Morphological, microstructural and mineralogical dataset of bauxite over Mainpat plateau from a part of Deccan traps, Surguja district, Chhattisgarh

Sanjay Kumar Balabantaray¹ · S. Aravindan¹ · R. Ravi¹

Received: 22 July 2020 / Accepted: 19 October 2020 / Published online: 26 October 2020
© Springer Nature Switzerland AG 2020

Abstract

In this study, we present the main findings from microstructural and mineralogical studies and their implications for the genesis of bauxite/laterite in Mainpat plateau. Megascopic studies showed reddish laterite to off-white bauxite. Strong hydrolytic action formed small oolites and large pisolites with sizes of 1–2 cm in diameter. Pisolites and oolites were elliptical, circular, and as broken pieces. Matrix of gibbsite and hematite was found in petrographic observations. Morphological characteristics include pisolitic, oolitic, lamellar, and euhedral gibbsite. Microstructures discovered were spongy gibbsite, flower-like crystals, elongated gibbsite, and framework type. Crystals of gibbsite were found to be predominant with partially crystallized ilmenite and hematite as subordinate phases. Scattered bauxite crystals made free pores for passage of solutions enhancing leaching conditions. Al, Ti, Fe, Si, Cu and Zn were identified as significant components; out of which, Al and Ti have the highest concentration. The samples have high alumina constitutes of 61.45% and 65.40% with a low iron content of 6.66% and 5.61%. High Ti content of 19.38% and 17.55% might be due to strong hydrolytic action during the alteration of basalt to bauxite. Low Si content of 2.68% indicates strong leaching activity. XRF analysis showed that the samples have undergone strong lateritization. XRD examination of bauxite/laterite revealed a mixture of minerals like gibbsite, boehmite, goethite, hematite, and anatase. Enrichment in boehmite shows in situ weathering. The study aims to extract the genesis and depositional characterization of bauxite through its morphological, microstructural, and mineralogical properties.

Keywords Bauxite/laterite · Morphology · Microstructures · Mineralogy · XRD · XRF · Al · Fe

1 Introduction

Bauxites are valuable concentrations of aluminum. Indian bauxite reserves are restricted to peninsular shield apart from the outcrops in Jammu in the Extra Peninsular area. In the Peninsular area, around 85% of the complete reserves are related to "elevated level" level laterite that outcrops along the eastern and western coast; out of which almost 74% of the deposits are limited to the east coast. Around 10% of the outcrops are located in the inland plateau. The significant bauxite reserves of India

are basically connected with laterite that occurs as capping at high elevation (around 700 m to 2100 m above mean sea level (msl)) in parts of Odisha, Andhra Pradesh, Jharkhand, Madhya Pradesh, Maharashtra, Chhattisgarh, Karnataka, and Tamil Nadu [1]. The Eastern Ghat bauxite deposits of Odisha [2] and Andhra Pradesh [3] are formed from khondalite and Tamil Nadu [4] from charnockite rocks. The majority of the Indian bauxite deposits are under the capping of laterite formed over a variety of rock types. They are the result of sub-aerial weathering and lateritization of rocks, although the significant

✉ Sanjay Kumar Balabantaray, sanjaybalabantaray3@gmail.com; S. Aravindan, aravindan_rs@yahoo.com; R. Ravi, rajuravi9725@gmail.com
| ¹Department of Earth Sciences, Annamalai University, Annamalai Nagar 608002, India.

deposits of Madhya Pradesh, Chhattisgarh, Maharashtra, Gujarat, Bihar, and Karnataka are formed on Deccan Trap lava flows. It forms by the weathering of aluminum-rich host rocks. Bauxite fits directly under the classification of lateritic rocks [5]. Precipitation of aluminum in bauxites happens as gibbsite or aluminum hydroxides. The main minerals in bauxite are gibbsite ($\text{Al}(\text{OH})_3$), boehmite ($\gamma\text{-Al}(\text{OH})$), and diasporite ($\alpha\text{-Al}(\text{OH})$) [6, 7]. Humid tropical to sub-tropical climate is the most favorable for bauxitization [8]. Weathering of bauxite includes modification of silica and alkali leading to the increase in the concentration of Al_2O_3 to over 45–50% [9].

