Study of Minor Bauxite Deposits, Madhya Pradesh: Geological Studies and Techno-Economic Evaluation

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Abstract

Indian bauxite deposits are mainly of lateritic origin. They have been grouped into five major bauxite districts based on similar geological and geomorphological features. Apart from major bauxite deposits of Eastern Ghat District (Orissa and Andhra Pradesh), minor pocket type deposits, particularly Satna, Rewa, Katni, Anuppur districts and adjoining areas belonging to Central Indian District have their own importance. Four representative deposits of these areas namely Naru (Satna), Tikar (Rewa), Padwar (Katni) and Chachandee (Anuppur) were studied with reference to their mineralogy, reserves and grade, mining and its impact on environment and techno-economic evaluation. Each of these deposits has reserves of less than 10 million tonnes mixed with three grades of ore namely metallurgical, refractory and cement. There are several other similar occurrences of bauxite in these areas. Mining methods in these deposits is erratic and selective. Associated clay and ochre mining is a characteristic feature of these deposits. Excavated areas are being backfilled in some places leaving others that may cause instability of slopes in future. As per chemico-mineralogical studies, the bauxite of Satna, Rewa area is boehmitic and titanium rich and of Katni, Anuppur areas is mixed gibbsitic-boehmitic. The ore mined from these areas is manually sorted on site into metallurgical and non-metallurgical categories and transported accordingly. There is scope for detailed study regarding complex utilization of ore belonging to these areas.

Keywords: Lateritic bauxite; Katni deposit; Deccan traps; Chachandee deposit.

1. Indian Scenario of Laterites and Bauxites

The Indian bauxite deposits are mainly of lateritic origin (in-situ and transported) with varying modes of occurrences and geological nature. The Chemical, physical and mineralogical characteristics of these bauxites vary widely. There are two basic approaches to bauxite classification schemes. First the pure scientific one which finds use in prospecting and exploration and second the techno-economic one reflecting industrial requirements. Indian bauxites were first classified based on their mode of occurrences as low level and high level deposits[1]. According to which, bauxite deposits in India are mostly associated with laterites which occur extensively as blankets or cappings, either on the high plateau and hill ranges of the peninsular India or in certain low level laterites on west coast and Central India. High level bauxites occur mainly in four regions or dissected table lands. They are: the Plateau regions bordering the states of Bihar and Madhya Pradesh, the Maikala range of hills in Madhya Pradesh, the Western Ghats and the Eastern Ghats.

Indian bauxites were regrouped [2] into five major bauxite districts based on similar geological and geomorphological features: the Eastern Ghat bauxite district (950-1450m above MSL), the Central India bauxite district (900-1200 m above MSL), the West Coast bauxite District (600-1200 m above MSL), the Gujarat bauxite district and the Jammu and Kashmir bauxite district

2. Bauxite Deposits of Central India

The Central Indian bauxites and laterites are plateau types, capping different rocks of Precambrian basement and basalts of younger age. They extend from Bihar, Jharkhand (Ranchi and Palamau districts) through Madhya Pradesh and Chhatisgarh (Surguja, Bilaspur, Mandla, Katni and Shahdol district) to Maharashtra (Kolhapur District). This paper focuses on minor pocket types of deposits belonging to Satna, Rewa and Katni districts extending up to adjoining Banda district of Uttar Pradesh. The discovery of Eastern Ghats bauxite during seventies in the states of Orissa and Andhra Pradesh brought a sea-change in the country's bauxite resource position. Resources of bauxite as on 01.04.2010 are placed at 3480 million tonnes[3]. Orissa has emerged as the lead producing state accounting for about 35% of total bauxite production. Next in the order are Gujarat (32%), Jharkhand (11%), Maharashtra (9%), Chhatisgarh (6%), and Madhya Pradesh (3%). The remaining 3% production of bauxite is contributed by Goa, Karnataka and Tamilnadu.

Although today all the attention has been diverted to the large resources of the east coast, nevertheless minor pocket type bauxite deposits of Madhya Pradesh belonging to Satna, Rewa Katni and Anuppur districts have their own importance because of their location near the existing alumina plants of Central India. Four deposits, selecting one from each district were studied with respect to their geological setup, salient features of bauxite mining and techno-economic valuation including uses and specification of the ore. Results are presented and discussed in this paper. The study of these four deposits will help to evaluate the existing bauxite deposits of similar nature and explore new occurrences in surrounding areas. An attempt in this paper has been made to delineate and propose sub groups within Central India bauxite district (Table 1)

Table 1.Sub grouping of bauxite deposits within Central India Bauxite district. (Refer Figure 1)

