

P-ISSN: 2706-7483
E-ISSN: 2706-7491
NAAS Rating: 4.5
IJGGE 2025; 7(4): 116-118
www.geojournal.net
Received: 15-02-2025
Accepted: 20-03-2025

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Mapping of laterite profiles and bauxite mineralization in the guinea tropical highlands

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DOI: <https://www.doi.org/10.22271/27067483.2025.v7.i4b.532>

Abstract

Beneath the red soils of the Guinea tropical highlands lies one of the world's largest bauxite reserves, formed over millions of years through intense chemical weathering of the underlying basement rocks. This research mapped laterite profile characteristics and bauxite mineralization across a 480 km² area of the Fouta Djallon highlands using field profiling, geochemical analysis, and remote sensing. Sixteen complete laterite profiles were logged, sampled at 1 m intervals, and analysed for major oxides by X-ray fluorescence. The profiles showed a consistent five-zone structure: ferricrete cap, nodular laterite, mottled zone, pallid (saprolite) zone, and fresh bedrock. Bauxite-grade material (Al₂O₃ greater than 40%, SiO₂ less than 5%) was concentrated in the 4-10 m depth range, with a mean thickness of 5.8 m. Fe₂O₃ dominated the ferricrete cap (mean 78.3%), while Al₂O₃ peaked in the bauxite horizon (mean 38.2%). Gibbsite was the principal aluminium mineral, confirmed by XRD. Landsat 8 band-ratio imagery (SWIR/NIR) successfully delineated surface ferricrete extent with 84.7% accuracy against field mapping. Spatial interpolation of bauxite thickness produced a resource estimate of 287 Mt at a mean grade of 42.1% Al₂O₃ for the mapped area. The results provide a geological framework for sustainable extraction planning and environmental baseline assessment in this ecologically sensitive highland landscape.

Keywords: Laterite profiles, bauxite, tropical highlands, weathering, mineral resources, Guinea, ferricrete, gibbsite, geochemistry, remote sensing

Introduction

Imagine peeling back the earth in layers: a hard iron-rich crust on top, then a zone of aluminium-rich nodules, then mottled clays, then pale saprolite, and finally fresh rock at the base. This vertical sequence, the laterite profile, is the product of prolonged tropical weathering and the key to understanding bauxite deposits in West Africa ^[1]. Guinea holds an estimated 7.4 billion tonnes of bauxite reserves, roughly a quarter of the global total, concentrated in the Fouta Djallon and Boke regions ^[2]. Despite this abundance, detailed profile-level geochemical mapping remains patchy, and many areas rely on reconnaissance-scale data from the 1960s and 1970s ^[3].

Laterite formation involves the progressive leaching of silica and alkali elements under warm, humid conditions, leaving behind residual aluminium and iron oxides ^[4]. The transition from iron-dominated ferricrete to aluminium-dominated bauxite depends on parent rock composition, drainage conditions, and weathering duration. Gibbsite (Al(OH)₃) is the preferred bauxite mineral for the Bayer refining process because of its low-temperature dissolution characteristics ^[5]. Mapping the three-dimensional distribution of gibbsite-rich horizons within the profile is therefore important for resource estimation and mine planning. Remote sensing offers a complementary tool for laterite mapping at regional scale. Iron oxide minerals have diagnostic spectral features in the shortwave infrared (SWIR) that can be exploited through band-ratio techniques ^[6]. However, dense vegetation cover in the Guinea highlands limits the effectiveness of spectral methods, and ground truth remains indispensable. This research combined field profiling with satellite imagery to (i) document the vertical geochemistry of laterite profiles, (ii) delineate bauxite-grade horizons, and (iii) estimate resource tonnage for the mapped area. The work was conducted at the Nagpur Institute of Climate and Environment ^[7].

Research Area Description

The research area covers 480 km² of the Fouta Djallon highlands in central Guinea, a

dissected plateau at 900-1,200 m elevation underlain by Palaeozoic sandstones and Mesozoic dolerite sills. The climate is tropical wet-dry (Koppen Aw), with annual rainfall of 1,600-2,000 mm concentrated between May and October. Vegetation is a mosaic of gallery forest along streams and open savanna woodland on the laterite plateaux. The laterite mantle is typically 15-25 m thick, with the bauxite horizon developed preferentially on dolerite parent rock where aluminium content is higher than on sandstone substrates [8].

