

Contrasting Genesis of Lateritic Bauxite on Granodioritic and Andesitic Rocks of Mempawah Area, West Kalimantan

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ABSTRACT

The lateritic bauxite deposits in the Mempawah area, West Kalimantan, were formed by the chemical weathering of Cretaceous granodioritic and andesitic rocks. They occurred locally on the low hills surrounded by swampy areas. Detailed surface geological mapping, test pits, mineralogical and geochemical analyses were performed to determine the characteristics and genesis of bauxite from different parent rocks. From bottom upward, the deposits are composed of fresh parent rocks, clay or pallid zone, bauxite zone with a few sparse ferricrete at the top of the bauxite zone, and soil. Bauxite derived from granodiorite exhibits brownish-red, massive, boulder to gravel-sized concretion in clay matrix and is composed of predominant gibbsite with subordinate kaolinite, quartz, goethite, and a minor amount of magnetite and hematite. In contrast, bauxite derived from andesitic rocks exhibits reddish-brown and is composed of predominant goethite. During the leaching process, SiO₂ as a mobile compound decreased significantly in neutral pH, while Al₂O₃ and Fe₂O₃ precipitated as residual materials to form bauxite concretion. The enrichment anomaly of bauxite derived from andesitic rocks is caused by physio-chemical changes from hydrothermal alteration. Bauxite was formed by indirect bauxitization through the leaching of primary minerals under a tropical-humid climate.

Keywords: Bauxite, Al₂O₃, gibbsite, leaching, physio-chemical

INTRODUCTION

Alumina, one of the demanding materials for industry, is used for beverage cans or alloy compounds for aircraft materials [1]. The increasing demand for alumina causes the increasing volume of bauxite production in the last decade. In 2018, global bauxite consumption reached 5.1 million tons, or approximately 30% higher than that in 2017 which made up 3.9 million tons [2].

Variation of mineralogy and lateritic bauxite characteristics has a strong relationship with the main factor, particularly for the textural and mineralogical composition of their parent rocks, according to Bardossy

and Aleva, 1990 within [3]. It suggests that the characteristics have been affected by the genetic occurrence of bauxite laterite. To optimize the mining operation and production, domaining should be performed accurately according to the specific bauxite characteristics.

REGIONAL GEOLOGY

The study area is located in the Mempawah area, West Kalimantan, which is known as one of the bauxite prospect locations in Indonesia. This area belongs to the bauxite belt of West Kalimantan [4] (Figure 1).

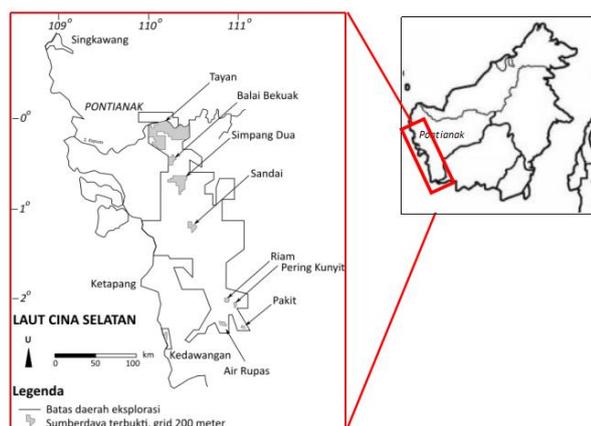


Figure 1. Bauxite lateritic belt in West Kalimantan [4].

According to the geological map of Singkawang sheet, West Kalimantan [5], the research area consists of three formations, i.e., Gunungapi Raya Rock Formation, Mensibau Granodiorite, and the youngest formation of Alluvial and Marsh Deposits. Gunungapi Raya Rock Formation comprises altered andesite, dacite, mixed-basal rocks of andesitic and dacitic pyroclasts which contain abundant chlorite, epidote, thin conglomerate intercalation, sandstone and Early Cretaceous mudrock. These rocks are partly metamorphosed by Cretaceous and Tertiary intrusion, hence altered to pyrite, chalcopyrite, molybdenite, arsenopyrite and sphalerite [6]. Mensibau Granodiorite Formation consists of early to late Cretaceous granodiorite, granite, quartz diorite, diorite, adamellite, and tonalite. Alluvial and marsh deposits comprise recent mud, sand, pebble and plant remnant deposits.