Sector	Geological and Geographical area	Type	Reserves in Million Ton	Bauxite sub groupswithin Central India Bauxite district (proposed)
A	Rewa*, Satna*, Sidhi, Katni* districts of Madhya Pradesh and adjoining Banda, Mirzapur and Varanasi districts of Uttar Pradesh	Small group of deposits (No. of known occurrences - 171**)	<10	Eastern MP sub group (covers part of U P)
B	Mandla, Dindori, Balaghat, Shahdol, Anuppur* and Balaghat districts of Madhya Pradesh	Small group of deposits	<10	
C	Area of Madhya Pradesh covering Malwa plateau	Laterite occurrences, detail exploration is required.	<10	Western MP sub group
D	Guna, Shivpuri districts of Madhya Pradesh and adjoining Lalitpur district of Uttar Pradesh of Chhatisgarh	Laterite occurrences, detail exploration is required.	--	Northern MP sub group
E	Bilaspur, Surguja, and Raigarh districts of Chhatisgarh	Small deposit	--	Chhatisgarh sub group
F	Bastar area	Actual reserves not known	--	

* Four deposits selected for study belong to these districts ** Refer Table 3

3. Geological Setup

Deposits belonging to Sector - A (Table 1) lie on Vindhyan sandstone or shale while deposits of Sector-B are found to rest over Deccan traps but Vindhyan lime stone and marbles cover large part of Katni district. Bauxite deposits of Sector-C are found mostly over Deccan traps however some laterite profiles have been found to be derived from Gondwana sandstone or Archaean granite gneiss. Bauxite bearing plateaus of Sector-D i.e. Bastar area are found resting over Vindhyan or equivalent formations. Laterite cappings of Malwa plateau (Sector-E) have been thought to be derived from Deccan traps and of Sector-F from Kaimur sandstone and intercalated shales. Geological setup of bauxite bearing sectorsof Madhya Pradesh (A to D) is shown in Figure 1. The physical characteristics of the four deposits are given in Table 2.

4. Mode of Occurrence and Configuration of the Ore Body

Based on study of various Indian bauxites, three broad groups have been suggested [4]. 1. Thick continuous ore body with undulating roof and floor as in bauxite deposits of Eastern Ghats. 2. Continuous with variable thickness and grade as in Western Ghats and Gujarat bauxite deposits. 3. Pockety and discontinuous ore body. The bauxite deposits of these four locations belong to third category.

