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Genesis of Bauxite Ore in Toba Area Sanggau District, West Kalimantan Province

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Abstract

Indonesia's largest bauxite reserves are in the province of West Kalimantan, which is 703 million tons Bauxite is formed from rocks with a high relative aluminum (Al) content, low iron (Fe) content, and small amount of quartz. The mineralogy and characteristics of lateritic bauxite deposits are closely related to several factors, one of which is the texture and composition of the bedrock such as color, mineral composition, and shape of the ore. This study discusses the genetic type of bauxite deposits based on mineralogy and geochemistry using mineragraphic, XRD, and XRF methods. The primary data from bauxite ore samples were collected from the stockpile of PT. Dinamika Sejahtera located in Toba area. The quantitative result of the geochemical analysis indicates a higher amount of alumina observed using the XRF method. Granodiorite bauxite, which is bauxite coming from granodiorite bedrock, generally has abundant geochemical elements, especially SiO_2 and Al_2O_3. The lateritic bauxite type in the Toba area is a product of granodiorite weathering from the Sepauk Tonalite formation is embedded within a clay matrix which exhibits a brownish to red color with coarse to boulder-size of concretion texture without relict. Some important elements in bauxite laterite deposits are Al, Fe, Si (Silicon), and Ti (Titanium). The comparison between Al and Si values is a benchmark for the economics of bauxite mines. Gibbsite is the major mineral in the bauxite ore, while hematite, goethite, kaolinite, and quartz are the accessory minerals. The deposit is recognized as Low-Fe bauxite due to comparing Al_2O_3, Fe_2O_3, and Si_2O_3 concentrations. The weathering process has altered the primary texture, remaining resistant and secondary minerals. The petrographic analysis shows the replacement of Gibbsite as bauxite ore which presents as kaolinite replacement and fills the mineral cracks. The result of this study is expected to be useful in determining the exploration method for the bauxite deposits.

Keywords: Al_2O_3; Bauxite; Fe_2O_3; Gibbsite; Si_2O_3; XRF methods.

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Introduction

Laterite bauxite is a concretion layer rich in alumina and iron, reddish-brown in color due to contamination by iron oxide, porous, and found dominantly in tropical–subtropical areas (Toreno & Moe'tamar, 2012). To produce 1 ton of alumina, 2 to 3 tons of bauxite is required to extract alumina using a smelter to produce aluminum. Aluminum is most used in transportation, but it is also used in building and construction materials, machine tools, energy, packaging, durable goods, and other applications (Pusat Sumber Daya Mineral Batubara dan Panasbumi, 2022).

Indonesia has the sixth largest bauxite reserve in the world with approximately 1,200 million tons spread across the Riau

Islands, Bangka and Belitung, West Kalimantan, and a small portion is found in Central Kalimantan and Banten (Haryadi., 2016). In 2021, indicated resources and probable reserves dominated the bauxite resources and reserves. West Kalimantan has the highest bauxite resources in Indonesia, around 2.07 billion tons or 57.32% of all bauxite resources in Indonesia, with bauxite reserves total 0.84 billion tons, or 66.77% of total national mineral reserves. To increase the resilience of reserves, exploring new areas is required to increase the inferred resources, detailed exploration is also needed to improve the measured resources (Pusat Sumber Daya Mineral Batubara dan Panas bumi, 2022). Accordingly, the demand for bauxite ore has also increased and is estimated to reach 18,616,342 tons during 2020-2025 (Anggrahini et al., 2020).

Indonesia's largest bauxite reserves are in the province of West Kalimantan, which is 703 million tons (Haryadi., 2016). West Kalimantan is supported by felsic to intermediate bedrock (such as Sienite, Quartz Diorite, Granodiorite, and Nefelin). The characteristics of West Kalimantan, with the rainfall rate, tropical climate, and the mechanism of the weathering process so that lateritization processes occur in the formation of deposits and the characteristics of the resulting bauxite (Ramadhan et al., 2014).