The current investigation intends to describe the genesis and depositional characteristics of bauxite formed over the Deccan traps of Central India Craton around Mainpat plateau of Surguja district, Chhattisgarh based on their morphology, microstructure, and mineralogy.

2 Geology of the study area

The investigated area lies in toposheet no. 64N/5 inside a territory of about 83.33 sq. km between longitudes E $83^\circ 07' 0''$ to $83^\circ 12' 30''$ and latitudes N $22^\circ 46' 30''$ to $22^\circ 52' 30''$ shown in Fig. 1. The study area is partially covered by formations of the Chhotanagpur Gneissic complex and partially by Talcher formations. The greatest height being 1060 m, the average altitude is 1053 m above mean sea level. Different archaean to recent rocks like basalt, syenite, shales, and arkose structures the Mainpat level of which the top layer is composed of basalt, followed by sandstone of Gondwana and Archean rocks at the base. The top basaltic layer includes the bauxite store. Bauxite occurs at shallow depth thereby making it easy for mining exercises by companies like BALCO. The thickness of the bauxite deposit is around 10–14 m from the surface. Underneath it, there is a clayey layer called lithomarge that is

Fig. 1 Land set up of the investigated area. The state Chhattisgarh is shown in India map and broadened map shows the study area with sampling points 1–6 of Mainpat plateau

followed by weathered basalt. Red/yellow lateritic soil and loamy soil are the main soil types. The laterite profile depth is 70 m to 80 m from the surface with pisolitic laterite, bauxite, laterite (aluminous and ferruginous), saprolite, and bedrock from top to bottom. The stratigraphic progression of Mainpat plateau according to Adil et al. [10] is shown in Table 1.

3 Materials and techniques

Six fresh bauxite samples were gathered with safeguard from various locations of Mainpat plateau. Surface examples were gathered utilizing Simple Random Sampling (SRS) strategy as bauxites cropped out at a shallow depth. Thin sections and polished sections for petrographic investigation were set up at the Department of Earth Sciences, Annamalai University, Tamil Nadu. Powdered samples were prepared from three samples (1, 3, and 5) for XRD studies to interpret the mineralogical composition (mineral phases) at Council for Scientific and Industrial Research (CSIR) lab, Thiruvananthapuram utilizing Diffractometer system XPERT-PRO, keeping Cu K-Alpha1 [$\text{\AA}$] at 1.54060 and radiation of 30 mA, 45 kV. OriginPro 8 software was used to generate the XRD peaks. XRF of six samples (1–6) was carried out at the same institute using Epsilon 3 model with excitation capability of 30 kV, 1 mA. Scanning Electron Microscope (SEM–EDS) examination for six samples (1–6) were completed at Centralized Instrumentation and Service Laboratory (CISL), Department of Physics, Annamalai University, Tamil Nadu using JEOL-JSM-IT 200 with EDS to interpret the microstructural properties. EDS was carried out for two samples (2 and 4). Table 2 shows the sampling details.

Table 2 Sampling details of the study area

Sample location/ no	Location	Coordinates
1	Dand kesara	83°08'45.6"E 22°48'17.9"N
2	Parpatia	83°09'39.6"E 22°50'13.1"N
3	Parpatia	83°11'56.3"E 22°50'45.6"N
4	Parpatia	83°11'02.3"E 22°48'46.7"N
5	Dand kesara	83°11'60.0"E 22°47'20.4"N
6	Dand kesara	83°09'14.3"E 22°47'2.3"N

4 Results and discussions

4.1 Macroscopic properties

The bauxite created over the Deccan trap basalts showed various morphological characteristics, such as pisolitic, oolitic, dispersed, and massive (Fig. 2). The top bauxite/ laterite layer shows reddish to off-white color and spongy structures. The pisolitic bauxite zone of the examined zone is reddish to dark red earthy colored in shading, comprising predominantly pellet molded pisolites/oolites. Comparable kind of pisolitic surface deposited over the Precambrian Iron Ore group of Sundergarh district, Eastern India has been described by Sahoo et al. [11]. The pisolites are enclosed inside the aluminous matrix (Fig. 2a). Pisolites contain both alumina and iron minerals. The pisolites are found in various shapes such as elliptical, circular, and broken pieces. The scattered sort of bauxite has off-white shading with speckled form and comprises iron particles encased inside the aluminous matrix (Fig. 2b). The massive kind shows hard and off-white pisolitic bauxite shading, reaching up to 1 to 2 cm in breadth (Fig. 2c). The spotted kind is light red in shading and is non-pisolitic, often having a spotted appearance due to inclusions of white materials (Fig. 2d).