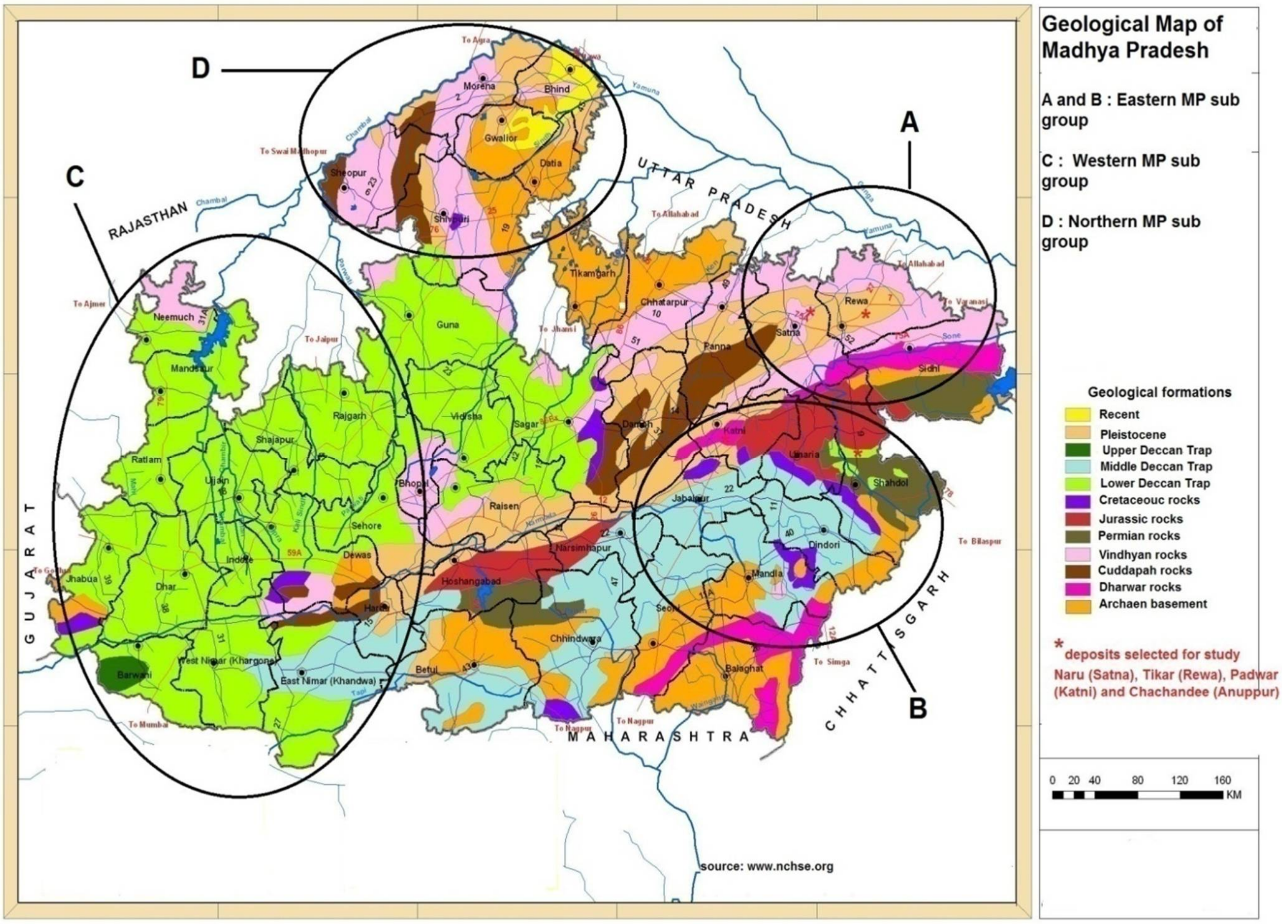

Figure 1. Geological setup of bauxite bearing sectors (sub groups) in Madhya Pradesh (Refer Table 1).

Table 2. Physical characteristics of the bauxite deposits selected for study.

Features	Naru (Satna)	Tikar (Rewa)	Padwar (Katni)	Chachandee (Anuppur)
Location	Naru plateau, Madhogarh village, Huzur Tehsil, Satna District	Tikar plateau, Govindgarh town, Rewa district	Padwar village, Bahoriband tehsil, Katni district	Chachandeeh village, pushprajgarh tehsil, Anuppur district
Approach	About 9 Km from Santa on Rewa road upto Modhogarh, then 6 km from Madhogarh to Naro plateau	About 35 Km on Shahdol state highway via Govindgarh.	About 38 Km from Katni to Sleemnabad and 6 km on Bahoriband road	About 37 km from Anuppur on Amarkantak road, then 10 Km towards Garhidadar
Toposheet	63D/14	63H/7	64A/2	64A/2
Longitudes	81°59'00" to 81°00'00"	81°23'25" to 81° 26'10"	80°11'45.4" to 80° 12'25.7"	81°34'00" to 81°37'31"
Latitudes	24°26'00" to 24°30'30"	24°22'40" to 24°23'10"	23°36'56.7" to 23°37'7.9"	22°49'51" to 22°51'00"
Height of the plateau	600 m.	660 m.	200 m.	1100 m.
Thickness of laterite profile	50 - 60 m	50 - 60 m	20 - 30 m	60 - 70 m
Thickness of ore body	0 to 8 m	0 to 6 m	0 to 8 m	0 to 8 m
Parent rock	Shale	Shale	Deccan Traps	Deccan Traps
Bed rock	Bhander Sandstone	Rewa Sandstone	Deccan Traps	Deccan Traps

5. Techno-Economic Evaluation

Techno-economic studies of the four deposits include their reserves and grade, detail chemico-mineralogical Characteristics, mining process and factors determining cost of mining, uses and specification of bauxite of these deposits.

5.1 Reserves and grade of the deposits

5.1.1 Naru (Satna) and Tikar (Rewa) deposits

The Directorate Geology and Mining (DGM), Madhya Pradesh carried out the exploration work through detailed geological mapping, pitting, trenching and drilling at Naru and Tikar. In order to determine the different commercial utility, the bauxite ore of Naru has been categorized into two grades:

Grade A, Al_2O_3:SiO_2 - 19.68 to 45.77 and
Grade B, Al_2O_3: SiO_2 - 11.54 to 45.77

The extent of bauxite deposit of Naru plateau was determined by pits and bore holes and the ore bearing areas were demarcated. Reserves of bauxite have been calculated grade wise. The total in-situ ore reserves of 'A' and 'B' grade bauxite in all the five blocks are of the order of 4.52 and 3.23 million tonnes respectively [5].

The mineable reserves of bauxite of ‘A' and 'B' grade in all the blocks has come to 2.17 and 1.53 million tonnes respectively.

The bauxite of Tikar area has been divided into three grades:

Grade A, Al_2O_3 - 55 % and more, SiO_2< 3 %;
Grade B, Al_2O_3 - 50 to 55 %, SiO_2<3 % and
Grade C, Al_2O_3 - 42.5 %, SiO_2<5%.