Bauxite is formed from rocks with a relatively higher Aluminum (Al) and low iron (Fe) content with small amount of quartz (Jafar, 2017). The various mineralogy and characteristics of lateritic bauxite deposits are closely related to several factors, including the texture and composition of the bedrock. This study discusses the genetic type of bauxite deposits based on mineralogy and geochemistry using mineragraphic, XRD and XRF methods. Mineragraphic and XRD methods are used to determine the mineral content of bauxite ore, while the XRF method determines the elemental composition of bauxite deposits. It is versatile and able to evaluate up to eighty elements at different sensitivities, detecting concentrations ranging from 100% to a few parts per million (Winarno et al., 2023a). The percentage of minerals and elements in bauxite will determine the genetic type of bauxite deposits in the study area which will guide in selecting the appropriate exploration method. The research location was carried out in West Kalimantan because it is the largest bauxite producer in Indonesia.

Geological Setting

Regional stratigraphy

Based on regional conditions, the research area located in Sanggau Regency is included in the regional geological map of the Pontianak/ Nangataman sheet (Figure 1), where the research area is only composed of Tonalite Sepauk and Alluvial which was mapped by Sanyoto & Pieters (1993). While regionally, this area consists of various rock formations from old to young described by Sanyoto & Pieters (1993):

1. Pinoh metamorphic rocks

This formation consists of slate, hornstone, phyllite, quartzite, schist, amphibolite, gneiss, and migmatite (Sanyoto & Pieters, 1993), which also acts as the source rock for uranium mineralization in West Kalimantan (Tjokrokardono et al., 2004). These rocks are estimated to be Carboniferous to Triassic in age and are intruded by the Sepauk Tonalite of Lower Cretaceous to Upper Cretaceous age.

2. Sepauk Tonalite

Sepauk tonalite is widely distributed in the Pontianak/ Nangataman sheet, the formation is the bedrock and dominates the rocks in the study area. This formation is of Lower Cretaceous to Upper Cretaceous age and consists of granodiorite and biotite-hornblende tonalite, quartz diorite, slightly diorite, and monzogranite (Sanyoto and Pieters, 1993), which intrude into the Pinoh metamorphic rock so that the metamorphic rock seems to be floating above the tonalite complex. The tonalite complex is medium to coarse-grained, homogeneous in texture, and with a quartz content of around 15-30%, while feldspar is around 40-50% (Tjokrokardono et al., 2004).

3. Laur Granite

This formation is aligned with the Sepauk Tonalite, which is Lower Cretaceous to Upper Cretaceous in age, composed of monzogranite biotite-hornblende rocks, a little biotite syenogranite and granodiorite hornblende-biotite (Sanyoto & Pieters, 1993).

4. Gabro Biwa

Gabro Biwa is estimated to be of Upper Cretaceous age and is not aligned with the Sepauk Tonalite and Laur Granite. This formation consists of gabbro, composed of hornblende-clinopyroxene minerals, sometimes with biotite, hypersthene, and olivine, and a little hornblende diorite with or without clinopyroxene. Some gabbro shows a layered texture (Sanyoto & Pieters, 1993).

5. Tebidah Formation

This formation is Lower Oligocene in age (Sanyoto and Pieters, 1993), composed of alternating wake lithos and green and red mudstones, a bit of siltstone withlternating layered sandstones and mudstones (Tjokrokardono et al., 2004).

6. Alluvium deposits, beaches, lakes, swamps, and terraces

This deposit consists of mud, sand, gravel, and plant residues of Quaternary age and covers the Sepauk Tonalite Formation unconformably (Sanyoto and Pieters, 1993).

