, pp.59-70

Ramana Rao, K.V., Bhukte, P.G. and Kutumba Rao, V. V. (2000): Organic and microscopic characteristics of Indian bauxite: Proceedings of (BAUXMET-2000) CD Vol-I.

Rao, M.G. and Ramam, P.K. (1979) The East coast Bauxite deposits of India. Bull. Geol. Surv. India, Series A – Econ. Geol., No. 46 pp 1-24

Rao, M.G. (1998) 3 billion tonne resource potential. Proc. BAUXMET-1998, pp 65-80

Roy Chowdhury, M.K. (1965) Bauxite in India- An assessment of Reserves: Bull. Geol. Surv. India, Series A- Econ. Geol., No.25, pp 1-127

Singh, V., Chatterjee, G. and Behera, P. K. (2008) An overview of East coast bauxite deposits with special reference to quality control and mine planning at Panchpatmali bauxite mine. Proc. ICSOBA 2008, pp.3-14

Xiluo Hao, Kwunlum Leung, Rucheng Wang, Weidong Sun, Yiliang Li (2010) The geomicrobiology of bauxite deposits. Jour. Geosci. Front., pp.81-89.

(Received: 2 February 2011; Revised form accepted: 25 March 2014)