The total proved reserves of bauxite was estimated at about 2 million tonnes. While considering 20 % loss during mining, the total mineable reserves of bauxite are of the order of 1.7 million tones.

Overall the quality of bauxite at Tikar and Naru, is suitable for alumina production. Bauxite supplied for alumina production from Tikar and Naru has average 48% Al_2O_3 and 2-3 % SiO_2.

5.1.2 Padwar (Katni) and Chachandee (Anuppur) deposits

At Padwar and Chachandee there are three grades of bauxite intermixed with each other, the Refractory grade, the Metal grade and the Cement grade. The refractory grade bauxite has been again divided into two categories namely the Refractory grade-I and the Refractory Intermediate Product (RIP) grade. The Refractory grade-I bauxite is one which has Fe_2O_3 less than 5%. It is off-white, grey to cream colour, soft and pisolitic type of bauxite. The RIP grade bauxite has been defined withFe_2O_3 of 5 to 6%. This variety is slightly more reddish in colour as compared to refractory grade-I bauxite. Within the entire thickness of Refractory grade- I and RIP grade bauxite there are irregular bands and patches of reddish brown bauxite with more than 6% Fe_2O_3. This bauxite is metallurgical grade bauxite and sorted separately for the Hindalco (Hindustan Aluminium Company, Limited) alumina plant.

5.2 Similar deposits of the area

There are number of similar deposits of almost the same economic value in Satna, Rewa, Katni and Anuppur districts. An attempt has been made in this study to identify and categorize the pockets/deposits belonging to these districts. The characteristic feature of these deposits is the association of bauxite with laterite, ochre and clays. On this basis these deposits have been grouped into following categories (Table 3, Figure 2)

A. Bauxite bearing plateaus
B. Bauxite deposits associated with other minerals
C. Laterite deposits
D. Laterite deposits associated with other minerals
E. Deposits of ochres and clays

Table 3. Present status and categorization of similar deposits of the study area

Category	**Satna Area**		**Rewa Area**		**Katni Area**		**Anuppur Area**	
	WD	ER	WD	ER	WD	ER	WD	ER
A	08	17	05	--	02	03	01	11
B	11	06	--	--	12	11	--	--
C	07	01	05	--	02	02	--	--
D	07	--	--	--	22	06	--	--
E	06	08	--	--	09	01	--	--
TOTAL	**39**	**32**	**10**	--	**47**	**23**	**01**	**01**

WD = Number of working deposits; ER = Locations need detailed exploration.

5.3 Chemico-Mineralogical studies

About twenty samples from each area covering saprolite, laterite and bauxite were analysed by X-ray diffraction to carry out detailed quantitative mineralogy. A few samples were also subjected to infra-red and thermo-gravimetric analytical studies to corroborate the results of XRD analysis. Combined results of these analytical studies are presented in Table 4. In the X-ray diffractograms of ferruginous laterite, aluminous laterite and bauxite, and the presence of gibbsite is ascertained by hundred percent peaks at 18.28 A^0. Along with X-ray diffractograms, special XDB quantitative phase analytical system (software) decides the boehmitic nature of bauxites in these four deposits. Alumina as boehmite ranges between 5-30% (Table 4), and the presence of boehmite is indicated by peaks at 14.50 A^0. Alumina as the diasporic phase is also recognised by its peaks at 22.28 A^0 in these bauxites.

Iron minerals in the profile are fairly indicated by colours, which depend upon the type and amount of iron minerals present. The yellowish brown material of laterite /aluminous laterite contains significant amounts of goethite and some hematite, and the reddish brown ferruginous laterite is rich in both goethite and hematite. Presence of goethite is indicated by the characteristic XRD peaks at 21.24 A^0. Molecular substitution of Fe by Al is indicated by prominent XRD peak at 21.35 A^0, identified as alumino-goethite [6]. Dark brown and reddish brown coloured phases of ferruginous and aluminous laterite contain good amounts of hematite, which is identified by XRD peaks at 33.18 A^0. The presence of clay minerals, especially kaolinite, in laterite and bauxite is recognised by its hundred percent XRD peak at 12.34 and 12.36 A^0. Montmorilionite in some samples of ferruginous laterite of Naru, and halloysite in some samples of bauxite of Tikar were also detected by XDB software. Titanium minerals particularly rutile and anatase were identified by their characteristic XRD peak at 27.40 A^0 and 25.30A^0.

According to the classification scheme of Indian bauxites [7], bauxite of Naru and Tikar are boehmitic titanium rich and Padwar and Chachandee bauxite are mixed gibbsitic - boehmitic type.

