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Petrological Characteristics of Lateritic Bauxite Deposits of India and Their Significance in Mineral Processing

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Abstract

India is endowed with 3896 million tons of bauxite resources and ranking it fifth globally. Thebauxite comprises various minerals such as gibbsite, boehmite, diaspore, hematite, goethite, kaolinite, quartz, anatase and rutile. India possesses abundant lateritic bauxite resources originating from parent rocks like Khondalite, Deccan trap basalt, Granite Gneiss, Sandstone, etc., each exhibiting its specific characteristics. The geotechnological evaluation of India's lateritic bauxite deposits, conducted by Jawaharlal Nehru Aluminium Research Development and Design Centre (JNARDDC), revealed the presence of two types of deposits: high-level and low-level (coastal). In this study, bauxite and laterite samples were collected from different regions in India and subjected to comprehensive technological evaluation.

Mineral processing techniques are optimized based on the mineralogical and petrological characteristics of the bauxite deposits. The mineral liberation, association, and alteration information obtained through petrological analysis guide the selection and optimization of various methods. The understanding of the mineralogy and petrological characteristics also assists in predicting the behaviour of bauxite during the processing stages, facilitating process control and minimizing losses.This paper aims to highlight the petrological, chemico-mineralogical characteristics of Indian lateritic bauxite deposits and emphasize the significance of petrology and mineralogy in their evaluation and mineral processing.

Microscopic examination plays a vital role in mineral characterization and the beneficiation process by enabling mineral identification, texture analysis, grain size, mineral liberation, association, alteration, and process optimization. Such comprehensive analysis contributes to maximizing the economic value of mineral resources, aiding informed decision-making in exploration, mining, and mineral processing industries.

Keywords: Bauxite, Lateritic Deposits, Petrological Characteristics, Mineralogy, Mineral Processing

Introduction

Lateritisation can be described as a process where mineral phases undergo re-equilibrium to adapt to the temperature, pressure and other environmental conditions present at the Earth's surface, particularly within the underlying weathering zone, which can vary in thickness (Bardossy and Aleva, 1990). Laterites are formed through intense subaerial weathering of alumino-silicate rocks under warm and humid climatic conditions, primarily in the intertropical regions of the world (Sarkar *et al.,* 2023; Adinda *et al.*, 2021, Bhukte, *et al.*, 2020). Bauxite ore results from the weathering of parent rocks, such as Khondalite, Deccan Trap basalt, Granite gneiss, Charnockite, and others. Based on the bedrock lithology, bauxite deposits are mainly classified into three types: (a) lateritic bauxite, (b) karst bauxite, and (c) Tikhvin type. Lateritic bauxite overlays aluminosilicate rocks of igneous, sedimentary and metamorphic origins. Karst bauxites occur in depressions on karst or eroded surfaces of carbonate rocks, and this type is predominant in Europe, the Caribbean region, the western Pacific region, and China. Tikhvin types are detrital bauxite deposits that overlay eroded surfaces of aluminosilicate rocks and are the result of the erosion of lateritic bauxite deposits (Bhukte *et al.*, 2023; Singh and Srivastava, 2018).

India has significant bauxite resources found in the Eastern Ghats region, although laterite and bauxite occurrences are distributed throughout various parts of the country (Adhikari, 2021; IBM, 2022). Lateritic bauxite deposits are located in the states of Odisha, Andhra Pradesh, Chhattisgarh, Madhya Pradesh, Maharashtra, Jharkhand, Gujarat, Goa, Karnataka, Kerala, Tamil Nadu, Uttar Pradesh, Rajasthan, and the union territory of Jammu (IBM, 2022; USGS, 2022; Bhukte *et al.*, 2020). There are distinct geological variations in the mode of occurrence and configuration of ore bodies in different deposits. Based on studies of Indian bauxites, three broad groups can be identified: (1) thick continuous ore bodies with undulating roofs and floors, which are mostly found in the Eastern Ghat region; (2) continuous ore bodies with variable thickness and grade, found in selected Western Ghats and Gujarat bauxite deposits; and (3) pocket and discontinuous ore bodies, prevalent in most central Indian and Gujarat deposits (Bhukte *et al.*, 2018; Bhukte Chaddha, 2014; Kale and Wadpalliwar, 2016). The

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mode of occurrence and configuration of ore bodies significantly influence the mining techniques to be adopted. The authors believe that bauxite mines/deposits can be evaluated and ranked based on parameters such as bauxite resources, quality of run-of-mine (ROM), bauxite characteristics (chemical, mineralogy, trace elements, petrology, available alumina, and reactive silica), present mining capacity, and quality of beneficiated ore (Bhukte *et al.*, 2021, 2023; Nandi, 2019). Bauxite deposits typically comprise four horizons: Duricrust (Laterite), Bauxite, Saprolite or Partially Lateritised Khondalite (weathered), and the parent rock. The characteristics of bauxite ore depend on the composition of the underlying parent rock, which is responsible for the formation of the bauxite profile. JNARDDC has conducted an evaluation of bauxite and laterite deposits in India from geological, mining, beneficiation and metallurgical perspectives. India possesses various grades of bauxite and laterite suitable for both metallurgical and non-metallurgical industries (Fig.1).