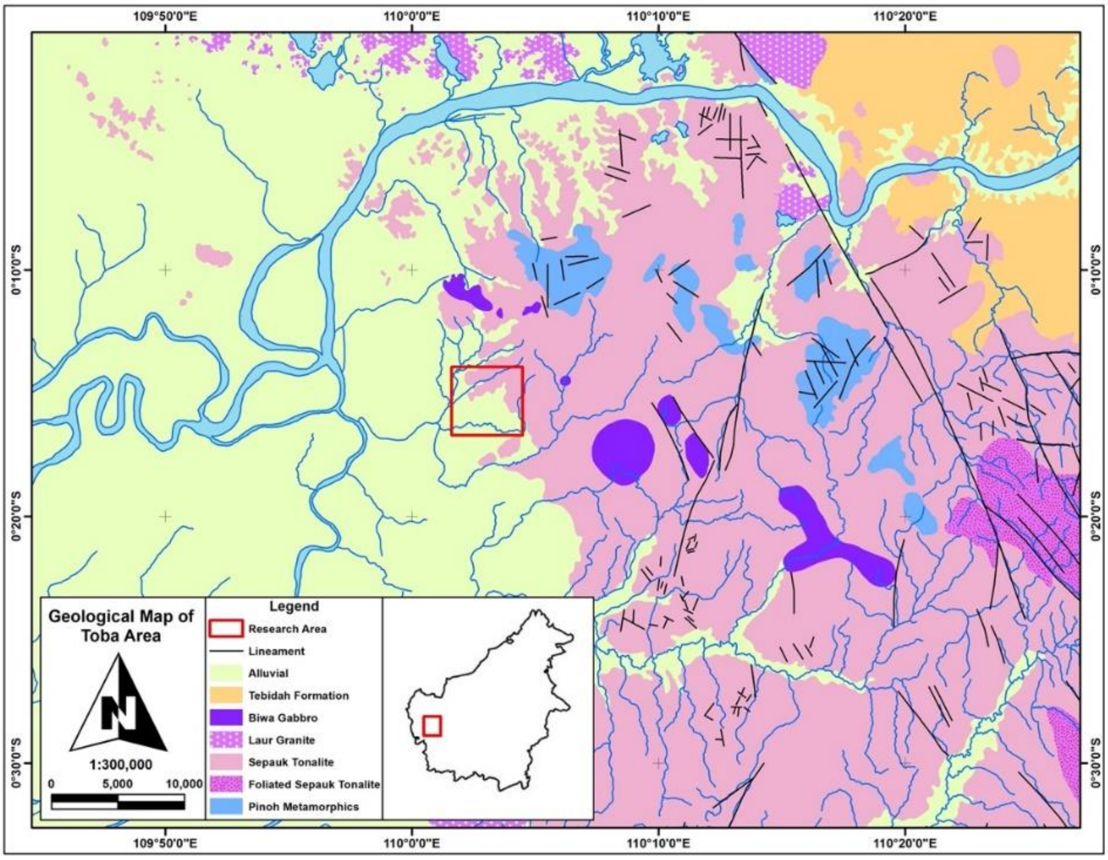

Figure 1. Geological map of research area in Pontianak/ Nangataman sheet after Sanyoto and Pieters (1993).

Bauxite deposits

Bauxite in Indonesia is produced by the supergene enrichment of the Cretaceous peralkaline and alkaline igneous rocks (Nugraheni et al., 2021). According to Economou-Eliopoulos & Kanellopoulos (2022), the most preferred global bauxitization period is the Cretaceous to Eocene. The lithology in the researched area consists of granodiorite, quartz diorite, biotite-hornblende granite, and tonalite. In comparison, the bauxite around the researched area in Tayan District, Sanggau Regency, West Kalimantan, is found in diorite, quartz monzodiorite, quartz diorite, and microdiorite pyroxene (Nugraheni et al., 2022). A previous study by Ramadhan et al. (2014) in the Kenco area, Landak Regency, West Kalimantan, showed that laterite bauxite in the area derived from weathering of Al-rich igneous rock including granodiorite, quartz diorite, and diorite.

Topography, Rainfall and Weathering

The topographical condition of Sanggau Regency is located at an altitude of 0 – 400 meters above sea level with flat landscapes to undulating hills with maximum daily rainfall for the last 10 years, which is from 2011 - 2020 of 1,231 mm/day (Gazhian et al., 2022), with slopes ranging from 0 - >21% (Purwanto & Paiman, 2014). Such topographical conditions will affect the process of rock weathering (Wakila et al., 2019). Rocks on steep slopes tend to be easily weathered compared to rocks on sloping places (Hasria et al., 2021) because rocks will be very easily eroded or weathered because they will directly meet the weather around them (Boinauw, 2017; Wang et al., 2023).