Table 1 Stratigraphy of the investigation region

Period	Super group/group	Litho-units
Recent to sub-recent		Bauxite and Laterite
Upper cretaceous to lower paleocene	Deccan traps	Basalts
Cretaceous	Lameta	Sandstone
Upper carboniferous to lower cretaceous	Barakar Talchir	Coarse- to fine-grained sandstone, Coal bed, siltstone, green shale
Middle to upper carboniferous	Gondwanas	Sandstone, Conglomerate
Precambrian	Chhattisgarh	Granite-gneiss, phyllite, quartzite etc
Archaean	Basement	Gneissic complex, quartzite, phyllite, acidic to basic inclusions

Fig. 2 **a.** Bauxite indicating development of pisolites and oolites. **b.** Dispersal of tidies of iron within clayey network. **c.** Enormous sort pisolitic bauxite appearing thick structure with incidental patches

of fine material. **d.** Spotted bauxite having little holes loaded up with aluminous grid

4.2 Petrography

Representative samples were selected for micro section segments groundwork for mineral identification. The photomicrographs show the matrix of mineral composition of bauxite minerals. The main minerals identified were gibbsite, hematite, and cliachite.

In refracted light (Fig. 3a and b), concretionary, brecciated, and pisolitic bauxite were observed. Khanapurkar et al. [12] observed similar properties on lateritic bauxite deposits formed from the Deccan flows of Kolhapur district, Maharashtra. Gibbsite is identified by pale earthy color with weak pleochroism. Hematite encompasses the gibbsite and looks amorphous and dark in color. Goethite appears to be microcrystalline. In reflected light (Fig. 3c), large oolites and pisolites encompassed by a matrix of alumina are visible which might have formed due to strong hydrolytic action. The pisolites contain iron and aluminous minerals. Cliachite was present in amorphous form with high water content, identified from its circular shape. (Fig. 3d) shows significant gibbsite in lamellar structure and not many as euhedral gibbsite.

4.3 Microstructural features

Microstructural properties of oxide and silicate minerals of aluminum and iron were studied from the representative samples (sample 1–6) under Scanning Electron Microscope (SEM). SEM studies on bauxite had been reported by Yu et al. [13]; Bhukte and Chaddha [14]; Ling et al. [15] and Sahoo et al. [11]. The work focuses on the microstructural and morphological characteristics of bauxite minerals and their genetic development.

Figure 4a–e shows the microstructural features of the Mainpat bauxite. It shows a variety of textural features like spongy gibbsite (Fig. 4a), light-colored gibbsite crystals inside a groundmass of dark-shaded hydrous iron metal microcrystals, flower-like crystal (Fig. 4c), elongated gibbsite (Fig. 4d), and framework-type arrangement (Fig. 4f). It is composed of crystals of gibbsite as a major phase and partially crystallized ilmenite and hematite (Fig. 4d, e). The hydrothermal activity has affected the structures of iron and alumina. The gibbsite matrix shows microcavities filled with ilmenite microcrystals (Fig. 4d). These microstructural features are comparable to the findings of Sahoo et al. [11]

Fig. 3 (a, b) under Optical microscope in PPL and XPL, respectively, in 10X magnification indicating light-hued gibbsite (G) encompassed by dark-colored amorphous hematite (H). Gibbsite is characterized by pale earthy color shading, weak pleochroism, and

moderate relief. (c, d) under ore microscope in 10X magnification. **c** Shows pisolitic bauxite with well developed pisolites and oolites. Gibbsite is identified by pale earthy to grayish color, weak pleochroism, moderate relief. **d** Shows lamellar and euhedral gibbsite

on bauxites of Sundergarh district, Eastern India. The latter shows more prominent features. This might be due to the high rate of bauxitization compared to the former.