Geological Background

In India, bauxite ore has originated from various rocks such as Deccan trap basalt, khondalite, granite gneiss, *etc.* (Table 1). Laterites developed over both the khondalite and granite are primary and formed in-situ by lateritisation of the crystalline rocks during pre-Oligocene before the deposition of Tertiary Formations. (Reethu *et al.*, 2023). The geological processes play an important role in the development of lateritic bauxite profile by the process of lateritisation and bauxitisation. The lateritic bauxite deposits are present in various landforms *viz.* plateaus-flat or uneven topped, dome shaped hills, elongated cuestas, slopes of mountain ranges, flat coastal peneplains and sedimentary flats and shallow depressions on flat peneplains in order of diminishing frequency (Aleva, 1994; Bardossy and Aleva, 1990) .

Depending upon elevation above mean sea level, the Indian bauxite deposits are classified into the following groups (Bhukte *et al.*, 2017, Kale *et al.*, 2013; Bhukte, 2002).

a) High level deposits (>850 m. above msl) *e.g.* Eastern ghat deposits (Odisha, Andhra Pradesh), Central India (Chhattisgarh, Maharashtra, Jharkhand), Western Ghats (Karnataka, Tamil Nadu) and b) Low level deposits (<350 m. above msl), West coast, Gujarat, part of Maharashtra

Sampling and Sample Preparation

For the scope of the current investigation, the representative samples of bauxite and laterite were collected from bauxite deposits located in various regions across India, encompassing the West Coast, Central India, Gujarat and East Coast. Upon collection, these samples were subjected to a crushing process via a Jaw crusher, resulting in a reduction of size to -25 mm. For characterization studies, samples of -74micron size were generated through the employment of a universal mill or ball mill and subsequently homogenized to ensure uniformity. To extract a representative sample, a coning and quartering procedure was followed. Comprehensive analyses, both chemical and mineralogical, were conducted on the samples. Wet chemical methods and X-ray Fluorescence (XRF) wereused for chemical analysis, while X-ray Diffraction (XRD) techniques were employed, supplemented by Experience Database (XDB) software, for quantitative mineralogical analysis. The geological, physical, chemical and mineralogical characteristics are given in Table 1.

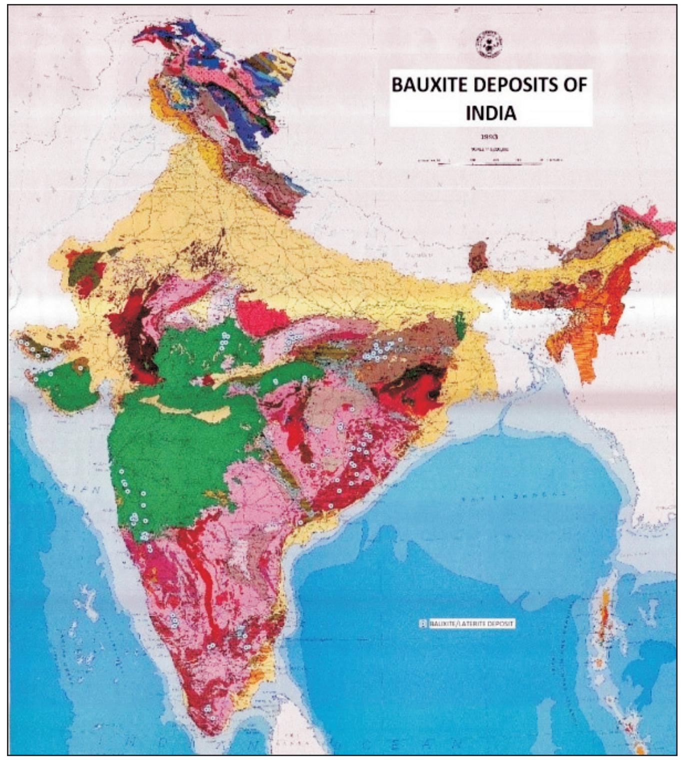

Fig.1. Geological map of bauxite and laterite deposits of India

Characterization Studies

Mineralogy and Morphology

Mineralogically, the bauxite found along the East Coast, West Coast and Gujarat displays a gibbsitic in nature.On the other hand, the bauxite from Central India exhibits amixed gibbsitic boehmiticin mineral characteristics (Table 2). The morphology study was conducted using Scanning Electron Microscope (SEM-IT 300, JEOL, Japan) in conjunction with Energy Dispersive Spectroscopy (EDX-Octan Plus, EDAX, USA).Morphological studies through scanning electron microscopy (SEM) have shown that bauxite samples contain well-formed gibbsite crystals. However, in the laterite deposits, the gibbsite crystals are undeveloped due to the partial bauxitisation process. A notable observation is that minerals habit, crystal morphology and related attributes are less conspicuous in low grade ores in contrast to typical bauxite ores (Bhukte *et al.*, 2023; Bhukte, *et al.*, 2020; JNARDDC, 2012).

Petrological Study

Microscopy is the most widely used and indispensable method for mineral identification. The optical properties differ from mineral to mineral because their crystal structure is different and the chemical constituents of the mineral; also, their relative positions in the crystal lattice sites differ.In the realm of textural investigations, no alternative method emerges capable of supplanting its efficacy. However, the microscopic study does exhibit certain limitations, particularly when tasked with discerning exceedingly fine-grained minerals, synthetic phases, cryptocrystalline compositions, and minerals featuring mutable configurations due to solid solution substitutions. Petrography studies give information about mineral

