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TEXTURAL AND MINERALOGICAL STUDY OF LAVA FROM MOUNT GAMALAMA, NORTH MALUKU, INDONESIA

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ABSTRACT

Petrographic analysis using a polarizing microscope was carried out to determine the texture and minerals of Mount Gamalama's lava in North Maluku, Indonesia. Microscopic observations were made on seventeen representative samples. The results of these observations indicate that in general the lava is classified as an extrusive rock in the form of basalt. The mineral composition of the lava consists of phenocryst plagioclase and pyroxene set in the groundmass of needles and plagioclase microlites, pyroxene, opaque minerals and volcanic glass. Sericite mineral and iron oxide occur as secondary minerals. The general textures of the rock are micro aphanitic porphyry, inequigranular, and vesicular, while the special textures found are hyalopilitic, glomeroporphyritic, oscillatory zoning, and sieve.

Keywords: texture, mineralogy, lava, gamalama, North Maluku.

INTRODUCTION

Indonesia has active volcanoes that spread from the Sumatra Island to the Halmahera Island. The volcanic ranges are located along the volcanic arc formed from interaction of three main plates of the Eurasian plate in the west, India-Autralia in the south and the Pacific plate in the east (Macpherson and Hall, 1999; Hall and Wilson, 2000; Hall, 2008; Maulana *et al.*, 2016). In the eastern part of Indonesia there is a collision complex resulting from the confluence of the Sangihe arc pushing eastward and the Halmahera arc pushing westward. The intersection of these arcs forms a symmetrical impact area such as an inverted "U" (McCaffrey *et al.*, 1980; Hall and Wilson, 2000). The sharpening of the Halmahera arc to the west under the Maluku Sea resulted in the formation of a series of volcanoes on the island. The active volcanoes formed include Mount Gamalama, Mount Dukono, Mount Ibu, Mount Gamkonara, and Mount Kie Besi (Hakim and Hall, 1991; Van Gorsel, 2018). Mount Gamalama's magmatic eruption occurred in 1538 in its main crater. The next eruption occurred in 1907, which was a side eruption that released lava on the east to the Kulaba coast. Thefrozen lava isknownas Batu Angus (Pratomo *et al.*, 2011).

The wide stretch of Batu Angus rocks is often used by the local residents as a non-metal commodity for things such as building materials and road constructions. Previous researchers (Yanny *et al.*, 2020) reported that, in general, the Batu Angus rocks have chemical compositions of SiO_2 (61.91%), Fe_2O_3 (13.57%), CaO (10.73%), Al_2O_3 (10.73%), K_2O (1.19 %) and MnO (0.32%) with tetragonal, cubic, hexagonal, orthorhombic and trigonal mineral geometries. However, research on the texture and mineralogy of the rock has not been done in detail. Information on the various textures and mineralogy of the rocks can provide understanding on geological characteristics as well as potential industrial values. This research is focused on the lava Batu Angus of Mount Gamalama with a petrographic method approach which aims to obtain information on the texture and mineralogy of the igneous rocks in this area. In addition, this study will also provide information on the physical characteristics of Batu Angus rocks, which will be very useful in evaluating its utilization, especially in the field of industrial minerals.

REGIONAL GEOLOGY

Halmahera Island is located in the southwest of the Philippine plate and included as an active arc-arc collision along the western part of the Halmahera to the Maluku (Hall, 1987; Katili, 1991). The collision of the active arcs resulted in a subduction process that constructs the formation of several islands such as the islands of Ternate, Tidore, Moti, Mare and Makian. Ternate Island as the body of Mount Gamalama is still active today.