4.4 Energy-dispersive X-ray spectroscopy (EDS)

To support the above interpretation, further EDS analysis (samples 2 and 4) was carried out which clearly supported the presence of alumina in abundance. Figure 5 Shows partially developed hexagonal crystals of gibbsite randomly clustered within the microcavities creating channels for hydrolytic actions. Impressive level of pore spaces, loose packing of cryptocrystalline amorphous minerals shows loose framework texture (Fig. 6). The crystals of alumina show less porosity but the spongy types do not. Random arrangements of gibbsite crystals that occur in sporadic groups around depressions inside the spongy framework establish the

scattered surface of bauxite (Fig. 7). The proximity of this surface along with the spongy framework allows the accessibility of aqueous solutions thus encouraging strong leaching conditions. Similar aggregates were found by Bhukte and Chaddha [14] on the bauxite deposit of Eastern Ghats, and Meshram and Randive [16] on the laterites of Jamnagar district, Gujarat. Aggregates of gibbsite were found to be predominant in the sample. It confirms that the Mainpat bauxite is mainly formed of gibbsite with high alumina concentration. The presence of iron in semi-crystalline hematite was also detected by the EDS analysis. The major elements found in the bauxite samples were Al, Ti, Fe, Si, Cu, and Zn out of which Al and Ti have the maximum intensity counts (Figs. 6, 8). The samples show the high alumina content of 61.45% and 65.40% with the low iron content of 6.66% and 5.61% as shown in Tables 3 and 4, respectively. The high Ti content of 19.38% and

Fig. 4 SEM analysis (sample 1–6) showing: **a** gibbsite showing spongy texture with dark-colored hematite as groundmass, **b** light-colored gibbsite crystal within the matrix of dark-colored hydrous iron ore microcrystals, **c** hydrous alumina of gibbsite microcrystals with rhombohedral structure and flower-like masses, **d** microcrystal of ilmenite (I) within elongated spongy gibbsite microcavity, **e** hematite microcrystal along with less iron-rich microcrystals, **f** gibbsite crystal with well-formed framework order and dark-colored hematite in a microcavity

17.55% suggests the strong hydrolytic action. The low SiO_2 concentration of 2.68% indicates strong leaching during bauxitization.

4.5 X-ray fluorescence (XRF)

Geochemical analysis of six powdered bauxite samples was carried out using the XRF technique to obtain the major elements in the oxide form as shown in Table 5. The wt% of major oxides like Al_2O_3 , Fe_2O_3 , TiO_2 , and SiO_2 varies

Fig. 5 Image showing well developed crystals of gibbsite (sample 2) in white color and minor amount of hydrous Fe-minerals in dark phases

in ranges from 38.611–58.20, 5.853–33.54, 10.75–15.255, and 0.580–2.561, respectively.

The degree of lateritization was explained by Schellmann [17] by a triangular diagram, based on the mobility of oxides during the weathering process. The apices of the triangular plot, i.e., SiO_2 - Fe_2O_3 - Al_2O_3 depict phases of lateritization from kaolinization to strong lateritization. When the samples were plotted in the (SiO_2 - Fe_2O_3 - Al_2O_3) ternary diagram, they fell in the zone of strong lateritization zone (Fig. 9).

4.6 X-ray diffraction (XRD)

The exact identification of bauxite mineralogy is essential for describing the bauxite deposit as well as its suitability

for alumina and non-metallurgical applications. X-Ray Diffraction (XRD) is widely acknowledged as the typical method for the mineralogical identification of any crystalline solid [5]. In the current work, XRD investigation has been done to obtain detailed data on the mineralogical composition of various bauxite and host rock samples. For the most part, different varieties in lateritization forms are shown by varieties in constituent bauxite minerals. Chosen samples (samples 1, 3, and 5) were ground into a powder with iron mortar and pestle. These samples were measured with an X-ray diffractometer to resolve the mineralogical composition. The XRD examination of bauxite uncovers the mixture of minerals like gibbsite, boehmite, hematite, and anatase as the major components of the bauxite/laterite samples. Gibbsite is predominant in the mixtures, with a subordinate amount of boehmite. The co-occurrence of boehmite and goethite indicates extreme in situ weathering. The minerals were recognized by their characteristic d-spacing (Å) and Position ($^{\circ}2\theta$). The peak values were investigated and compared with the Joint Committee on Powder Diffraction Standards (JCPDS) information book and other published literature [18–21]. The peak values of the distinguished minerals are shown in Fig. 10. The following minerals were identified.