5.4 Mining process

Bauxite is mined manually in these deposits. These mines are open cast and the thickness of overburden is very low. There is no systematic plan for mining in these areas and mining activity is confined to only along the scarps. Thus, the mining method applied in these areas may be called simply quarrying or stripping. Figures 3, 4 and 5 present a view of a mine face in these areas. First of all, a thin soil cover, covering laterite/bauxite is removed and quarrying up to a depth of 2 to 3 meters is done along the scarp boundary, so that the bauxite bearing laterite face is exposed. Then explosives are used to blast the hard material and big bauxite/laterite boulders are obtained. For blasting, a diesel operated machine is used to make deep holes. In these holes explosive material is put and detonated. Boulders obtained through blasting are further reduced by hand operated compressed air driller. Material is further broken with big hammers into small pieces of appropriate size. All operations of production are done manually with hand tools like crowbars, spades, chisels and hammers. Material thus obtained, is manually sorted and sized into three types (Figure 3), i.e. laterite (very low grade iron rich bauxite), aluminous laterite (low grade bauxite) and bauxite. After sorting of material into these three categories, samples from each category are analysed for alumina and silica, and it is again sorted grade wise, i.e. grade 'A', grade 'B' and grade 'C' material. 'A' and 'B' grade bauxite is loaded into trucks and dumpers and brought down to the hill and to the railway yard from where it is sent by train to Korba plant of Balco (Bharat Aluminium Company, Limited) and Renukoot plant of Hindalco, for alumina production. Refractory grade bauxite is consumed by refractory industries located around Katni and Jabalpur. Low grade bauxite and laterite are used by Cement plants.

Table-4. Chemico-mineralogical analysis of Satna (Naru), Rewa (Tikar), Katni (Padwar) and Anuppur (Chachandee) deposits.

Mineralogical details	Satna	Satna	Satna	Rewa	Rewa	Rewa	Katni		Anuppur	
Samples ⟶	NR-1	NR-2	NR-3	TR-1	TR-2	TR-3	PD-1	PD-2	CH-1	CH-2
Al_2O_3 % in										
Gibbsite	40.52	49.67	32.68	30.72	39.21	42.48	41.18	43.25	32.68	38.23
Boehmite	01.70	05.95	06.80	31.44	08.50	11.90	05.95	03.90	11.05	05.10
Al-Goethite	00.18	00.36	01.18	--	00.18	--	00.45	00.86	00.63	00.90
Kaolinite	03.95	--	02.17	00.79	--	01.97	01.97	01.62	01.97	01.58
Diaspore	--	00.85	--	01.70	01.70	--	01.70	02.15	02.55	02.12
Halloysite	--	--	--		02.08	--	--	--	--	--
Total	46.35	58.83	49.93	64.65	51.67	56.35	49.65	51.78	51.25	48.88
Fe_2O_3 % in										
Hematite	15.00	03.00	02.00	01.00	02.00	02.00	10.00	11.25	12.00	09.00
Al-Goethite	01.61	03.21	06.42		01.61	04.49	04.01	04.31	05.62	08.03
Total	16.61	06.21	08.42	01.00	03.61	06.49	14.01	15.56	15.52	17.03
SiO_2 % in										
Kaolinite	04.65	--	03.26	00.93	--	02.33	02.33	02.28	02.33	01.86
Quartz	--	--	--	--	--	--	--	--	01.00	01.00
Halloysite	--	--	--	--	02.45	--	--	--	--	--
Total	04.65		03.26	02.45	02.45	02.33	02.33	02.28	03.33	02.86
Ti_2O_2 % in										
Anatase	2.00	04.00	07.00	07.00	07.50	03.00	05.00	06.00	07.00	07.00
Rutile	--	01.00	01.00	02.00	02.00	02.00	01.00	01.00	01.00	01.00
Total	2.00	05.00	08.00	09.00	09.50	05.00	06.00	07.00	08.00	08.00

5.5 Cost of mining

Cost of mining is low in these deposits because of following factors:

1. Location of deposits: All four bauxite deposits lie near to city with railway station with loading facility. Route-wise Hindalco Renukoot alumina plant is nearer to all four deposits. Metal grade ore from these four locations is transported to the Hindalco Renukoot plant either by road transport or by rail. The distance of the Renukoot plant from these four locations is 200 to 300 Km.

2. Mining in these deposits is not fully mechanized. Local laborersare employed for breaking, sorting and loading of ore into trucks.

3. Power consumption is also very low, only few machines are diesel operated.

4. The different grades of bauxite are mainly consumed by nearby cement and refractory industries and alumina plants located in Madhya Pradesh and Chhatisgarh.