Table 1: Characteristics of lateritic bauxite deposits in India

Region/ State	Area/ District / Deposit	Parent/ base rock	Nature of deposit	Chemical Feature	Mineralogical feature	Remarks	References
Central India Chhattis-garh and Madhya Pradesh	Surguja, Raigarh, Bastar, Balrampur, Bilaspur, Rajnandgaon, Kondagaon, Shahdol, Mandla, Jabalpur, Balaghat and Satna	Deccan Trap, Upper Rewa Sandstone, Vindhyan Sandstone, Shale	Mostly high level occurs as discontinuous lenses or tabular bodies within laterite occurrences	Moderate to high Al_2O_3 (42-54%) and high titania (TiO_2-5-10 %) Bastar bauxite contains high Al_2O_3 60%.	Mixed gibbsitic boehmitic and boehmitic type. At places (Bastar, Chhattisgarh) diaspore is dominant (30%)	Hard in nature (BWI-14-19 kwh/mt) Laterites occur above the bauxite zone and or sandwiched in the horizonHigh grade bauxite deposits (non-metallurgical grade) are small & unexplored	JNARDDC, 1999, 2024; Sarkar *et al.,* 2023
Mahara-shtra	Kolhapur, Satara, Raigad, Ratnagiri, Sindhudurag, Sangli and Thane	Mainly Deccan Trap Basalt	High level and low level (coastal); mostly pockets, lenses and blanket type	Medium to high Al_2O_3, (42-55%), low silica, titania (2-6%)	Gibbsitic (coastal) and mixed gibbsitic boehmitic type (high level)	Hard in nature (BWI-14-18 kwh/mt) The reworked bauxite is hard Laterites underlain by bauxite zone High grade bauxite deposits (non-metallurgical grade) are in pockets	Bhukte *et al.,* 2018, 2020; Kale *et al.,* 2013
Jhar-khand	Lohardaga, Gumla, Latehar, Godda	Deccan trap, Granite gneiss	High level-blanket type	Moderate to high Al_2O_3, (42-52%) and high titania (TiO_2-5-10 %)	Mixed gibbsitic boehmitic type	Hard in nature (BWI-16-18 kwh/mt) High grade bauxite deposits (non-metallurgical grade) are small	Bhukte *et al.,* 2023; Beck, 2021; JNARDDC, 2005
Eastern Ghats and coast Odisha Andhra Pradesh	Koraput, Kalahandi Visakhapatnam, East Godavari	Khondalite and Charnockite	High level lateritic type, occurs on plateau tops as blanket covers	Moderate Al_2O_3 (42-46 %), high Fe_2O_3 (22-30%), low silica (3-5 %) and titania (TiO_2-1-3%)	Fully Gibbsitic, a minor amount of boehmite	Soft in nature (BWI-9-12 kwh/mt) Laterites occur above the bauxite zone Deposits mostly cover metallurgical grade bauxite however; high grade bauxite is in pockets	Bhukte and Chaddha, 2014; JNARDDC, 2005
Gujarat	Kachchh, Jamnagar, Sabarkantha, Kaira, Bhavnagar, Valsad, Porbandar	Deccan Trap basalt, argi-llaceous and calcareous sandstone, Limestone etc.	Low level mainly pockety and bouldery	Kachchh - Moderate to high Al_2O_3, low SiO_2 and CaO (0.5-5%)	Gibbsitic, 0.5 to 5% alumina as boehmite and diaspore at places	Hard in nature (BWI-14-19 kwh/mt.) The reworked bauxite is hard Reserves of high grade (plant grade-PG) bauxite are exhausting. The high-grade bauxite remains in pockets. The resources of low to medium grade bauxite are abundant.	Singh and Sri-vastava, 2018; Bhukte *et al.,* 2017; Jadhav *et al.,* 2012; JNARDDC, 2005

characterization which helps inpreliminary beneficiation procedures.It includes the meticulous microscopic assessment and dissection of rock and mineral specimens, thereby yielding invaluable data relating to their composition, arrangement, structure, texture and mineral assemblages (Bhukte and Puttewar, 2014).

Petrological investigations were conducted utilising the Optical Petrological Microscope (Carl Zeiss Microscopy GmbH, Germany, Zeiss Axio Scope A1). The scope of this study encompassed petrographic analysis of representative bauxite and laterite samples. The primary objective was to gain an understandingof the diverse mineral properties relating to mineral beneficiation investigations.

Examination under the optical microscope revealed the presence of gibbsite minerals within bauxite deposits along the western coast (Kerala, Karnataka, Goa). The gibbsite minerals exhibit a distinctive rimmed texture characterised by polysynthetic twinning.When observed under the microscope, the gibbsite displayed a pale brown colour with weak pleochroism and moderate relief (Fig 2; Behera *et al*., 2021; Santha Kumar *et al.*, 2018). Iron oxide was present in the form of hematite and goethite minerals. The prevalent textures encompassed colloform, pisolitic, and oolitic, predominantly composed of iron-bearing minerals (Fig 3). Notably, it was suggested by the researchers that the oolites were predominantly composed of aluminium hydroxides (boehmite, gibbsite), sometimes occurring as fragments. The interstitial matrix amid the oolites contained kaolinite, iron oxides, and hydroxides. Detrital minerals such as ilmenite, rutile, chromite, zircon, calcite, etc. were identified within the deposits (Mondillo *et al.*, 2022). Several variations of aluminous laterite showcased either a gibbsitic or ferruginous ore, indicating solution migration. The raw laterite samples exhibited alternating coloured rings, whereas thin sections unveiled layers of gibbsite and goethite/hematite (Budihal and

Table 2: Mineralogical characteristics of lateritic bauxite deposits in India (JNARDDC, 2024; Bhukte et al.; Bhukte and Chaddha, 2014)