4.7 Aluminous minerals

4.7.1 Gibbsite ($\text{Al}(\text{OH})_3$)

The d-spacing values of gibbsite are 4.82X, 4.344, 4.302, 2.372, 2.442, 2.031, 3.351, and 1.981 based on Hanawalts Number [18]. The d-spacing values of the studied samples deviate a little from the above values. In any case, these deviations might be because of the use of different instruments.

Fig. 6 EDS spectrum showing abundance of different elements in the representative sample shown in Fig. 5. Al is present as major element in gibbsite crystals

Fig. 7 Disseminated, crystalline, framework microtexture of gibbsite crystals (sample 4) inside microcavities. The matrix shows loose framework structure

4.7.2 Boehmite ($\text{AlO}(\text{OH})$)

After gibbsite, boehmite is the second most abundant mineral in Mainpat bauxite samples. The d-spacing values are 6.11X, 3.16 7, 2.356, 1.863, 1.853, 1.452, 1.312, and 1.661.

4.8 Iron minerals

4.8.1 Hematite (Fe_2O_3)

It is a common phase present and is identified from its red color. The d-spacing values are 2.69X, 1.696, 2.515, 1.844, 1.484, 1.454, 2.203, and 3.663.

Table 3 Qualitative analysis of the sample shown in Fig. 5

Element	Line	Mass%	Atom%
Al	K	61.45 ± 0.39	74.67 ± 0.47
Si	K	2.68 ± 0.16	3.13 ± 0.19
Ti	K	19.38 ± 0.25	13.27 ± 0.17
Fe	K	6.66 ± 0.19	3.91 ± 0.11
Cu	K	5.99 ± 0.26	3.09 ± 0.13
Zn	K	3.83 ± 0.26	1.92 ± 0.13
Total		100.00	100.00

Table 4 Quantitative analysis of the sample shown in Fig. 6

Element	Line	Mass%	Atom%
Al	K	65.40 ± 0.36	78.57 ± 0.43
Ti	K	17.55 ± 0.22	11.88 ± 0.15
Cr	K	4.36 ± 0.15	2.72 ± 0.09
Fe	K	5.61 ± 0.17	3.25 ± 0.10
Cu	K	4.87 ± 0.22	2.48 ± 0.11
Zn	K	2.22 ± 0.21	1.10 ± 0.10
Total		100.00	100.00

4.8.2 Titanium minerals: Anatase (TiO_2)

It is wide-spread in the region and the samples have a high content of it indicating strong hydrolytic action. The d-spacing values are 3.52X, 1.894, 2.382, 1.702, 1.672, 1.481, 2.431, and 2.331.

Fig. 8 EDS spectrum showing abundance different elements present in the representative sample shown in Fig. 6. Al is present as major element in gibbsite crystals

Table 5 Major oxide composition of Mainpat bauxite samples

Sample no	Al ₂ O ₃ (%)	SiO ₂ (%)	P ₂ O ₅ (%)	CaO (%)	TiO ₂ (%)	MnO (%)	Fe ₂ O ₃ (%)	Total (%)
1	38.611	0.580	0.799	0.130	15.255	0.060	33.54	88.975
2	58.20	0.583	1.02	0.213	10.75	0.035	5.853	76.654
3	52.71	2.561	0.341	0.010	12.89	0.065	22.570	91.147
4	43.637	1.162	0.292	0.015	12.72	0.058	30.18	88.064
5	45.613	1.864	0.210	0.011	10.75	0.0161	28.36	86.8241
6	50.130	1.371	0.247	0.004	11.580	0.022	12.63	75.984