5.6 Uses and specifications of bauxite

As per the latest estimates[3], in 2013-14, consumption of bauxite was 13.30million tonnes (Table 5). The Alumina/aluminium industry was the principal consumer of bauxite and accounted for 94% consumption in

2013-14 (Figure 2) followed by Cement (4%) and Refractory (2%). Gujarat was the main supplier of abrasive andrefractory grade bauxite. Alumina plants draw supplies mostly from their captive mines. Hindalco sources bauxite from other suppliers too. It is important to note that at present no bauxite mine in Mahya Pradesh is being operated by any alumina plant including Hindalco. The contribution of Madhya Pradesh in different grades of bauxite is shown in Table 6. IBM study [3] shows that more than 87% of country's present bauxite resources are suitable for alumina/aluminium production. Thus the main area of emphasis for specification of bauxite must be in the direction of aluminium production.

Table 5: Consumption of bauxite by different industries (2013-14).

SNo	Industry	Consumption in Million tonnes	percentage
1	Alumina	12.4723	93.76
2	Cement	00.5271	03.98
3	Refractory	00.2800	02.11
4	Ferro-alloys	00.0071	0.15
5	Chemical	00.0059	
6	Abrasive	00.0034	
7	Ceramic	00.0012	
	Total	13.2970	

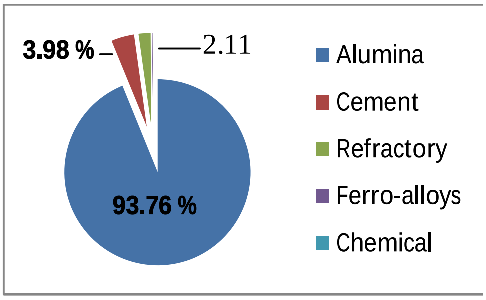

Figure 2: Consumption of bauxite

Table 6. Grade wise production of bauxite from Madhya Pradesh.

District	No of Mines	For alumina and aluminium production (in tonnes)				For other use				Total qty in tonnes	Value in `’000
		Al_2O_3 50-55%	Al_2O_3 45-50%	Al_2O_3 40-45%	Al_2O_3 Below 40%	Cement	Abrasive	Refractory	Chemical		
Anuppur	01	--		49851						49851	35943
Jabalpur	01	--		--		10000			2000	12000	896
Katni	10	--	91856	83190	180901	4508		4366		364821	281586
Rewa	03	--		57375						57375	30146
Satna	10	--		--	10937	20931		12408	19651	63927	47598
Shahdol	02	--		170603						170603	195875
Sidhi	03	--		--				14623		14623	23271
Total			91856	360272	191838	35439		31397	21651	732453	615315

5.6.1 Aluminium industry

The metallurgical use of bauxite depends on its mineralogical character which has a bearing on its digestion in caustic soda. If monohydrate, high temperature and a higher concentration of soda is necessary while the trihydrate variety is digested at low temperature and lower caustic concentrations. The important chemical impurities which affect the metallurgical process are reactive silica, titania and phosphorus pentoxide. The reactive silica causes the loss of alumina and caustic soda, while titania and phosphorus pentoxide bring about a loss of soda. The reactive silica is the most harmful impurity. It forms insoluble sodium aluminum silicates which go into bauxite residue (red mud) resulting in the loss of alumina and caustic soda. The Bureau of Indian Standards (BIS) has redefined the specification of bauxite for metallurgical use (Table 7).

It is relevant here to discuss in brief the scheme of metallurgical grades of bauxite based on mineralogy and reserves [8]. This scheme has five broad metallurgical grades for Indian bauxites in order of their relative value for alumina production. In this scheme, main parameters considered are mineralogy (type and specification), chemical criteria (alumina-silica factor, C-organics and titanium), technological factors (available alumina and reactive silica at two well defined digestion temperatures) and bauxite mining factors (ore reserves, configuration of ore body, thickness, stripping ratio, mode of mining and bauxite type). Some important mineralogical and mining factors of this scheme of metallurgical grading can be given as follows-

Grade-I :	:	Gibbsitic, Reserves 50-400 MT
Grade-II	:	Mixed gibbsitic-boehmitic, Reserves 10-50 MT
Grade-III	:	Boehmitic, Reserves 5-30 MT
GradeIV	:	Diasporic Reserves 1-20 MT
Grade-V	:	Gibbsitic or mixed gibbsitic-boehmitic, Reserves estimation not available

Metallurgical Grade-I bauxite is considered most suitable for alumina production because of its favourable mineralogy for low pressure digestion, alumina silica factor and bauxite mining factors. This is followed by Grade-II, III and IV bauxites. As per this scheme a major part of Tikar and Naru bauxite deposits is Metallurgical Grade - III, and a small part is of Grade-II and Grade-V. Further characterization and detailed study is required in this direction.