DATA AND METHOD

The research has been carried out using surface geological mapping and test pits. Samples used in this study include fresh parent rock, bauxite and clay samples. About 16 samples were analyzed using petrography and 12 samples for mineragraphy analyses. Two samples of bauxite were used to identify the mineralogy composition. Meanwhile, 2

samples of fresh rock, 2 clay samples and 28 bauxite samples were analyzed using XRF to observe the enrichment pattern of some major oxide, such as total SiO_2 , Al_2O_3 , and Fe_2O_3 . Bauxite samples were taken systematically from test pits, particularly 2 meters for each interval from the total thickness of bauxite.

RESULT AND DISCUSSION

Field Observation

Field observation has been conducted for some fresh outcrops and weathered rocks. Field study reveals 3 types of lithology, from older to young rock units consists of andesite, granodiorite and alluvium deposit in Figure 2.

Andesite exhibits greenish-grey, massive structure, holocrystalline, in equigranular, porphyritic-aphanitic texture and composed of plagioclase, hornblende and olivine. Andesite underwent hydrothermal alteration of propylitic, as evidenced by the presence of altered minerals, such as secondary quartz, chlorite, epidote, pyrite, chalcopyrite and sphalerite (Figure 3b).

Granodiorite exhibits light grey, massive, holocrystalline, equigranular and phaneritic texture. Microscopically, granodiorite is composed of plagioclase, quartz, hornblende, biotite and orthoclase with a crystal size of 0.1 to 2 mm (Figure 3a). Magnetite locally presents as inclusion within biotite, while plagioclase and orthoclase minerals are locally replaced by fine-sized sericite.

Alluvial deposits comprised of loose clayey to pebbly-sized clastic materials, produced by weathering processes of the older rocks. Meteoric water mainly contributes as the weathering agent and sediment transportation. The existence of alluvium deposits is characterized by lowland morphology, surrounded by hill topography.