The geomorphology of the Ternate Island is conical in shape dominated by the formation originating from volcanic processes (Ikqra *et al.*, 2012). Mount Gamalama is generally divided into three volcanic geomorphological units, namely the foot, the body and the peak of Mount Gamalama (Pratomo *et al.*, 2011). The foot of Mount Gamalama has a gentle slope to almost flat morphology, extending along the coast in the eastern, northern and southern foothills of Mount Gamalama. This morphology is formed from the process of erosion and deposition of the volcanic rocks. The morphology of the body of Mount Gamalama has a slope of 8% -40%, consists of two calderas, namely Tolire and Laguna lakes. The existence of the two caldera indicates that there are other craters in addition to the crater at the top. The formation of the two calderas occurred due to a side eruption resulting in a structure that leans relatively towards the northwest - southeast intersecting Mount Gamalama. The alignment pattern of the structure is a source of shallow anomalies which indicate that tectonic activities in the area are closely related to the activities of Mount Gamalama. The alignment of the structure with direction N 15ºE is parallel to the islands in the western part of Halmahera which include the islands of Ternate,

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Tidore and Hiri (Pratomo *et al.*, 2011). The constituting rocks in this morphology are volcanic breccias, tuffs and sand. The peak of Mount Gamalama has an elevation above 1000 m with a depth of more than 40% (Bronto *et al.*, 1982).

Based on its generation, the island of Ternate (Mount Gamalama) was composed of three generations of rocks. First, Gamalama Tua (Old), in which its remains can be found in the south and southeast area with a peak called Bukit Melayu. Second, Gamalama Dewasa (Mature), located in the western part with a peak called Buli Keramat. Third, Gamalama Muda (Young), found in the north of the island of Ternate with a peak, the center of eruptions, called Arafat Hill or Piek Van Ternate (Bronto *et al.*,1982).

ANALYTICAL METHOD

A. Sampling Method

The research area is located on the east side of Mount Gamalama where the Batu Angus rocks are spread. This location is at long 127º21'30"-127º22'40" E and lat 0º49'45"- 0º51'00" N. Seventeen samples were taken from ten stations (Figure-1). Samples BA.01, BA.02, BA.04, BA.05, and BA.06 are sourced form massive structured outcrops with scoria on their surface (Figure-2A and 2C). The BA.03 station is located in Kulaba beach in which sampling was carried out on the lava outcrop of Mount Gamalamain the lower part and laharic breccia at the top of the lava (Figure-2B). In this location, fractures are found cutting the massive texture of Mount Gamalama lava. At stations BA.07 (Figure-2D) the samples were taken from the massive Gamalama lava flow deposition, which is light gray in color without any scoria on the surface. Samples BA.08 and BA.09 are sourced from massive basalt lava outcrops and reddish surface parts (Figure-2E). At stations BA.10 there is also a massive lava outcrop (Figure-2F). In this sampling location, it is evident that community mining activities are invested toward building materials. The sampling conducted in the field was carried out randomly on relatively fresh rocks. The samples were then prepared and analyzed using a polarizing microscope to determine their texture and mineralogy.

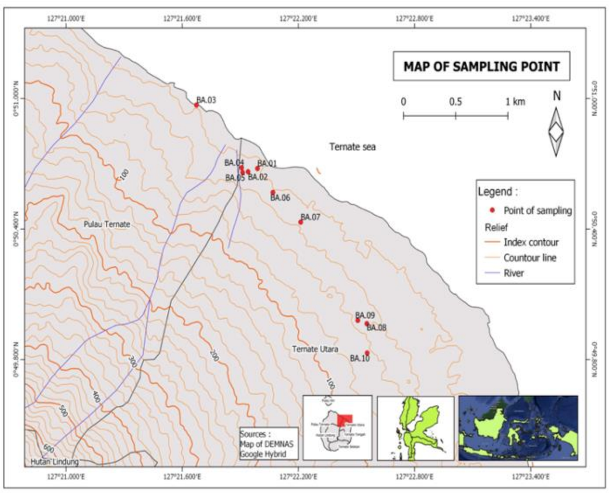

Figure-1. Topographic Map location of research.

Figure-2. A, The BA.01 station showing basalt rock outcrops with scoria structure; B, Basalt lava outcrop (BA.03) on Kulaba shoreline showing massive structure with intersecting fractures and overlain by laharic breccia deposits at the top; C, The BA.05 station on the side of a road showing block of lava; D, massive basalt lava outcrop at station BA.07; E, The BA.08 station showing massive basalt lava outcrops and a reddish surface due to oxidation near Sultan Babullah airport; F, massive basalt lava outcrop that has been used as building material located in Tabam Village.