5.6.2 Refractory industry

Specifications of bauxite for refractory use redefined by BIS, and criteria used by refractory industries [9] are given in Table 7. Chemical analyses of Tikar and Naru bauxites show that they may be used for refractory purposes. However, the main problem with these bauxites is their high iron and titanium content; therefore they cannot be directly used for refractory purpose despite selective mining. These bauxites must be beneficiated using more specialized beneficiation techniques such as magnetic separation, reduction roasting followed by isodynamic separation etc. A variety of ores at Padwar and Chachandee are suitable for refractory purposes.

5.6.3 Abrasive and chemical industry

The normal criteria for assessing the acceptability of a calcined bauxite for the production of brown corundum (abrasive) are both chemical and physical. The important components considered are $A1_2O_3$, SiO_2, Fe_2O_3, TiO_2, alkalies and water, both free and combined. The alumina content should be as high as possible (at least 55-60% $A1_20_3$ in raw ore, and 80% $A1_20_3$ in calcined form). The mineralogical form of the alumina is not critical but gibbsitic bauxites do comprise the bulk of feed stocks. Other specifications are mentioned in Table 7. Bauxite criteria for chemical industries are also mentioned in Table 7. As per specifications, bauxites of the study area are not directly suitable for the abrasives industry.

5.6.4 Cement industry

One of the specific uses of the bauxite is in the production of high alumina cement which differs from normal Portland cement, both in its composition and uses. Typical specifications of bauxite used for the two types of high alumina cement[10]are given in Table 7.Since the bauxites of the study area are boehmitic, they may be suitable for the production of Portland cement, but their titanium and iron rich nature makes them difficult to use for this purpose. Studies of effective beneficiation techniques are required to reduce the iron and titanium content. In addition to high alumina cement, a limited quantity of bauxite is also utilized for the manufacture of Portland cement. For this purpose, there is no specification, and so-called low-grade bauxites and laterites from Tikar, Naru, Padwar and Chachandee are sent to nearby cement plants.

Table 7. Specifications of bauxite for different uses.

(A) For metallurgical use (IS:5953-1984; Reaffirmed 2008 and 2014)			
SNo	Constituents	Grade-I % by weight	Grade-II % by weight
	Mineralogy	Essentially gibbsite or tryhydrate	Mixture of gibbsite, boehmite and diaspore or tryhydrate and monohydrate
1	Al_2O_3 (minium)	40.00	47.00
2	Total available alumina (minimum)	36.00	43.00
3	SiO_2 (maximum)	03.50	05.00
	Module Al_2O_3/SiO_2 (maximum)	12.00	12.00
4	P_2O_5 (maximum)	00.20	00.20
5	V_2O_5 (maximum)	00.20	00.20
6	Fe_2O_3+TiO_2 (maximum)	30.00	30.00
7	L O I at 1100^{o}C min.	20.00	20.00
(B) For refractory industry purpose (IS:10817-1984; Reaffirmed 2008 and 2014)			
	Al_2O_3 (minimum)	58.00	
	Fe_2O_3 (maximum)	03.00	
	TiO_2 (maximum)	03.00	
	CaO	00.50 - 00.60	
	LOI	27.00 - 30.00	
(B) Criteria use by refractory industry[9]			
	High alumina content (upto 75%)		
	Low iron oxide content, generally 2.5% maximum, after calcination		
	Low TiO_2 content generally 4% maximum		
	Trace amount of only alkalies and alkaline earths		
	Silica content exceeding 10% may be acceptable but it should be present mainly as clay minerals not as quartz		
(C) Specifications for abrasive industry			
	SiO2: Less than 7% (in calcined ore)		
	Fe2O3: less than 10%		
	TiO2: 02.00 - 04.00		
	Cao: less than 0.1%		
	Size: between 50 mm to 100 mesh		
(D) Specification for chemical and petroleum industries (IS:3605-1984 ; Reaffirmed 2010)			
	Alumina (as Al_2O,) minimum	58.00 % by mass	
	Silica (as SiO_2), maximum	03.00 % by mass	
	Iron oxide (as Fe_2O_3), maximum	02.00 % by mass	
	Titania (as TiO_2), maximum	04.00 % by mass	
	P_2O_5, maximum	00.30 % by mass	
	MnO_2 maximum	00.10 % by mass	
	CaO and MgO, maximum	02.00 % by mass	
	LOI, maximum	02.00 % by mass	
(E) Specification for Cement Industry[10]			
	Parameters	High iron product	Low iron product

	Al_2O_3:SiO_2	10:1 (minimum)	10:1 (minimum)
	Al_2O_3: Fe_2O_3	2 to 2.5:1 (preferred)	20:1 (minimum)
	Al_2O_3:TiO_2	--	16:1 (minimum)
	Mineralogy	As boehmite or diaspore	Not critical
	Free moisture	5 % (maximum, preferred)	Dry (preferred)
	Particle size	50 - 100 mm	Not critical

Figure 3: Manual Sorting of ore at Padwar.