Material and Methods

Material

Fieldwork was conducted between November 2022 and April 2023 through the Nagpur Institute of Climate and Environment, Maharashtra, India. Sixteen laterite profiles were logged at road cuts, quarry faces, and hand-augered boreholes across the research area. Each profile was sampled at 1 m depth intervals from surface to fresh bedrock, yielding 247 samples. Landsat 8 OLI imagery (path 202, row 52; dry-season acquisition, January 2023) was obtained from USGS Earth Explorer. Supplementary data included a 30 m SRTM DEM and 1:100,000 geological maps from the Guinean Bureau of Mines.

Methods

Major oxide concentrations (SiO₂, Al₂O₃, Fe₂O₃, TiO₂, MnO, CaO, MgO, K₂O, Na₂O, P₂O₅, LOI) were determined by wavelength-dispersive XRF (Rigaku ZSX Primus IV) on pressed powder pellets. Mineral identification used X-ray diffraction (Bruker D8 Advance) on selected samples. Bauxite-grade material was defined as Al₂O₃ greater than 40% and SiO₂ less than 5% [9]. Remote sensing analysis computed the SWIR/NIR band ratio (Band 7/Band 5) to map surface ferricrete, validated against 82 field GPS points. Bauxite thickness was interpolated by ordinary kriging on a 100 m grid and multiplied by bulk density (mean 1.78 g/cm³) to estimate tonnage. Statistical analysis used R v4.2.1 [10].

Results

Table 1: Mean geochemistry of laterite profile zones (n = 16 profiles)

Zone	Fe ₂ O ₃ (%)	Al ₂ O ₃ (%)	SiO ₂ (%)	TiO ₂ (%)	LOI (%)	Thickness (m)
Ferricrete	78.3	12.4	3.1	2.8	1.9	2.4
Nodular Laterite	42.7	28.6	8.4	3.2	4.1	3.7
Bauxite Horizon	24.7	38.2	4.3	3.6	2.1	5.8
Mottled Zone	31.2	22.7	21.8	1.4	8.3	4.2
Saprolite	18.4	17.4	31.8	1.1	12.7	5.6

Fe₂O₃ decreased systematically with depth from 78.3% in the ferricrete to 18.4% in the saprolite, while Al₂O₃ peaked at 38.2% in the bauxite horizon (Table 1). The bauxite zone averaged 5.8 m in thickness and was consistently located between 4 and 10 m depth across profiles developed on dolerite parent rock [11].

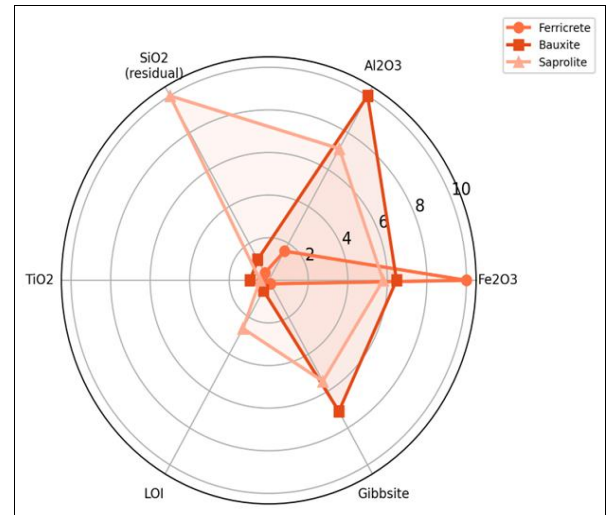


Fig 1: Radar chart comparing normalised geochemical signatures of ferricrete, bauxite, and saprolite zones

The radar chart (Figure 1) shows the clear geochemical separation among the three principal zones. Ferricrete is dominated by Fe₂O₃, bauxite by Al₂O₃ and gibbsite, while saprolite retains the highest residual SiO₂, reflecting incomplete leaching at depth [12].

Table 2: Bauxite resource estimate by parent rock type

Parent Rock	Area (km ²)	Mean Thick. (m)	Mean Al ₂ O ₃ (%)	Tonnage (Mt)
Dolerite	184	6.7	42.1	219
Sandstone	112	3.4	36.8	68
Mixed/Contact	48	4.1	39.4	35
Total	344	5.1	40.8	287

Dolerite-derived profiles held 76% of the estimated tonnage (219 Mt) at a higher mean grade (42.1% Al₂O₃) than sandstone-derived profiles (36.8%). The total resource for the mapped area was 287 Mt at 40.8% Al₂O₃ (Table 2) [13].