B. Laboratorium Analysis

Petrographic preparation and analysis were carried out in the Preparation Laboratory, Geology Department, Hasanuddin University. The fresh parts of the samples were first cut to allow clear observation of

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minerals under the microscope. The samples were cut using a chainsaw to form chips. The chips were dried on a hot plate with a temperature of90ºC. The surfaces of the chips were then given epoxy glue or Canadian balsam and were left so that the glue would seep into the pores of the rock and before attaching onto a prep glass. The chips were heated again at 120ºC to dry. The remaining parts of the chips were then cut to a thickness of about 3 mm. The chips that had been attached onto the glass were thinned using a Prepa-Lap grinding machine and rubbed with carborundum powder 100, 400, 1200 and 3000. After reaching a thickness of about 0.03 mm the samples were labeled. The samples were analyzed for texture and mineral composition by parallel and cross-polarization using a Trinocular Polarization Microscope package model LV100POL + DS-Ri1 – U3 + NIS BR.

RESULTS AND DISCUSSIONS

Petrographic analysis of the Mount Gamalama lava sample on parallel nicol observations shows a pale brown color with dirty brownish and black spots. From these microscopic observations, subhedral to anhedral crystals can be seen reaching up to 2.8 mm in size. The minerals identified in the lava of Mount Gamalama are plagioclase (Pl) and pyroxene (Prx) which are present as phenocrysts as shown in Figure-3A and 3B. These phenocrysts are embedded in the groundmass which consists of plagioclase (Pl), mafic mineral pyroxene (Pr), mineral ore (Opq) and volcanic glass (Gls) as shown in Figure-3C. Additional minerals were found in the form of xenoliths and altered minerals. In the lava, several vesicles with uneven distribution, smooth in size and empty cavities are also found. In general, the entire Gamalama lava sample is classified as basalt based on the Streckeisen (1979) classification.

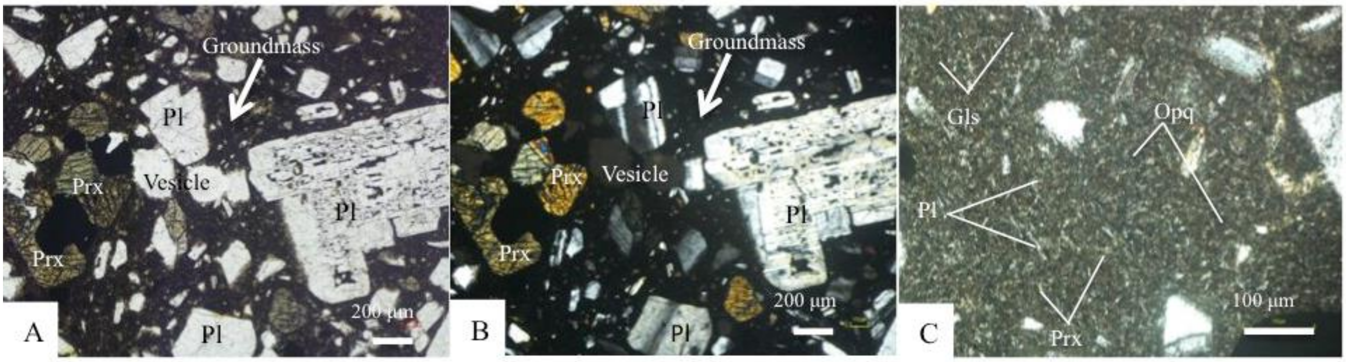

Figure-3. A, Microphotograph of Mount Gamalama lava appearance composed of plagioclase (Pl), Pyroxene (Prx), groundmass and there is also vesicle (parallel Nicols); B, Microphotograph of Mount Gamalama lava appearance composed of plagioclase (Pl), Pyroxene (Prx) and groundmass (crossed Nicols); C, The groundmass composed of needles and plagioclase microlites (Pl), pyroxene (Prx), opaque (Opq) and glass (Gls); crossed Nicols.