Mineral Phases (%)	Eastern Ghat Bauxite (Odisha)	Central India Bauxite (Maharashtra)	Central India Bauxite (Chhattisgarh)	Gujarat Bauxite (Kutch)
Al_2O_3 as Gibbsite	41.18	42.16	46.08	47.55
Boehmite	ND	0.85	0.42	0.85
Al- goethite	1.09	1.00	0.72	0.86
Kaolinite	1.58	1.18	0.39	2.57
Diaspore	ND	1.70	ND	0.42
Total	43.84	46.89	47.62	52.25
SiO_2 as kaolinite	1.86	1.40	0.47	3.03
Quartz	ND	ND	0.5	ND
Total	1.86	1.40	0.97	3.03
Fe_2O_3 as Al-goethite	9.64	8.43	6.42	7.63
Hematite	15.50	3.00	8.5	3.00
Total	25.66	11.83	14.92	10.3
TiO_2 as Anatase	0.75	9.50	10	3.00
Rutile	0.75	1.00	ND	ND
Ilmenite	0.53	ND	ND	ND
Total	2.03	10.50	10	3.00
CaO as Calcite	ND	ND	ND	0.98
Total	ND	ND	ND	0.98

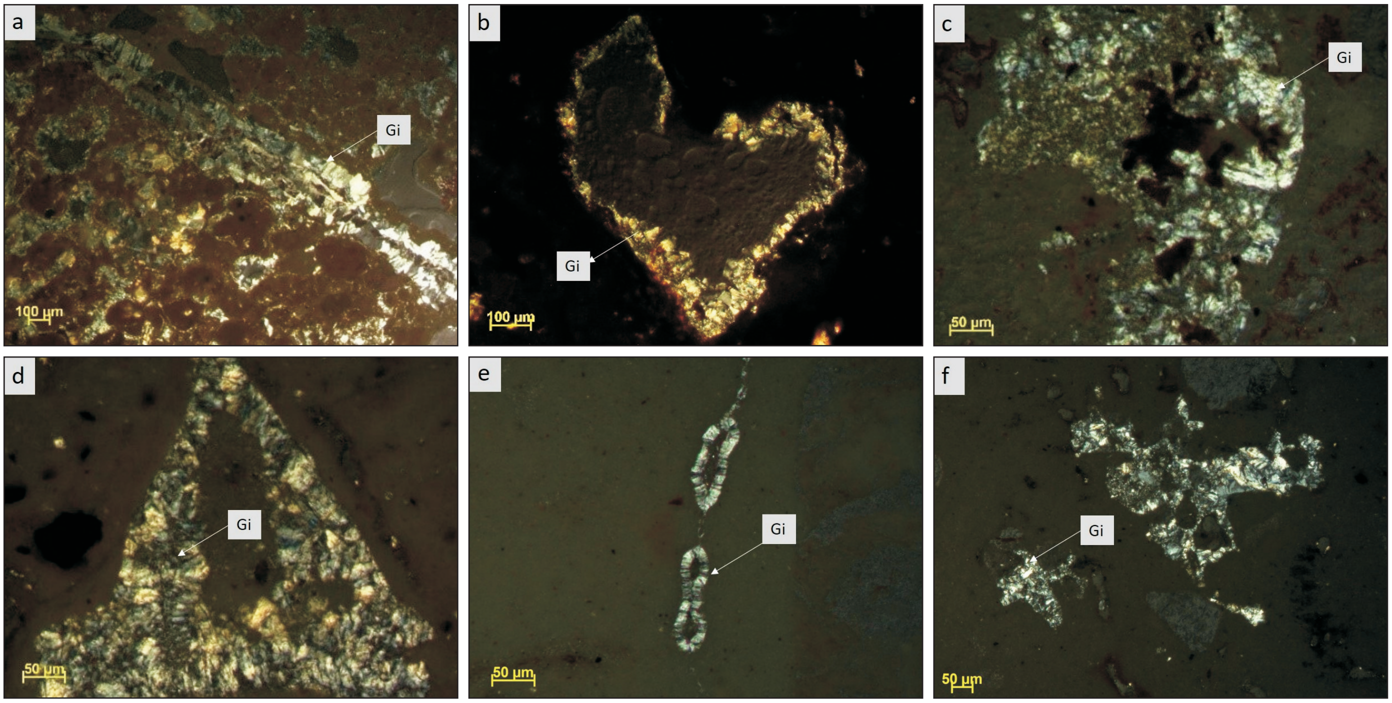

Fig.2. a-c)The photomicrograph show in gibbsite minerals exhibit characteristic twinning in bauxite. d-f) The rimmed texture formed by well-developed cryptocrystalline gibbsite in bauxite (west coast deposits),(Gi-Gibbsite)

Manjunatha, 2023). The authors assumed that Central Indian bauxite emerged from in-situ weathering of basaltic rocks, and the pisolitic texture denoting the substitution of goethite by euhedral gibbsite resulted from iron leaching during the later stages of bauxitisation (Das *et al.*, 2020; Das and Khan, 2018). Petrographic analysis unveiled the formation of bands/rings primarily composed of iron-bearing minerals (hematite and goethite), while gibbsite displayed subhedral cryptocrystalline characteristics, accompanied by discernible twinning (Fig 4).