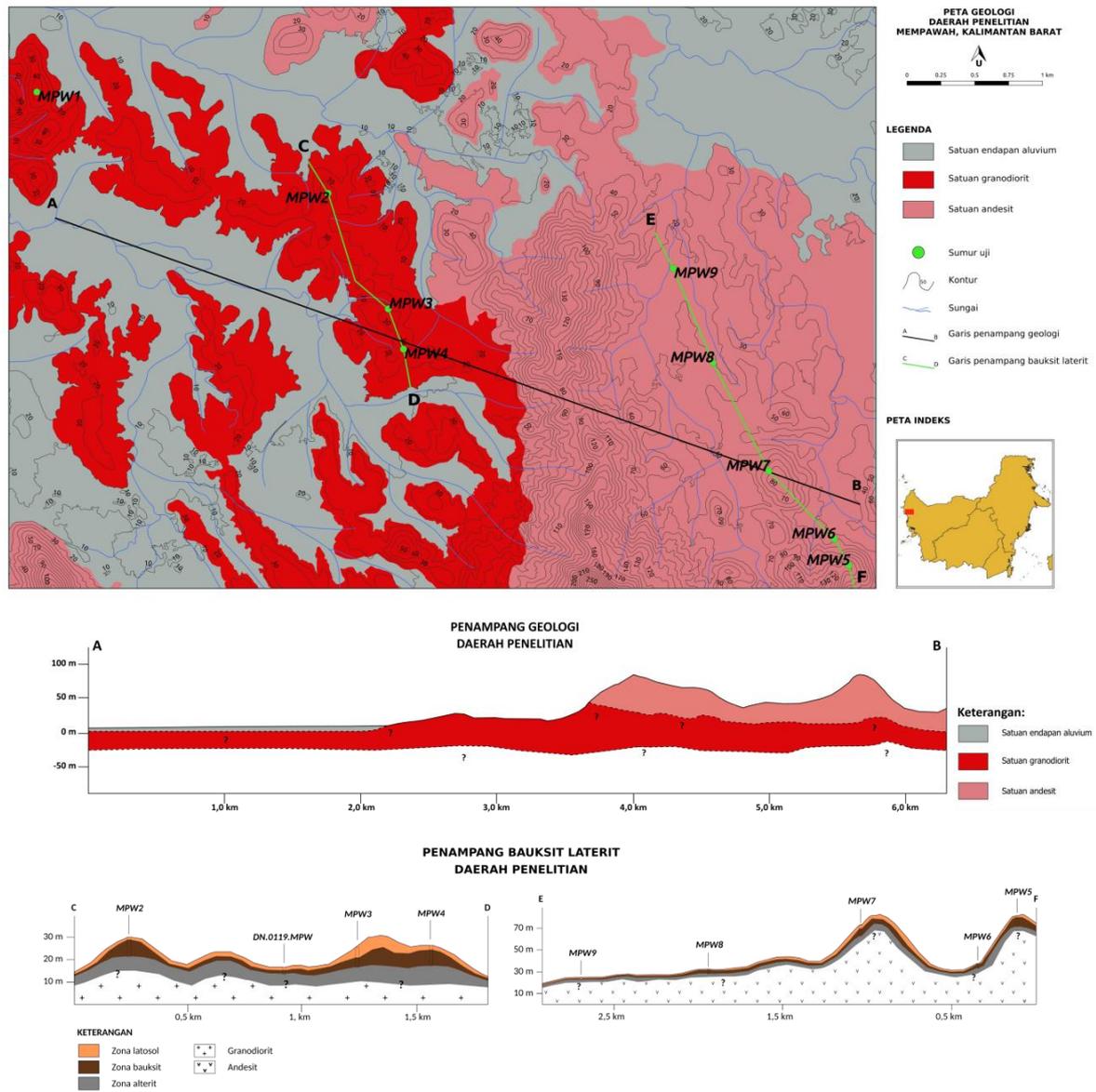


Figure 2. Geological map, geological cross-section and bauxite profile of the study area.

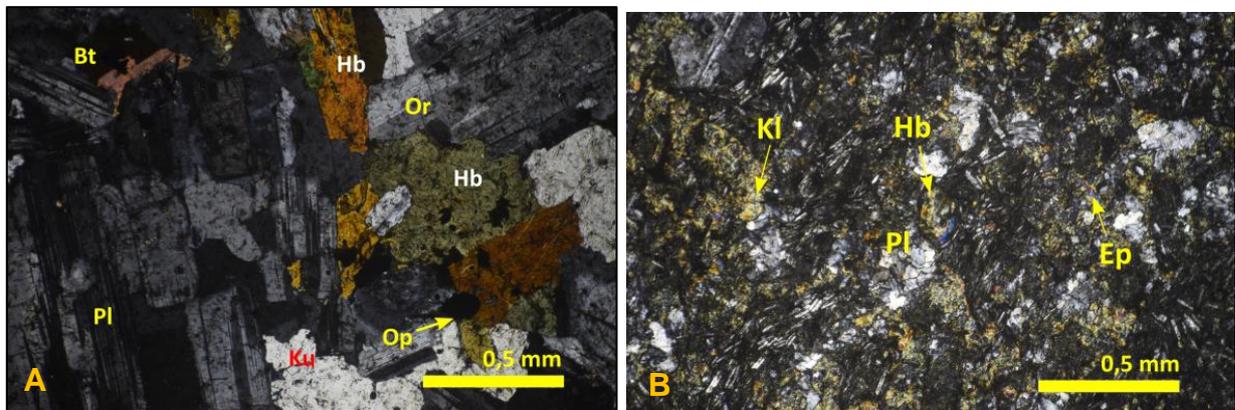


Figure 3. Microscopic images of some bauxite parent rock: a) Microscopic image of granodiorite with ubiquitous plagioclase (Pl), quartz (Ku), hornblende (Hb), biotite (Bt) and opaque minerals (Op); b) Epidote (Ep) and chlorite (K) replaced plagioclase and hornblende as the primary minerals of andesite.

Texture and Mineralogy Characteristics of Lateritic Bauxite

The observation of vertical bauxite profile was carried toward outcrops and test pits.

From this observation and laboratory analyses, there is 3 main horizon of clay or pallid, bauxite and latosol horizon respectively from the bottom to top (Figure 4 and 5).