Figure 4: Mining face at Padwar (Katni).

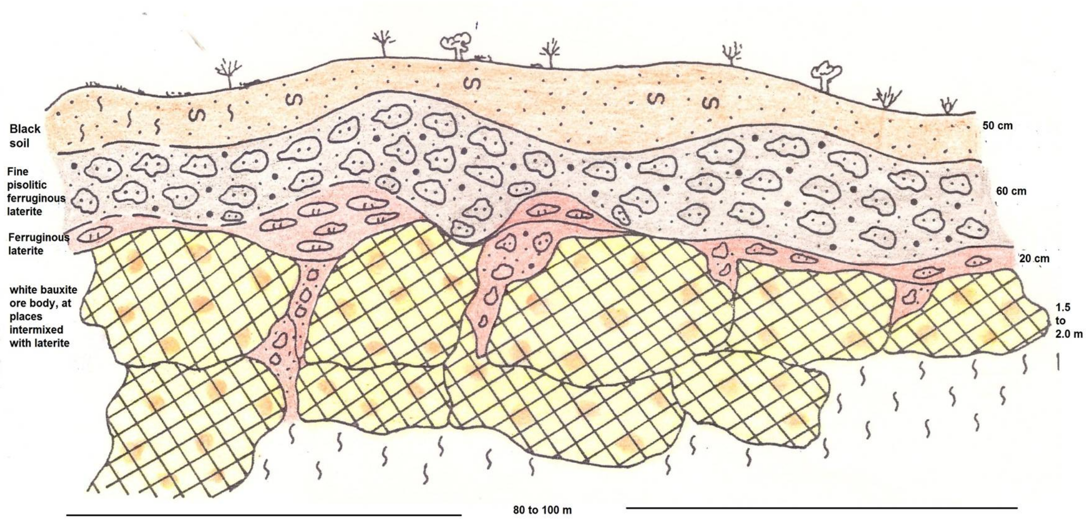

Figure 5: Insitu mine face, bauxite intermixed with laterite at Naru (Satna)

6. Conclusions and Recommendations

6.1 Present study of four representative bauxite deposits indicates the nature of the bauxite deposits of Madhya Pradesh. This approach of systematic study can be applied to other similar deposits (Table 3) of the area, and this may enhance the resources of bauxite in Madhya Pradesh. Individual reserves of these deposits are less but they can be reexamined in terms of groups of deposits in these districts. Delineation of sub groups and categorization of deposits carried out under this study will help further studies. These deposits cannot sustain Greenfield alumina plants, however they can regularly supply ore to Balco's Korba plant and Hindalco's Renukoot alumina plant, nearby refractory industries and cement plants.

6.2 Presently no alumina plant is operating a bauxite mine in Madhya Pradesh. This could be reexamined particularly around the Katni and Anuppur Districts. The scope of new exploration also lies in delineated sub groups.

6.3 As per chemico-mineralogical characteristics of bauxite and the classification scheme of Indian bauxites, the bauxites of the study area are boehmitic and titanium rich. These characteristics require high pressure digestion technology (240 - 250^0 C) i.e. European Bayer process, which is being used at Balco's Korba and Hindalco's Renukoot plants in India. A very high alumina - low iron bauxite can beselectively mined, which can be used for refractory and abrasive purposes as practiced in ACC's Katni bauxite mine. Low grade ferruginous laterites produced during the mining of metallurgical grade bauxite can besupplied to steel or cement plants. Bauxite can be beneficiated to reduce iron and/or silica content to use them in refractory or abrasive industries. A study on complex utilization of ore and low grade bauxite ore can be proposed for these deposits to conserve and increase the bauxite resources of the area.

6.4 Bauxite mining cost in these deposits is comparatively far lower than its transportation cost to the alumina plants of Balco and Hindalco. Mining operations in these areas are not being carried out in a planned manner. Quarrying is done wherever pockets of high grade ore are present on the plateau. The total excavation consists of soil, overburden, associated laterites, and clean ore. The soft overburden is loosely packed ferruginous pisolitic laterites associated with soil, which can easily be removed. The hard overburden is made up of massive ferruginous laterite and requires blasting for their fragmentation. Environmental issues like proper back filling of soil, stability of slopes and replanting, particularly by mine owners, need to be monitored.

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