The Gujarat bauxite is characteristic of calcium content in the form of calcite and it is devoid in other Indian deposits (Jadhav *et al.*, 2012; Meshram and Randive, 2011). The petrography study shows that band/ring is formed mainly by iron bearing minerals (hematite and goethite) and the gibbsite is subhedral, crypto-

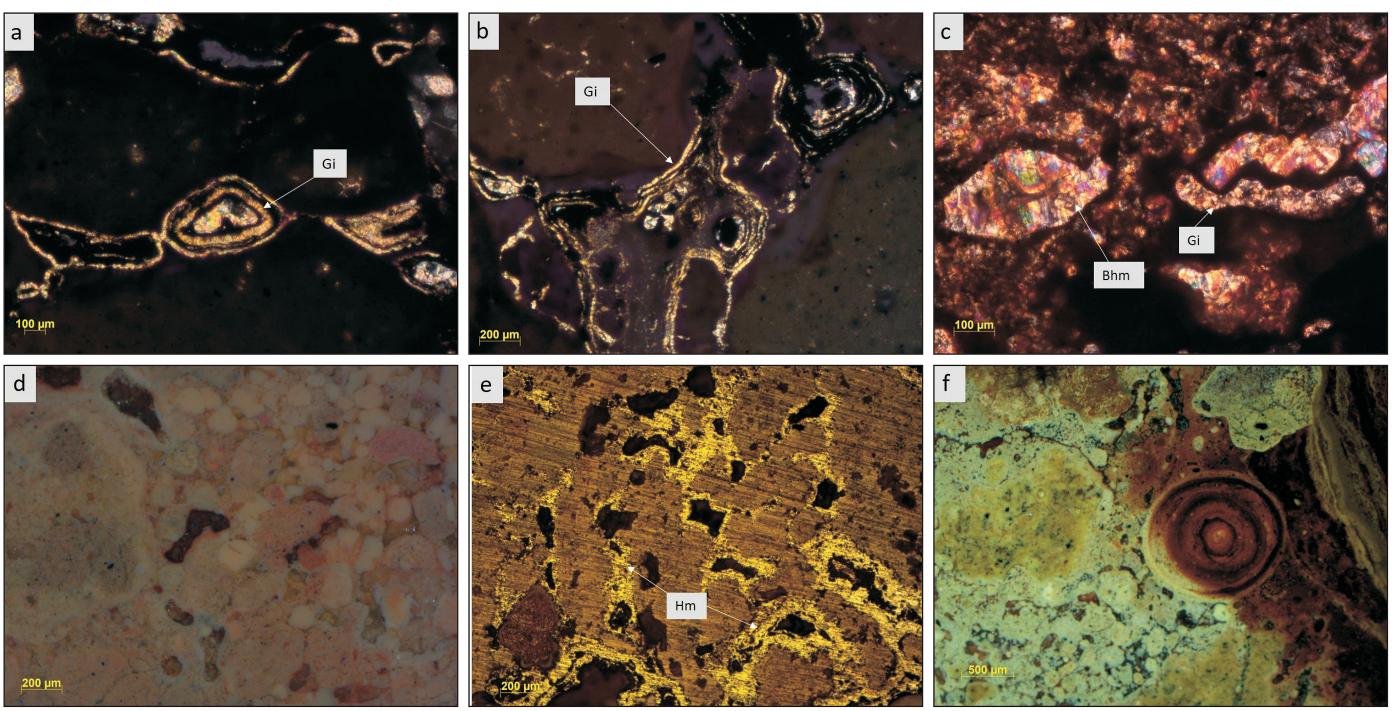

Fig.3. a-c)Colloform banding and rimmed texture formed by gibbsite minerals in bauxite. d-f) The photomicrograph showing pisolitic texture and colloform banding mainly of iron and alumina bearing minerals (Central Indian deposits), (Gi-Gibbsite, Bhm-Boehmite, Hm-Hematite)

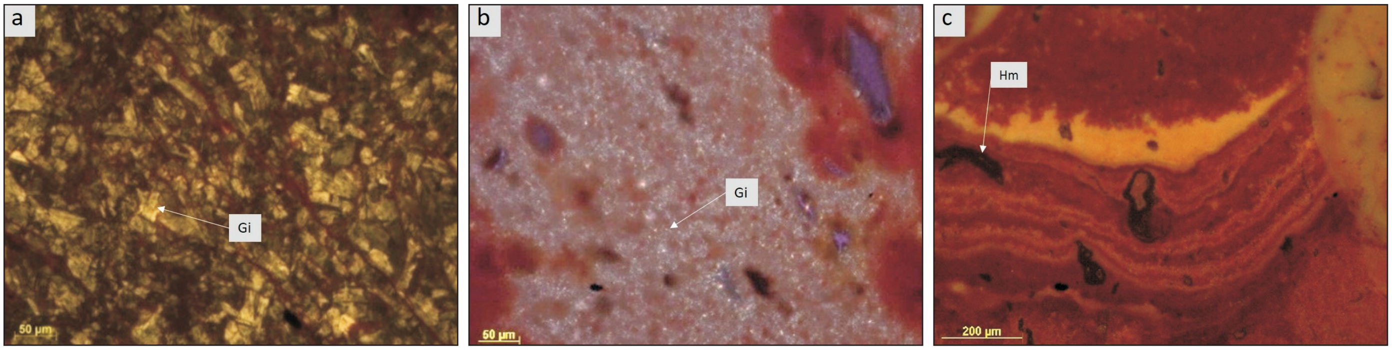

Fig.4. a-b) Gibbsite phase in bauxite associated with iron minerals. c) Colloform bandingformed by ferruginous minerals in bauxite (Gujarat deposits)(Gi-Gibbsite, Hm-Hematite)