Fig. 9 SiO₂—Fe₂O₃—Al₂O₃, Ternary diagram after Schellmenn (1981), shows degree of lateritization of the collected samples

5 Conclusion

The Mainpat bauxite ores are formed by alteration of basalts of the Deccan traps of Central India Craton. The normal depth is about 10–14 m from the surface making it easy to extract. Morphological features shown by the samples were pisolitic, oolitic, dispersed, and massive which might have formed due to hydrolytic action. Such properties were identified over the Precambrian Iron ore group of Sundergarh district, Eastern India by Sahoo et al. [11]. The bauxite and laterite deposits appeared reddish to off-white shading with a spongy texture. Reflecting photomicrograph showed the concretionary, brecciated, and pisolitic bauxite having pale earthy color, weak pleochroism, as gibbsite encompassed by dark-colored hematite. Lateritic bauxite deposits produced from the Deccan flows of Kolhapur district, Maharashtra showed similar properties as reported by Khanapurkar

et al. [12]. Refracting photomicrograph revealed large pisolites and oolites with totals of clachite. It additionally demonstrated lamellar and euhedral gibbsite. SEM investigation indicated that Mainpat bauxite has high alumina content. It demonstrated different surfaces like spongy, flower-like crystals, elongated gibbsite, and a framework type. The spongy structure of the bauxite surface allows the flow of solutions promoting extreme leaching conditions. The present microstructural properties of bauxite when compared to that of the deposits of Sundergarh district, Eastern India as reported by Sahoo et al. [11] revealed that the latter showed more prominent features which might be due to strong bauxitization. Crystals of gibbsite were recognized along with partially crystallized ilmenite and hematite. EDS affirmed the co-occurrence of high-alumina substance of 61.45% and 65.40% and low-Fe substance of 6.66% and 5.61%. The high Ti content of 19.38% and 17.55% may be related to hydrolytic action during the change of basalt to bauxite. The low SiO₂ concentration of 2.68% may indicate strong leaching during the alteration of basalt to bauxite. XRF analysis was used to study the process of lateritization after Schellmann [17], recognized in the area. The samples have undergone strong lateritization process. XRD analysis performed for identification of various mineral phases revealed gibbsite, boehmite, goethite, anatase, and hematite and was recognized in the majority of the bauxitic/lateritic examples. The abundance of goethite and boehmite showed extreme in situ weathering. Therefore, based on the field study, petrography, morphology, and microstructural properties, the genesis and depositional characteristics of Mainpat bauxite were found to be comparable to other previously studied bauxites in other regions. So, the combination of the above parameters can be used to distinguish the method occurrence and environmental conditions during the development of minerals, both on a surface and sub-surface level.

Fig. 10 XRD pattern indicating the mineralogical composition of different lithotypes with the help of d-spacing, 2θ , and intensity counts. Gibbsite (G), Boehmite (B), Hematite (H), and Anatase (A)

Acknowledgements We are thankful to the Dept of Earth Sciences, Annamalai University, Tamil Nadu for setting a platform on research activities. We are pleased to thank Dr. Sundararajan M., Principal Scientist CSIR-NIIST, Thiruvananthapuram, Kerala for helping to carry out XRD and XRF analysis. We also thank Dr. B. Shanthi, Professor (CISL.Physics), Annamalai University for helping to carry out SEM-EDS.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Reference