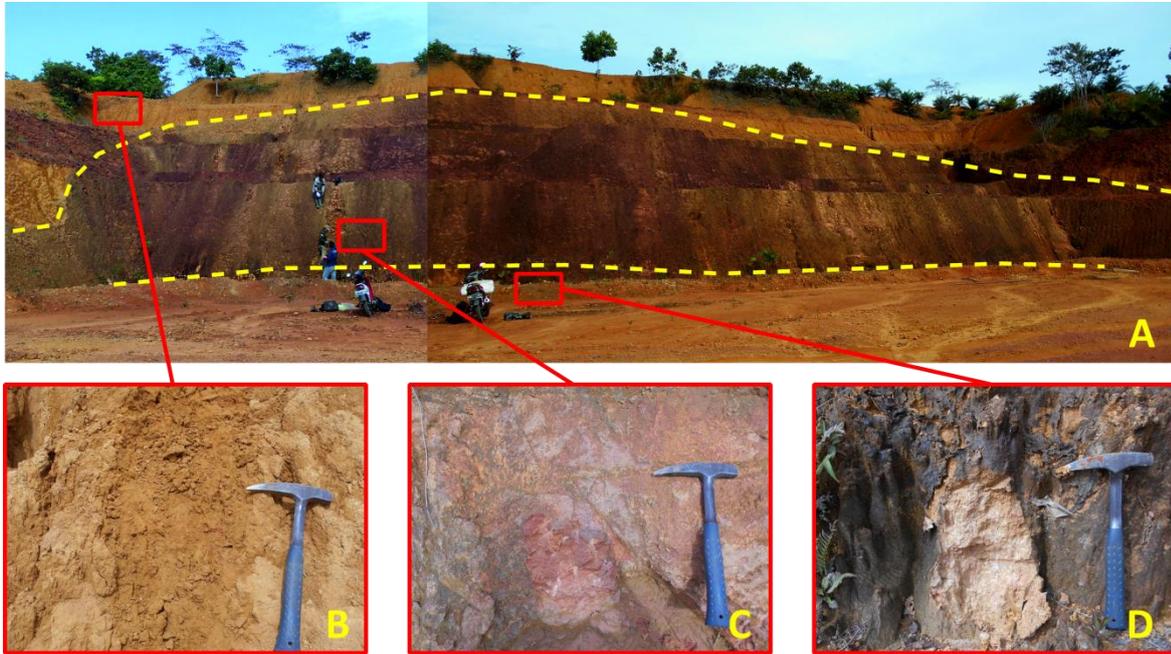


Figure 4: (a) The rock exposure depicts the vertical weathering profile of clay, bauxite and latosol horizon respectively from the bottom to top. The laterite derived from granodiorite parent rock; (b) Latosol exhibits brownish yellow; (c) Brownish red color of bauxite; and (d) relic texture of clay zone as indicated by white dots.



Figure 5: (a) Outcrop illustrates the vertical weathering profile of andesite parent rock consists of clay, bauxite and latosol horizon respectively from the bottom to top; (b) Latosol exhibits brown color; (c) Reddish-brown color of bauxite; (d) Boulder of andesite as the non-decomposed material within clay horizon.

Megascopic identification of clay horizon derived from granodiorite exhibits brownish white color, with relic texture and friable. Most of the feldspar was replaced by kaolinite (Figure 6a). Hornblende has been altered to goethite during the leaching process, while biotite was altered to interstratified vermiculite and kaolinite with additional rimming of goethite (Figure 6b). Magnetite was replaced by goethite and hematite.

Clay horizon derived from andesite has different characteristics as evidenced by greenish-brown color with common relic texture. The horizon was composed of goethite and kaolinite, in which goethite replaced the primary minerals of olivine, hornblende and epidote; whereas kaolinite replaced plagioclase and chlorite minerals (Figure 7A).

Trace of hydrothermal minerals of pyrite and kaolinite were respectively replaced by goethite and covellite (Figure 7b).

Bauxite horizon exhibits brownish-red to reddish-brown, sandy to boulder-sized concretions embedded within clay matrix without any relict texture. In general, bauxite has massive concretion. The clay matrix is composed of kaolinite, goethite, gibbsite, quartz, magnetite and hematite. Some features also display the alteration of pseudomorph plagioclase into kaolinite and subsequently replaced by gibbsite, particularly observed within bauxite samples derived from granodiorite (Figure 6c and 6d). Ferricrete presents as sealing of the upper bauxite horizon.