crystalline and exhibits characteristic twinning (Fig. 4).The eastern ghat (Odisha) bauxite shows characteristics of high iron oxide content which is in the form of hematite, goethite and limonite. The microscopy study shows that ferruginous bauxite exhibits colloform and pisolitic texture. These oval shaped pisolites mainly consist of iron and alumina bearing minerals (Fig 5).The authors opined that the ferruginous laterites have a pseudobreccia massive aphanitic texture, of yellowish dark red colour composed of more than 80 % ferruginous minerals (Abdoulaye *et al.*, 2023).The petrography studies show that bauxite is gibbsitic in nature, cryptocrystalline and exhibits polysynthetic twinning (Fig. 5d). In the case of Eastern Ghat bauxite (Odisha), a notable concentration of iron oxide, represented by hematite and goethite, was identified. Microscopic evaluation depicted colloform and pisolitic textures prevalent within the ferruginous bauxite (Fig. 5). Petrographic investigations further confirmed the gibbsitic nature of the bauxite, revealing a cryptocrystalline structure featuring polysynthetic twinning (Fig. 5d).

The acquired data provided insights into the physical characteristics of bauxite and laterite, encompassing crystal or mineral dimensions and configurations, alteration in mineral textures and the inherent properties of the parent rock. In general, the laterite exhibitsmoderately formed gibbsite crystals, whereas, prominently developed gibbsite crystals were known within the bauxite samples (Fig. 6).

Significance of Petrography in Mineral Characterisation and Beneficiation

Mineral beneficiation encompasses a series of physico-chemical processes aimed at recovering valuable minerals from gangue, facilitating the production of concentrated materials. The initial stage involves the comminutionof ore to an optimal size to achieve the physical liberation of valuable minerals from undesired gangue minerals. In the subsequent step, selective separation or concentration of desired minerals occurs through the exploitation of contrasting physical properties within the mineral assemblage. Accurate identification and comprehensive characterization of ore

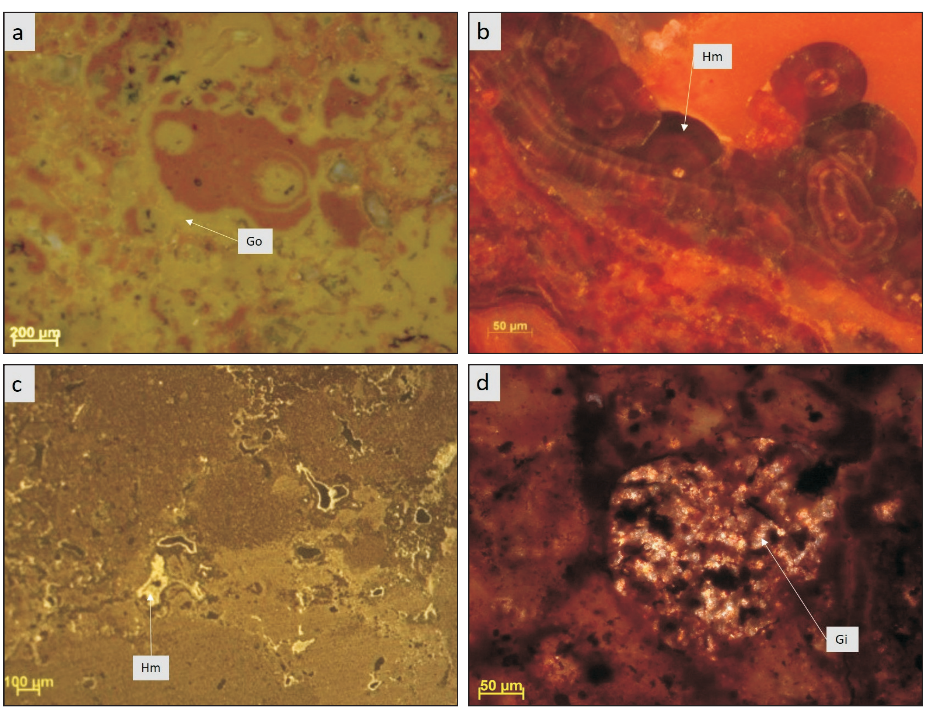

Fig.5. a-c)The photomicrograph showing pisolitic, colloformtexture in ferruginous bauxite. d)The photomicrograph showing morphology of gibbsite crystalsin bauxite (Eastern Ghat, Odisha deposit)(Gi-Gibbsite, Go-Goethite, Hm-Hematite)

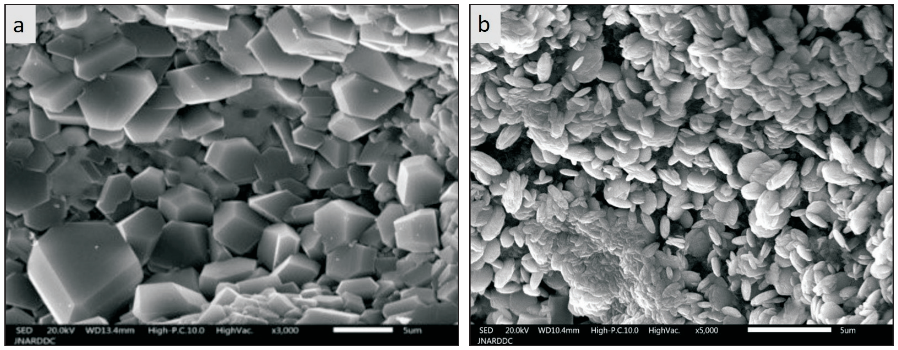

Fig.6. The scanning electron microscopy (SEM) images of a) typical hexagonal, rhombohedral gibbsites in bauxite, b) iron bearing minerals in laterite