Materials and Methods

This study uses primary data from a sample unit of bauxite ore weighing 20 kg taken from the stockpile of PT. Dinamika Sejahtera located in Toba area. The 1 kg sample was then sent to the Hasanuddin University mineral geochemistry laboratory to prepare polish sections and manufacture bulk powders for petrographic analysis, X-ray Diffraction (XRD), and X-ray Fluorescence (XRF) analysis. Petrographic analysis used a Nikon polarizing microscope instrument Model: Eclipse Ci-L (Ci-L BF-BP), which aims to identify rock-forming minerals, secondary minerals, and the relationship between minerals or rock textures. Meanwhile, minerals that are very fine in size or glass-shaped minerals that cannot be identified by petrographic analysis are carried out using the XRD Shimadzu Model: XRD-7000L instrument. The Shimadzu XRF instrument Model: EDX720 was used to analyze the main chemical elements.

Results and Discussion

Results

1. Texture

The texture of the concretion megascopically is in the form of a hard-rounded material and is rich in aluminum hydroxide. According to Delvigne (1998), cement components in the form of iron oxide minerals and aluminum hydroxide minerals are possessed by the texture of concrete in thin sections. The source rock of bauxite in the study area comes from the granodiorite of Sepauk Tonalite. The megascopic appearance of the granodiorite bauxite sample is embedded within a clay matrix which exhibits a brownish to red color with coarse to boulder-size of concretion texture without relict (Figure 2).

Microscopically, the clay matrix is composed of kaolinite, goethite, gibbsite, and quartz. Silica in the bauxite predominantly appears in the form of kaolinite and quartz, while the other impurity minerals present as goethite and hematite. The appearance of a thin section shows the main role of the hematite as the cement, which occurs in very high amounts in the sample, and the quartz mineral with a coarse crystal size. The texture of granodiorite bauxite has predominantly aluminum oxide, while quartz and iron oxide minerals are abundant. The iron oxide minerals are well-distributed in the sample when observed under the microscope in the thin section sample because the iron oxide minerals are the cement in the concretion texture. The iron oxide and quartz minerals show that the mobile minerals' dissolution stage in forming bauxite has not taken place effectively. A small amount of aluminum hydroxide indicates that water circulation in forming bauxite is not dominant.

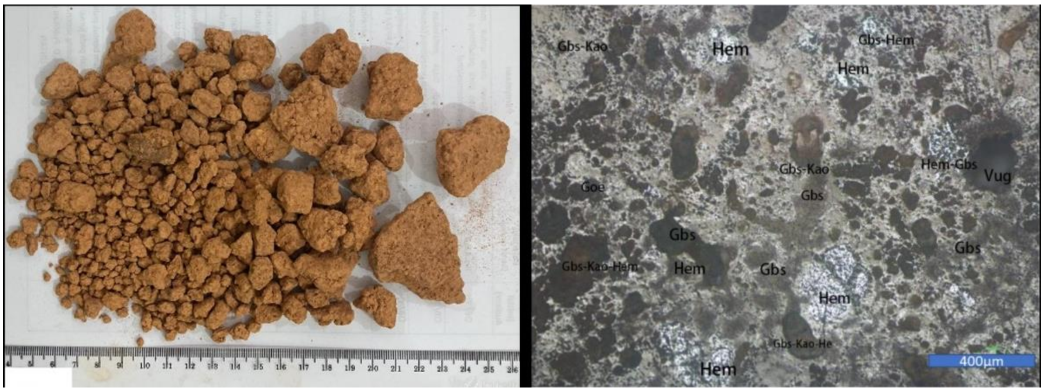

Figure 2. (left) Megascopic appearance of concretion texture of bauxite sample. (right) Petrographic appearance of concretion texture in PPL (Plain Polarized Light).