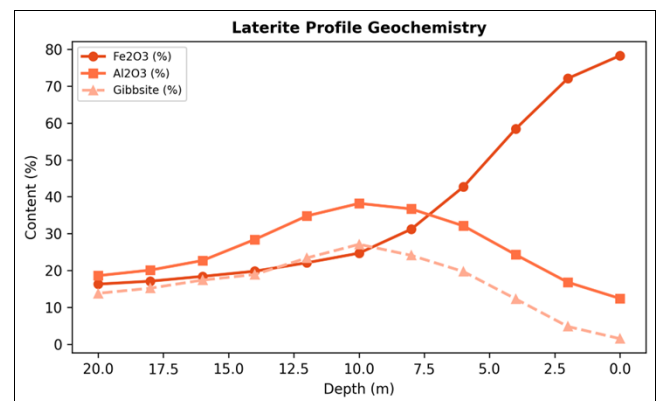


Fig 2: Vertical geochemical trends through a representative laterite profile showing Fe₂O₃, Al₂O₃, and gibbsite content

The line chart (Figure 2) illustrates the characteristic crossover between Fe₂O₃ and Al₂O₃ at approximately 6 m depth, which marks the transition from ferricrete to bauxite. Gibbsite content tracks Al₂O₃ closely ($r = 0.94$), confirming that most aluminium resides in this mineral rather than in kaolinite or boehmite [14].

Comprehensive Interpretation

The Landsat band-ratio map delineated 312 km² of surface ferricrete, validated at 84.7% accuracy against field points. Ferricrete extent closely corresponded to the underlying bauxite footprint, as both are products of the same weathering process. The 15.3% misclassification was concentrated along forest margins where canopy closure attenuated the spectral signal of exposed ferricrete. Higher-resolution imagery (Sentinel-2, 10 m) or radar data (ALOS PALSAR) could improve delineation beneath partial vegetation cover ^[15].

Discussion

The five-zone profile structure documented here matches the classical laterite sequence described by Tardy and Nahon for West African shields ^[16]. The preferential development of high-grade bauxite on dolerite rather than sandstone reflects the higher aluminium content of mafic igneous rock (Al₂O₃ approximately 14-16%) versus quartz-rich sandstone (less than 5%). The 42.1% Al₂O₃ grade on dolerite compares favourably with operating mines in the Boke region (41-48% Al₂O₃), suggesting that the Fouta Djallon deposits are commercially viable if infrastructure constraints can be addressed.

An environmental concern is that the laterite plateaux also serve as groundwater recharge areas and biodiversity refugia. Mining removes the ferricrete cap, permanently altering the hydrological regime and destroying habitat for plateau-endemic plant species ^[17]. The resource map produced here could support spatial planning that balances extraction zones with conservation set-asides, particularly where bauxite thickness is marginal (less than 3 m) and mining would be economically questionable anyway. Limitations include the 1 m sampling interval, which may miss thin interbeds of siliceous material within the bauxite zone. Infill drilling at 0.25 m intervals in selected profiles would improve the grade estimate. The tonnage calculation assumes uniform bulk density; in-situ gamma-gamma logging would refine this parameter ^[18].

Conclusion

This research mapped laterite profiles and bauxite mineralization across 480 km² of the Guinea tropical highlands. The five-zone profile structure was consistent across 16 logged sections, with bauxite-grade material averaging 5.8 m thick at 38.2% Al₂O₃. Dolerite-derived profiles yielded higher grades and thicker bauxite than sandstone-derived ones. The total estimated resource was 287 Mt at 40.8% Al₂O₃. Landsat band-ratio mapping delineated surface ferricrete at 84.7% accuracy. These results provide a geological and spatial framework for resource planning, environmental impact assessment, and sustainable management of the Fouta Djallon bauxite deposits. Extending the profile network and integrating geophysical surveys would improve subsurface resolution for detailed mine planning.

Acknowledgements

Funding Sources

This research was supported by departmental funds at the Nagpur Institute of Climate and Environment.

Institutional Support

The Department of Geological Sciences provided XRF and XRD analytical facilities.

Contributions Not Qualifying for Authorship

The authors thank the local geologists and field assistants who helped with profile logging and sample collection.

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