minerals are important in ore processing. Based on the mineralogical composition encompassing both valuable minerals and associated gangue, optimal concentration methodologies can be determined. Minerals of interest in mineral processing exhibit three primary categories of properties: compositional (chemical), physical and geometric (Lal, 2013). Compositional attributes pertain to the mineral's chemical composition, including considerations of metallic versus non-metallic, sulphide versus oxide, and silicate versus carbonaceous composition within an ore. Physical properties encompass characteristics like specific gravity, hardness, colour and magnetic susceptibility. Geometric attributes predominantly relate to textural and structural aspects of ores, as well as patterns of mineral interlocking. Mineral characterization is executed either qualitatively or quantitatively, contingent upon the chosen beneficiation approach and challenges associated with mineral separation. The distinctive attributes of minerals serve as anessential determinant for selecting the appropriate beneficiation pathway. Notably required mineralogical information includes: a) Mineral identification, b) Geometric characterisation (mineral morphology, shape, size, textural attributes, interlocking studies and interference pattern) and c) Quantitative estimation of minerals.

Mineral identification serves as the foundational step in ore characterization, offering crucial insights into the chemical and compositional attributes of mineral deposits. This essential information forms the basis for determining the most suitable beneficiation processes. The identification of minerals plays an integral role in discerning between valuable and gangue minerals, thereby guiding the selection of the optimal beneficiation approach. The composition of the gangue is of dominant significance, whether it comprises siliceous, aluminous, ferruginous, or carbonaceous components, as it profoundly influences the choice of beneficiation methods. Mineral identification yields valuable data regarding the contribution of various minerals within an ore to the content of a specific metal or element. Notably, minerals sharing the same metal or element may exhibit divergent responses to a given beneficiation process. Consequently, multiple process routes may be necessary to effectively recover the desired metal. Mineral identification also facilitates the estimation of the maximum attainable grade in the concentrate; a critical parameter for assessing the ore's economic viability.Furthermore, the identification of deleterious impurities assumes great importance in the selection of the appropriate beneficiation process for their removal. The presence of specific gangue minerals may even offer opportunities for their recovery as valuable by-products. For instance, bauxite ore often contains impurities like hematite, limonite, goethite, and kaolinite, which necessitate beneficiation to mitigate their adverse effects. Mineral identification extends its significance to the detection of alterations or oxidations in primary minerals, which can significantly impact the beneficiation process and lead to tailing losses. Geometrical characterization encompasses the examination of mineral shapes, sizes, textural features, and interlocking patterns. Textural studies provide geometric data that reveal howminerals are interlocked, both among themselves and with gangue materials. This information encompasses details on grain size, shape, and fractures within the ore. These geometric characteristics exert a profound influence on the liberation of valuable minerals from gangue during comminution processes, ensuring that the desired minerals are liberated at optimal size ranges. In essence, mineral identification and geometrical characterization are essential elements of ore characterization, guiding the selection of beneficiation processes and optimizing the extraction of valuable metals and minerals from ore deposits.

The liberation of minerals is a primary objective within the size reduction process, a critical stage in mineral processing. Achieving a high degree of liberation is desirable, as it means that the minerals are effectively separated from each other. Ideally, this separation would occur along the grain boundaries, ensuring that individual mineral grains are fully detached. However, in most size reduction processes, random fracturing occurs, resulting in the creation of more locked particles where minerals remain interconnected. Consequently, simply examining grain size and interlocking patterns cannot provide precise information on liberation studies. However, these factors are valuable in estimating the required fineness of ore grinding. The reduction of a large lump into smaller particles does not necessarily break the bonds between dissimilar minerals completely. Instead, mineral locking is generally limited to a relatively small portion of the original lump. Several factors influence liberation during the comminution process.

Liberation by Size Reduction (Grain Size)

The grain size of the ore is animportantfeature. If the material consists of coarse grains, liberation through comminution is expected to occur at a coarse grind, up to the size of the individual grains. Conversely, for fine-grained ore, a finer grind is required to achieve liberation.

Shape of Grains

The shape of mineral grains plays a significant role in the grinding process. Grains can be rounded, sub-rounded, angular, sub-angular, flaky, or irregular in shape and each shape affects how the material behaves during grinding and liberation.

Hardness of the Interlocked Minerals

The relative hardness of the minerals that are interlocked is crucial. If both locked minerals have similar hardness levels, liberation can be achieved at sizes below the grain size. However, if a hard mineral is interlocked with a relatively softer mineral, liberation may occur at a coarser size due to differences in hardness, as well as the presence of intergrowths and inclusion.

JNARDDC has conducted extensive studies on various bauxite deposits originating from different geological sources. The findings show that coarser fractions of bauxite, specifically those within the size range of -100+50, -50+25, and -25+16 millimetres, exhibit a higher percentage of Al_2O_3(aluminium oxide) and a reduced SiO_2 (kaolinite) content in comparison to finer fractions measuring -2 millimetres and finer, such as -100 mesh. However, it is essential to note that these outcomes can vary significantly from one bauxite deposit to another, depending on factors like the inherent characteristics of bauxite, mineral interlocking patterns, geological setting, *etc* (Bhukte *et al.*, 2023). Petrography plays a vital role in the characterization and beneficiation of minerals by providing crucial insights into the mineral, texture, and structure of bauxite. This involves a meticulous microscopic examination of thin sections of the samples to identify, analyse, and understand the minerals present and their interrelationships within the sample. The contributions of petrography to mineral characterization and beneficiation are as follows.