2. Mineralogy

The granodiorite bauxite contains common minerals such as halloysite, illite, kaolinite, boehmite, diaspore, gibbsite, goethite, hematite, and quartz (Wulansari et al., 2016). Al is the most widely distributed metal in the environment, occurring naturally in the trivalent state (Al^{+3}) as silicates, oxides, and hydroxides, but may combine with other elements such as chlorine, sulfur, fluorine, and form complexes with organic matter (Igbokwe et al., 2019). The petrographic analysis of bauxite ore reveals that mineral content consists of gibbsite ($Al(OH)_3$) which is very dominant, kaolinite ($Al_2Si_2O_5(OH)_4$), hematite (Fe_2O_3), and goethite ($FeO(OH)$). Gibbsite is more common in a humid tropical climate, and boehmite is more common in a tropical climate with a long dry season. In addition, dehydrated minerals appear more often in the dry, upper parts of the profiles than in the lower, wetter parts close to the groundwater level. It is also well known that sedimentary bauxite deposits contain more gibbsite when they are porous and young but more boehmite and diaspore when they are old and compacted (Bárdossy, 1982). Gibbsite in the ore sample is present in granular subrounded nodules measuring 50-200µm, whereas some grains indicate the alteration of gibbsite from kaolinite (Dyussenova et al., 2022). Some grains show the exolution texture together with hematite measuring 10µm in granular shape, while the others are present in the matrix along with kaolinite and partially hematite. In the matrix, there are also traces of gibbsite which have been altered from kaolinite (Figure 3).

The kaolinite mostly occurs in a matrix and fills the space among grains where the kaolinite alteration by gibbsite is very clear under the microscope. Iron oxide minerals are dominated by hematite which presents as isolated minerals in sub-angular to sub-rounded shapes measuring 50-200 µm. Some are in the form of microcrystalline assemblages of fine-grained, rounded shapes altering the minerals that were formed before. It is also present in the matrix along with gibbsite and kaolinite. Generally, laterite bauxite from granodiorite bedrock still contains 10 to

30% quartz, there are also iron oxides (FeOx) such as goethite, hematite, and other clay minerals (Winarno et al., 2023b). The other iron oxide mineral is goethite in irregular texture and smooth acicular shapes around 10-50µm in size. Goethite resembles gibbsite and is associated with the gibbsite, particularly in the form of grains. Further, the XRD analysis shows the mineralogy of the bauxite sample composition quantitatively, including gibbsite (70,4 wt%), dickite (23,8 wt%), hematite (5,8 wt%), and other minerals (3,9 wt%).

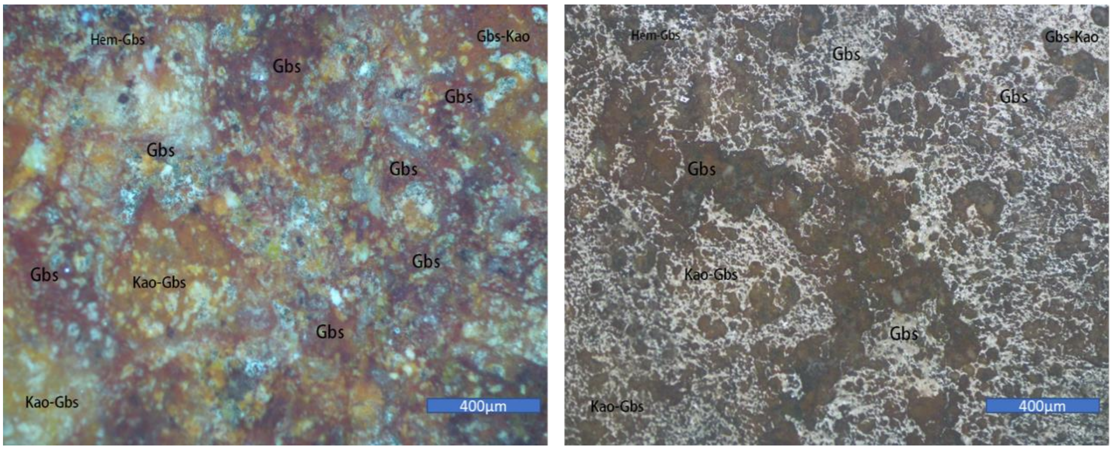

Figure 3. The petrographic appearance of the bauxite ore sample depicted the kaolinite alteration by gibbsite and hematite in XPL (Crossed Polarized Light) and PPL (Plain Polarized Light).

3. Geochemistry

The quantitative result of the geochemical analysis indicates a higher amount of alumina observed using the XRF method. Granodiorite bauxite generally has abundant geochemical elements, especially SiO_2 and Al_2O_3 (Wulansari et al., 2016). The abundance is influenced by the intermediate igneous bedrock, which is rich in Al_2O_3 and SiO_2 found in the lateritic bauxite as gibbsite and quartz respectively (Figure 4).