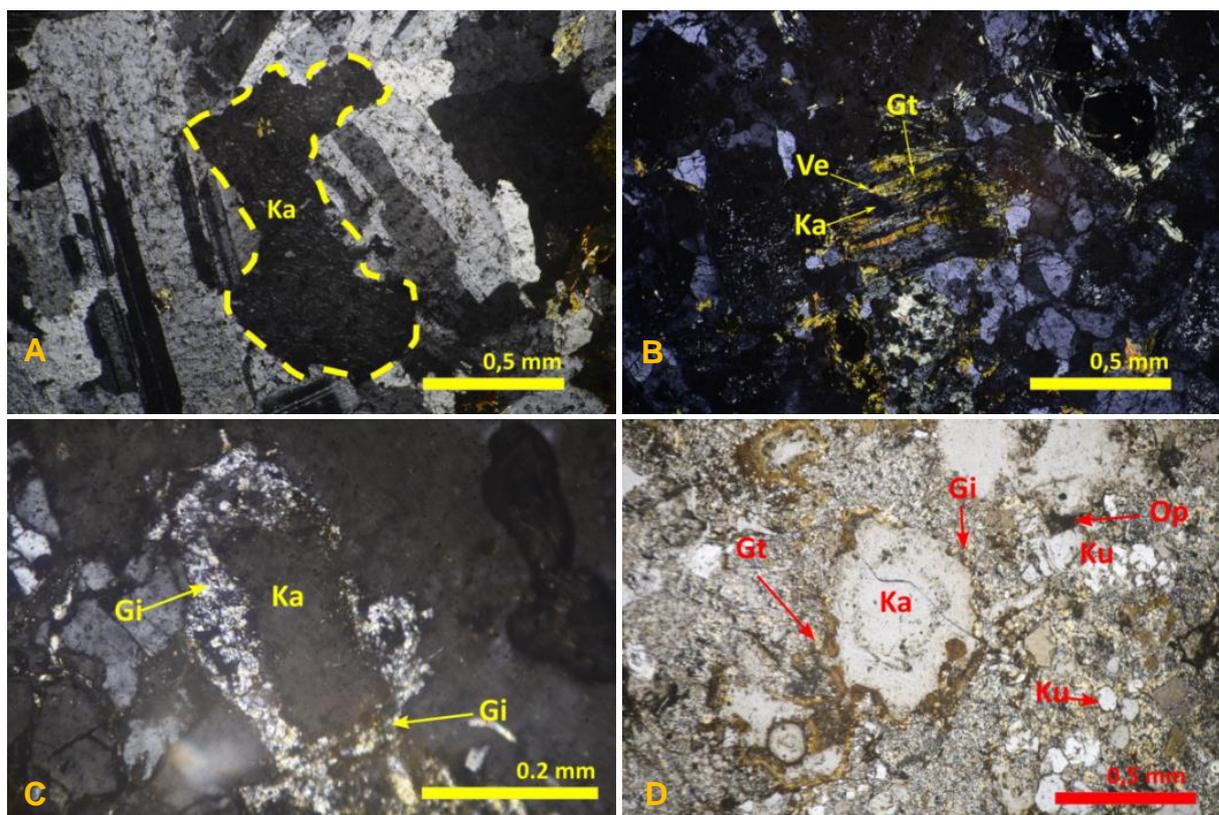


Figure 6. Microscopic image of clay and bauxite samples derived from the weathering of granodiorite. (a) Pseudomorph feldspar is replaced by kaolinite (Ka); (b) Biotite alters to interstratified vermiculite (Ve) and kaolinite with additional goethite (Gt); (c) Pseudomorph feldspar initially replaced by kaolinite but subsequently overprinted by gibbsite (Gi); (d) Quartz (Ku), opaque mineral (Op), and kaolinite with the rim of goethite and gibbsite.