Mineral Identification

Petrographic analysis utilizes polarized light microscopy to ascertain the mineral composition of ore samples. By examining the optical properties of minerals, petrologists can accurately identify minerals within the sample. This information is fundamental for understanding the mineralogical makeup of the deposit, which is crucial for assessing its economic viability. For example, in bauxite ore, minerals like gibbsite, boehmite, diaspore, hematite, goethite, kaolinite, quartz, anatase, and rutile can be identified along with size, texture and morphology, which are important in mineral processing.

Textural Analysis

Petrography offers insights into the texture and fabric of ore. Observations of grain size, shape, arrangement, and mineral spatial relationships yield valuable information regarding the deposit's origin and history. This is particularly beneficial for understanding how valuable minerals can be liberated from gangue minerals during beneficiation. For example, pisolitic and oolitic textures in bauxite, primarily composed of alumina and iron-bearing minerals, play a role in mineral liberation. Additionally, colloform and colloidal textures, mainly consisting of goethite, hematite, and limonite minerals, are observed.

Mineral Association and Interlocking Pattern

The petrographic examination reveals the association between different minerals in the ore. This is essential for determining potential associations between valuable and gangue minerals, influencing the selection of beneficiation methods. Understanding intergrowth patterns and mineral interrelationships helps optimize mineral separation processes. Interlocking refers to the crystalline structure of the minerals that are present in the ore.

Identification of Alteration Minerals

Petrography facilitates the identification of alteration minerals and chemical changes within bauxite. Such alterations can impact mineral beneficiation processes by affecting mineralogy, physical properties, and behaviour during processing. Understanding the extent and nature of these alterations supports optimizing beneficiation strategies and addressing potential challenges. In the case of bauxite originating from Deccan trap basalt, the plagioclase feldspar alters to gibbsite mineral to prolong the residual weathering process.

Process Optimization

Petrographic data integration with other mineralogical and metallurgical data allows the development of efficient beneficiation strategies. Information about the mineralogical characteristics of a deposit guides the selection of appropriate processing techniques, equipment, and operating parameters. This optimization process enhances valuable mineral recovery, reduces energy consumption, and minimizes environmental impacts.Petrography also plays a crucial role in quantitatively determining minerals, especially in cases where chemical analysis alone falls short.

Study of Modal Distribution

Modal distribution of minerals by microscopy with an image analysis system or by grain counting helps in the statistical distribution of ore and gangue minerals.It is directly related to the grade of ore and also helps in the liberation studies (Lal, 2013). It can also be extended to beneficiation products to find the efficiency of beneficiation.

$$\text{Liberation} = \frac{100 \times \{\text{No. of free ore minerals} + (\text{No. of free gangue minerals})\}}{\text{No. of free minerals} + \text{free gangue minerals} + \text{interlocked minerals}}$$

Liberation Study by Microscopy

The liberation of ore and gangue is achieved by size reduction (through grinding). The statistical count of interlocked grains, ore minerals free of gangue (liberated ore) and gangue minerals free of ore minerals (liberated gangue) gives the quantitative percentage of liberation.

Conclusions

Petrological and mineralogical studies play a crucial role in understanding the composition, structure, texture, grain size, and intergrowth relationships of bauxite and laterite. These examinations provide vital understandings of the distribution and association of valuable ore minerals with gangue minerals, guiding the design of effective mineral processing approaches. The identification of predominant minerals, such as gibbsite, boehmite, kaolinite, and iron oxide/hydroxides, along with gangue minerals like hematite, goethite, limonite, kaolinite and rutile highlights the challenges in achieving efficient liberation during grinding. Optimal grain size determination is essential to ensure effective liberation, minimizing losses of valuable minerals in tailings while avoiding energy wasteand production withmaximizing ore recovery and economic viability. The composition of bauxite, specifically a higher concentration of alumina minerals (boehmite, gibbsite, diaspore) and a lower presence of hematite and goethite, suggests its potential as a promising ore for the non-metallurgical industry (abrasive, refractory, *etc.*). The well-developed, hexagonal crystals, such as gibbsite, within bauxite hold promise for enhancing the available alumina, animportantparameter in alumina production.

The mineral associations and interlocking patterns can be studied through petrology which are vital for beneficiation. At a particular size, the valuable minerals particles can be separated/free/unlocked from the gangue mineral. Economic point of view,itmay reduce the grinding cost and increase the yield. Depending on these factors, the selection of an appropriate beneficiation method becomes crucial for reducing impurities (iron oxide Fe_2O_3%, silica SiO_2% and titania TiO_2%) and enrichment of alumina (Al_2O_3%). Methods such as magnetic separation, hydrocyclone, gravity concentration, screening/sieving, *etc.* emerge as viable options in this context.Additionally, petrological and mineralogical investigations play a pivotal role in pinpointing the most viable techniques for mineral beneficiation. They are instrumental in maximizing the economic value of mineral resources by empowering informed decision-making within the mining and mineral processing industries.

Authors' Contributions

PB: Conceptualisation, Methodology, Writing-Original Draft, Interpretation. **GD**: Data Curation, Petrology, Investigation. **TB**: Literature, Formal Analysis, Petrology, Editing. **BK**: Sampling, Draft Figures. **AA**: Reviewing and Editing.

Conflict of Interest

Authors declare that they have no conflict of interests.

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