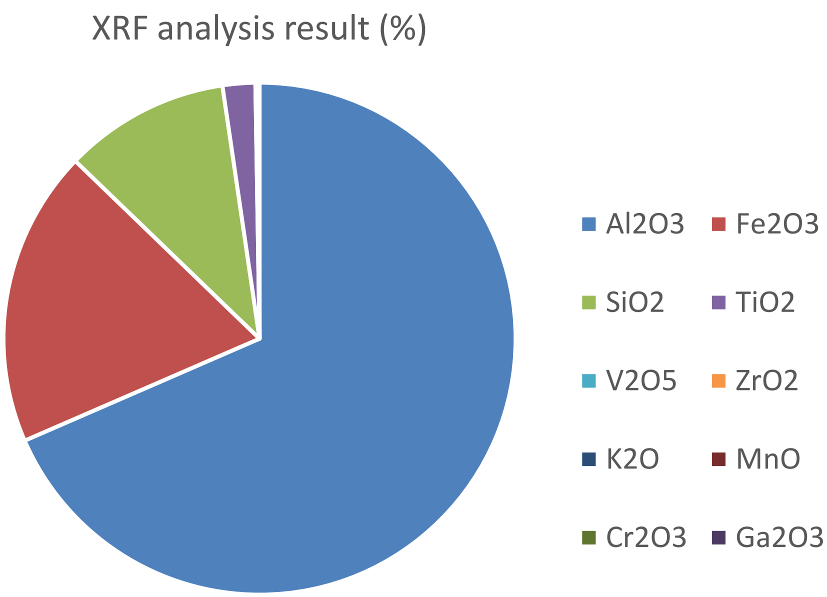

Figure 4. Mineral occurrence in the lateritic bauxite ore sample from XRF analysis.

Similar with Wulansari et al. (2016), the amount of aluminum oxide is relatively higher around 68.478%. Below the aluminum oxide, iron oxide, and silica oxide measuring 18,736 % and 10,467 % respectively. Lastly, titanium oxide is counted at around 2,061 % while V_2O_5, ZrO_2, K_2O, MnO, Cr_2O_3, and Ga_2O_3 are very low amounts, less than 1 %.

Discussion

Some important elements in bauxite laterite deposits are Al, Fe, Si, and Ti. The comparison between Al and Si values is a benchmark for the economics of bauxite mines. According to Ramadhan et al. (2014), the formation of lateritic bauxite deposits is controlled by several interrelated and influencing factors, but these factors can also change in forming deposits, such factors as Al-rich bedrock as the source, subtropical areas with relatively higher rainfall, Daily temperature above 200C, Undulating topography, old age river, and the formation above the permanent groundwater table. The compound elements considered are single-element enrichment bonds that react to water media and precipitate new compounds, in bauxite mining, these compounds are Aluminum trihydrate (Al_2O_3), Iron trihydrate (Fe_2O_3), Silicate oxide (SiO_2), Titanium oxide (TiO_2) and Total silicates (R-SiO_2). Studying the mineral composition of various genetic and lithological types has allowed us to solve one of the most important problems of forming the main rock-forming minerals of bauxite—gibbsite and boehmite—and trace their spatial and genetic relationships (Mamedov et al., 2022). Many believe that boehmite is formed due to the dehydration of gibbsite under the influence of elevated temperature due to the pressure of overlapping strata and the igneous intrusions, as well as metamorphisms (Bárdossy, 1982).

The ore sample from the lateritic bauxite deposit formed by the weathering of Sepauk tonalite as a bedrock contains a rich amount of aluminum hydroxide identified as gibbsite, while the dominant iron oxide was found as hematite. The weathering process has altered the primary texture, remained resistant and secondary minerals. The petrographic analysis shows the replacement of Gibbsite is known as bauxite ore which presents as kaolinite replacement and fills the mineral cracks (Mildan et al., 2021). The enrichment of the gibbsite indicates the significant influence of meteoric water circulation during chemical weathering. Al_2O_3 (68,478 wt.%) and Fe_2O_3 (18,736 wt.%) are the main oxides of the bauxite ore sample from the lateritic bauxite deposit while scarce contents of SiO_2 and TiO_2 occurred around 10,467 wt% and 2,061 wt% respectively. The other major elemental oxides (V_2O_5, ZrO_2, K_2O, MnO, Cr_2O_3, and Ga_2O_3) have concentrations that are systematically below 1 wt.%.