- Patel VN, Trivedi RK, Adil SH, Golekar RB (2014) Geochemical and mineralogical study of bauxite deposit of Mainpat plateau, Surguja district, Central India. *Arabian J Geosci* 7(9):3505–3512
- Ramam PK (1978) Bauxite residuum derived from Khondalite and Charnockite. *J Geol Soc India* 19(4):181–182
- Reddy MK, Ramesh V, Kumar VS (2015) Mode of occurrence and distribution of bauxite deposits in Andhra Pradesh and feasibility of aluminum industry. *Procedia Earth Planet Sci* 11:115–121
- Rao MJ, Mohammad CHPM, Kakkassery AI (2016) Bauxite mining in eastern ghats of Andhra Pradesh, possible environmental implications and measures for environmentally friendly mining. <https://www.ijsr.net/archive/v5i4/NOV162872.pdf>
- Jadhav GN, Sharma N, Sen P (2012) Characterization of bauxite deposits from Kachchh, Gujarat. *J Geol Soc India* 80(3):351–362
- Putzolu F, Piccolo AP, Mondillo N, Boni M, Balassone G, Mormone A (2018) Geochemical characterization of bauxite deposits from the Abruzzi mining district (Italy). *Minerals* 8(7):298
- Noel Y, Demichelis R, Pascale F, Ugliengo P, Orlando R, Dovesi R (2009) Ab initio quantum mechanical study of γ -AlOOH boehmite: structure and vibrational spectrum. *Phys Chem Miner* 36(1):47–59
- Calagari AA, Abedini A (2007) Geochemical investigations on Permo-Triassic bauxite horizon at Kanisheeteh, east of Bukan West-Azarbaidjan Iran. *J Geochem Explor* 94(1–3):1–18
- Zafar ZI (2008) Determination of semi empirical kinetic model for dissolution of bauxite ore with sulfuric acid: parametric cumulative effect on the Arrhenius parameters. *Chem Eng J* 141(1–3):233–241
- Adil SH, Patel VN, Trivedi RK, Gupta SK, Golekar RB (2013) Structural evolution of Mainpat plateau, Surguja district, Central India. <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.975.3122&rep=rep1&type=pdf>
- Sahoo S, Mishra P, Mohapatra BK (2016) Morphological and microstructural characteristics of bauxite developed over a

- part of Precambrian Iron Ore Group of rocks, Sundergarh district Eastern India. *Arabian J Geosci* 10(1):12
12. Khanapurkar JV, Suryawanshi RA, Desai RV, Patil SR, Patil SH, Mali VR, Pisal PB (2018) Petrographical and mineralogical studies on lateritic bauxite profiles of shahuwadi taluka of Kolhapur district Maharashtra. *J Appl Geochem* 20(4):432–442
 13. Yu W, Wang R, Zhang Q, Du Y, Chen Y, Liang Y (2014) Mineralogical and geochemical evolution of the Fusui bauxite deposit in Guangxi, South China: from the original Permian ore body to a Quaternary Salento-type deposit. *J Geochem Explor* 146:75–88
 14. Bhukte PG, Chaddha MJ (2014) Geotechnical evaluation of eastern ghats bauxite deposit of India. *J Geol Soc India* 84:227–238
 15. Ling KY, Zhu XQ, Tang HS, Wang ZG, Yan HW, Wen Han T, Yi C (2015) Mineralogical characteristics of the karstic bauxite deposits in the Xiuwen ore belt, Central Guizhou province, Southwest China. *Ore Geol Rev* 65:84–96
 16. Meshram RR, Randive KR (2011) Geochemical study of laterites of the Jamnagar district, Gujarat, India: implications on parent rock, mineralogy and tectonics. *J Asian Earth Sci* 42(6):1271–1287
 17. Schellmann W (1981) Considerations on the definition and classification of laterite. In: *Proceedings of the International Seminar on Lateritisation Processes*. Oxford and IBH Publishing Company, New Delhi, pp. 1–10. <https://ci.nii.ac.jp/naid/10027158276/>
 18. Beyliss P, Berry LG, Mrose ME, Smith DK (1980) Mineral powder diffraction file, search manual (JCPDS). *Int Cen Powder Diffraction Data*. 1–447
 19. Desai RV, Khanapurkar JV, Suryawanshi RA (2018) Geochemistry of upland laterites of tarale-thoseghar plateau of bamnoli range of Satara District of Maharashtra India. *J Appl Geochem* 20(4):421–431
 20. Glenn RC, Nash VE (1963) Weathering relationships between gibbsite, kaolinite, chlorite, and expansible layer silicates in selected soils from the lower Mississippi coastal plain. *Clays Clay Miner* 12(1):529–548
 21. Brown G (1980) X-ray diffraction procedures for clay mineral identification. *Crystal structures of clay minerals and their X-ray identification*. 305–359

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.