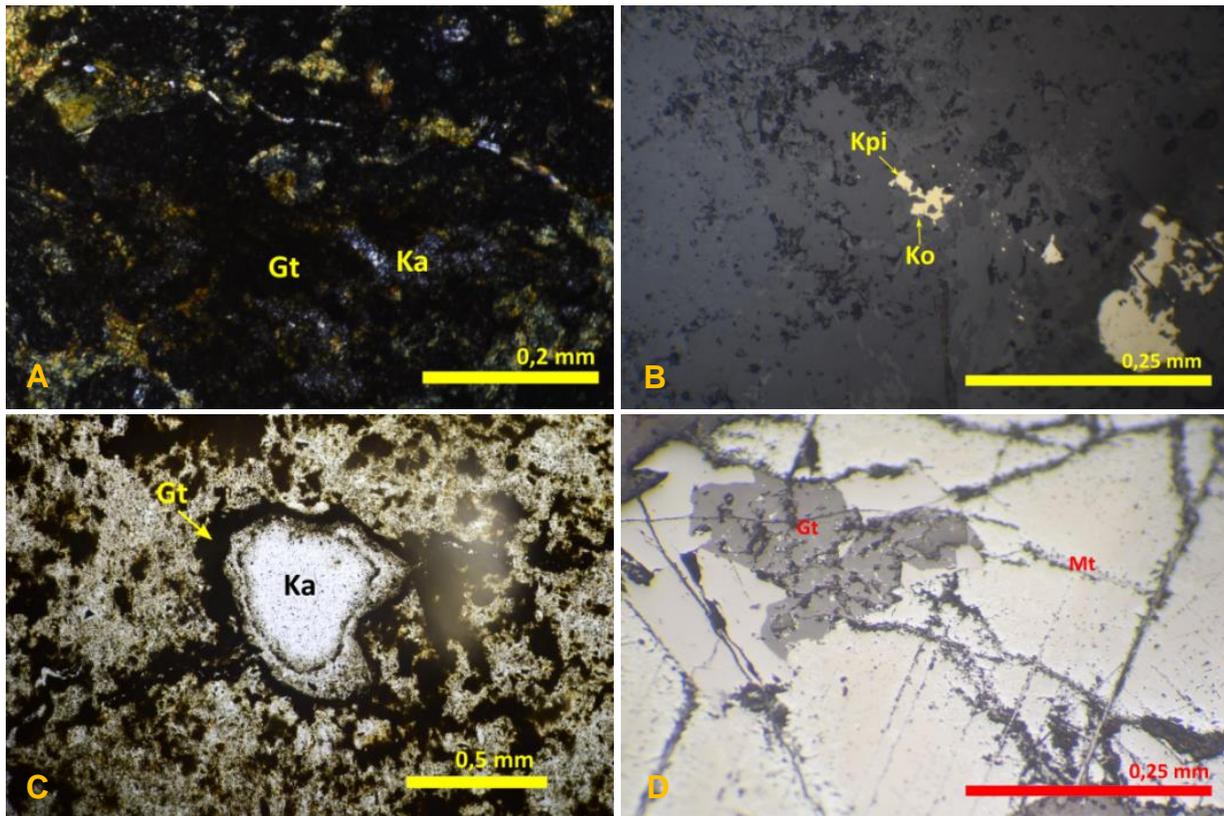


Figure 7. Photomicrograph depicts clay and bauxite composition under the polarized microscope. Sample derived from andesite parent rock; (a) Goethite (Gt) and kaolinite (Ka) as secondary minerals; (b) Covellite (Ko) replaced chalcopyrite (Kpi); (c) Cluster of kaolinite which is surrounded by goethite as replacement minerals; (D) Magnetite (Mt) is replaced by goethite.

Bauxite derived from andesite contains minor quartz with abundant goethite minerals (Figure 7c). This iron mineral was replaced the primary mineral of magnetite. The uppermost horizon of latosol (lateritic soil) exhibits brownish yellow to brown with common silty to clayey-size particles. No relic texture was observed on this horizon. In regards to the three horizons with distinct physical and mineralogical characteristics as described above, bauxite can be classified as the type of ortho-bauxite [7].

Geochemical Data of Bauxite Profile

Bauxite derived from granodiorite, contains SiO_2 which ranges from 28,849 – 54,255%, Al_2O_3 38,974 – 58,090%, and Fe_2O_3 6,504 – 19,041%, geochemical data reveals that bauxite samples underwent low to

moderate lateritization. Bauxite from andesite contains SiO_2 ranges from 2,518 – 31,237%, Al_2O_3 28,432 – 71,702%, and total Fe_2O_3 25,269 – 43,981%, it suggests that the bauxite experienced moderate to strong lateritization.