According to the bauxite classification of Bárdossy (1982), the bauxite deposit mainly consists of a Low-Fe bauxite, as suggested by the sample distribution in the Al_2O_3–SiO_2–Fe_2O_3 ternary diagram shown in Figure 5.

Binary plots among the major elemental oxides (Figure 6) indicate that, in the ore bauxite sample there is a positive correlation exists between Al_2O_3 and TiO_2, and between Al_2O_3 and Fe_2O_3, whereas negative correlations exist between Al_2O_3 and SiO_2 and Al_2O_3 and CaO. These correlations are typical of strongly weathered deposits where immobile elements accumulate and mobile elements are leached out (Putzolu et al., 2018). This is also confirmed by the low contents of alkali and alkali earth elements, which are highly mobile during chemical weathering (Gu et al., 2013; Zamaniana et al., 2016).

The intensive development of laterite in the wet tropics causes the formation of laterite soils. Generally, the lateritization process in bauxite comprises several stages: dissolving, transporting, and re-depositing of minerals. The most important factors in dissolution are pH, solubility, and mineral stability. Factors affecting minerals' transport and re-deposition are climate, topography, morphology, and mobility of elements. Weathering results will be transported by groundwater or rainwater, then precipitated again. The process occurs well on a sloping land surface with a certain slope, morphological, and topographical conditions that tend to be undulating.

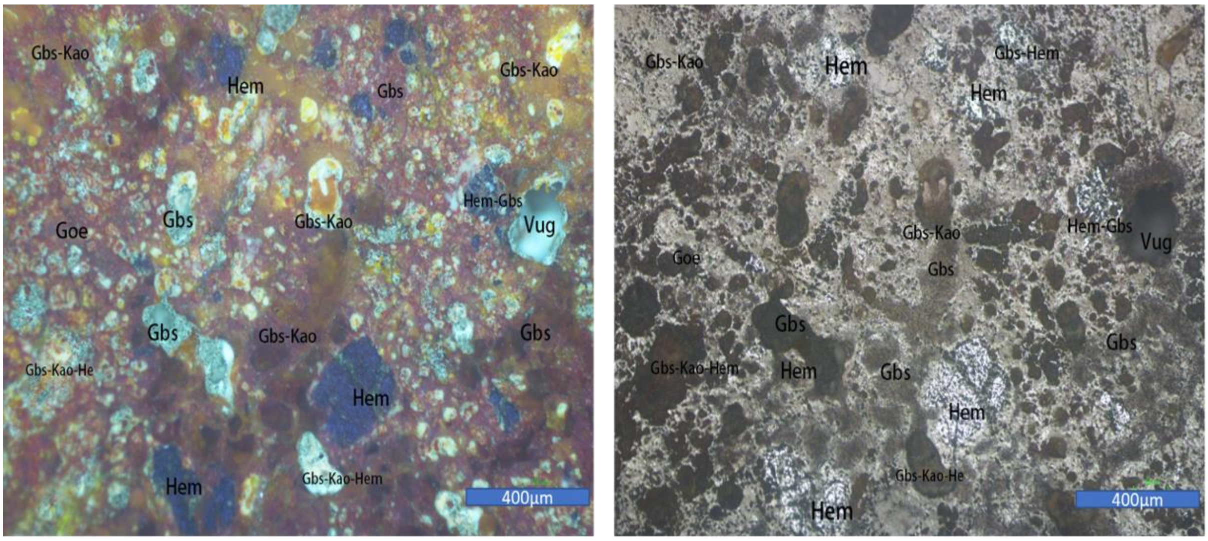

Figure 5. The petrographic appearance of the bauxite ore sample depicted occurrence of gibbsite as major mineral while hematite, goethite, and kaolinite are the accessory minerals in in XPL (Crossed Polarized Light) and PPL (Plain Polarized Light).

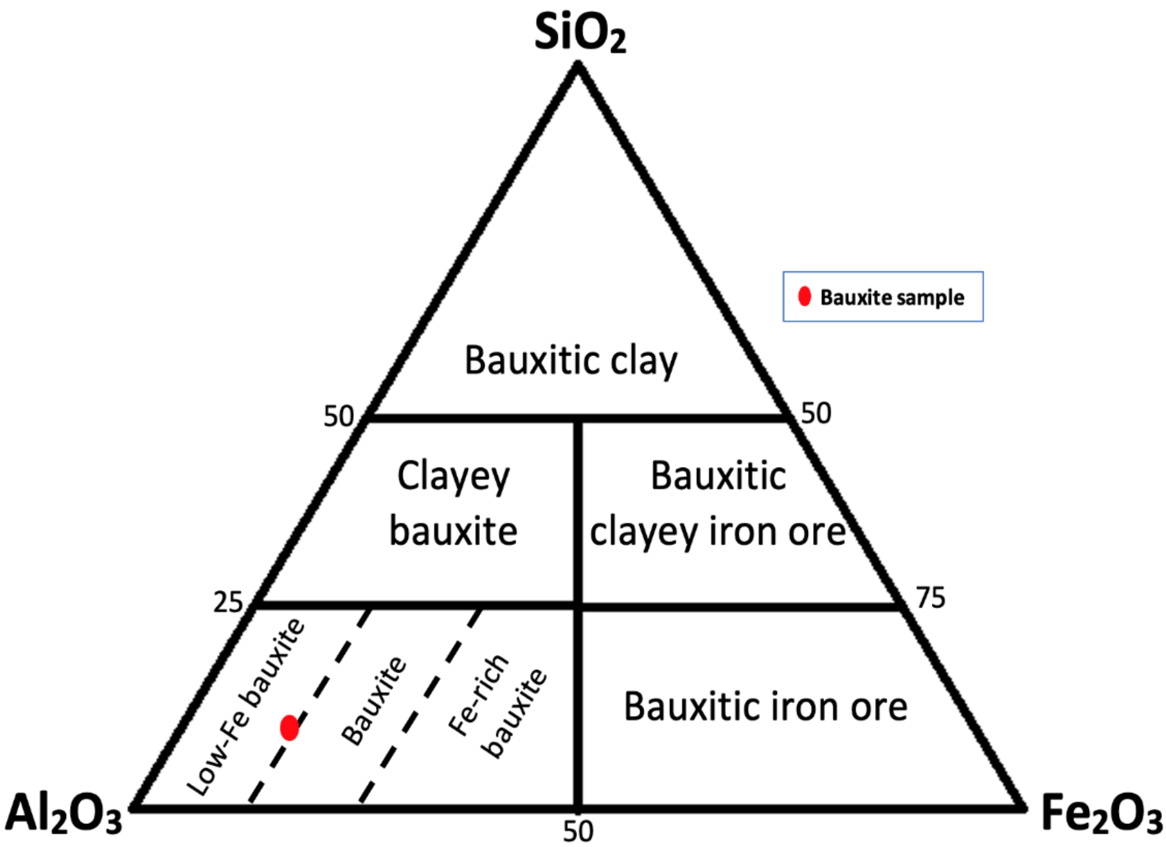

Figure 6. Al_2O_3–SiO_2–Fe_2O_3 classification diagram (modified from Bárdossy (1982), for the display of bauxite ore sample.

Conclusion

The conclusion of this study is the lateritic bauxite type in Toba area is a product of granodiorite weathering from Sepauk Tonalite formation. Gibbsite is the major mineral in the bauxite ore, while hematite, goethite, kaolinite and quartz are the accessory minerals. The deposit is recognized as Low-Fe bauxite due to comparing Al_2O_3, Fe_2O_3, and Si_2O_3 concentrations.

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Author Contribution

This paper was completed thanks to the collaboration of all authors. The idea on this topic was first proposed by Ibnu Munzir and he also analyzed the results and made maps. Field surveys and sampling was done by Ricka Aprillia. Wahdaniah Mukhtar determines the method and analizes the problem. Septami Setiawati collected references and Govira Asbanu helped arranged the background and some editing. Hopefully this kind of collaboration will continue.

Conflict of Interest

This research was conducted independently without any financial support from any parties.

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