The plotted geochemical data to Schellman diagram [8] shows the enrichment pattern of Al_2O_3 and Fe_2O_3 increased subsequently to the top horizon; while SiO_2 decreased subsequently relative to parent rock. Bauxite derived from andesite has fair grade range from 28,432 – 71,702% for Al_2O_3 and 25,269 – 43,981% for Fe_2O_3 total. The grade of Fe_2O_3 from sample MPW5-B jump significantly as compared to other samples of MPW5. The value for SiO_2 from sample MPW7 has a lower grade than other test pit samples.

Genetic of Bauxite Laterite

The genetic occurrence of bauxite in the study area is divided into 2 stages, 1) clay-zone formation, 2) bauxite formation. Both were distinguished based on the presence of secondary minerals during the leaching process, and their major elements of SiO_2 , Al_2O_3 and Fe_2O_3 . The clay horizon is indicated by the existence of abundant secondary clay minerals as produced by the leaching process of host minerals. The surficial process has altered primary minerals to secondary minerals [9]; [10].

Secondary kaolinite mineral replaces plagioclase, orthoclase, sericite and chlorite. Goethite replaces hornblende, olivine, epidote and magnetite. Biotite is mainly replaced by interstratified vermiculite, kaolinite and goethite. Sulphide minerals have also experienced alteration during the formation of clay, as such pyrite has been replaced by goethite and chalcopyrite has been replaced by covellite as rim minerals.

Weathering and leaching processes due to perpetual groundwater circulation are possibly generating the bauxite laterite. In general, bauxite is composed of kaolinite, gibbsite, goethite, quartz, magnetite with lesser hematite. The weathering process has altered the primary texture, remained resistant and secondary minerals. Gibbsite is known as bauxite ore which presents as kaolinite replacement and fills the mineral cracks.

The subsequent alteration from the parent rocks to clay and bauxite zone indicates the characteristic of indirect bauxitization. The incomplete hydrolysis causes the dissolution of some mobile elements. Fe, Al and partial Si elements were accumulated locally as kaolinite and goethite. Kaolinite presents as a pseudomorph of the host mineral, while

goethite presents as infilling minerals within cracks [11].

Sample MPW5-B shows an elevated grade of Fe_2O_3 significantly than that from test pit MPW5. SiO_2 grade from test pit MPW7 has a low value. It is caused by the presence of hydrothermal alteration minerals and the changes of physio-chemical condition, including the groundwater pH and Eh as caused by the interaction of groundwater and sulphide minerals.

Hydrothermal alteration involves the circulation of hydrothermal fluid and leading to the physiochemical alteration of adjacent fractures. The interaction of hydrothermal fluid and rocks lead to the imbalance chemical condition during dissolution and precipitation of neomorphic minerals [12]. The transformation of texture, mineralogy and chemical composition of the host rock determines the weathering product.

Iron and aluminum elements have immobile characteristics during chemical weathering under tropical climate conditions. Both are easily dissolved under low pH condition ($\text{pH} < 4$) and oxidized ($\text{Eh} > 0.4$) [13]. Under this condition, dissolution of groundwater carries Al^{3+} and $\text{Al}(\text{OH})_4^-$ ions that prevent the precipitation of gibbsite. Low pH condition is produced by the interaction of oxygen, meteoric water, sulphide mineral (i.e. pyrite, arsenopyrite and chalcopyrite [14].

CONCLUSION

Bauxite laterite in the Mempawah area is classified to orthobauxite type, with the vertical profile consists of clay, bauxite and latosol horizon, respectively from bottom to top. Bauxite occurs during indirect bauxitization of humid tropical climates. In general, bauxite exhibits massive texture, with concretion embedded within clay matrix and

composed by assemblage minerals of kaolinite, goethite, gibbsite, quartz, magnetite and hematite. Bauxite derived from andesite exhibits reddish-brown, with predominant goethite and lesser quartz; meanwhile, bauxite derived from granodiorite exhibits brownish-red contains greater quartz and lesser goethite. The bauxite characteristics are reliant on the textural and mineralogical characteristics of the parent rock. Geochemically, bauxite from andesite has a greater grade range than that of bauxite derived from granodiorite. It is suspected that local hydrothermal alteration contributes to the diverse characteristics of neomorphic minerals.

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