A. Primary Minerals

The primary mineral that make up the lava rock of Mount Gamalama are plagioclase (Pl) and pyroxene (Prx) in the groundmass. Plagioclase (Pl) is found as the dominant mineral at around 25-40%, clear in appearance, subhedral - anhedral, up to 2.8 mm in size, showing Carlsbad-albite and polysynthetic twin as shown in Figure-4A. This phenomenon, according to Mollo and Hammer (2017), reflects the formation of the composition of each plagioclase when certain equilibrium occurs during the placement and rise of the magma. Plagioclase is of the labradorite type with a little andesine (An_{46} - An_{58}) based on the diagram presented by Kerr (1977). This plagioclase mineral is still relatively fresh although in some parts found to have hollow corrosions. Several samples show that plagioclase minerals were found to intergrowth with pyroxene as shown in Figure-4A. Another major mineral found is pyroxene (Prx) occur as phenocryst with an abundance of about 10-20%. This mineral has clear brownish color, prismatic crystal form with a balanced amount of ortho pyroxene and clino pyroxene, subhedral - anhedral shape and size up to 2.1 mm. Slight cracks and sometimes clumping with plagioclase that forms a glomeroporfiritic texture. This texture formation proves the existence of the simultaneous formation of two crystal types (Suhada and Hastuti, 2019). Pyroxene mineral is generally still fresh but some have transformed partly into iron oxide minerals (Figure-4B) on the edges and parts of the crystal. Xenolith of dioritic to gabroic rocks was also unevenly found (2 %) with a size of up to 2.60 mm. The presence of plagioclase and pyroxene as the mainminerals in basalt rock have also previously been reportedby Ipranta and Irzon (2019) around the location of West Halmahera.

The groundmass is composed of plagioclase feldspar (Pl) microlites (16-20%) which are generally still fresh and smooth (<0.1 mm). It is mixed with mafic pyroxene (5-8%) and opaque minerals (3-5%) which have been slightly oxidized. Volcanic glass (15-24%) with no internal structure is also found with clear to brownish cloudy appearance in the groundmass in between the plagioclase and pyroxene crystal space and showing a slightly altered condition. Meanwhile the pore content (porosity) of this rock is 2-5%.

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B. Secondary Minerals

The secondary minerals found are sericite (4 %) and opaque minerals generally iron oxide (1 %). The presence of sericite minerals in the Mount Gamalama lava indicates a weathering process (Odat, 2014). This sericite mineral appears to replace plagioclase and the groundmass (Figure-4B). Yellowish to reddish-brown iron oxide minerals are found locally replacing pyroxene.

C. Texture

In general, the lava rock of Mount Gamalama has micro aphanitic porphyry, inequigranular, and vesicular textures. Aphanitic porphyry micro-textures are formed due to differences in grain size of the minerals that make up the rock attributed to the presence of plagioclase and pyroxene phenocrysts and a very small groundmass. According to MacKenzie *et al.* (1982) the presence of this texture indicates different degrees of crystallinity. The different degrees of crystallinity of phenocryst minerals and the groundmass of Mount Gamalama lava occur because of different freezing speeds or the degree of magma cooling. The mineral crystallization first formed the plagioclase and pyroxene. Pyroxene and plagioclase minerals have almost the same temperature and magma composition and thus can form simultaneously in the early stages of magma crystallization. The crystallization process of plagioclase and pyroxene to form Mount Gamalama lava occurs slowly, producing large euhedral-anhedral crystals as phenocrysts. The remaining liquid magma was injected out and frose rapidly to form thegroundmass of the Mount Gamalamalava. The two-stage formation results in non-uniform or inequigranular mineral forms (Mills, 2015). When lava reaches the surface, it may still contain gas. Due to the difference in temperature in the freezing process, the trapped gas would eventually leave a trail of holes.

The presence of plagioclase minerals that cluster together with pyroxene minerals formed a glomeroporphyritic texture as show in Figure-4C probably occurred in two ways. First, the nucleation of crystals that are close looking to be fused together. Second, collisions between minerals and eventually merging due to turbulence in the magma (Vernon, 2004). This texture common find in calc-alkaline volcanic (Vernon, 2010).

The groundmass faintly forms a hyalopilytic flow structure as show in Figure-4D, indicating that the type of lava forming the Mount Gamalama Angus Rock is the lava flows. Meanwhile, the oscillatory zoning texture of plagioclase minerals as show in Figure-4E indicates significant change in temperature during magma crystallization, kinetic occurrence due tomagma mixing and crust contamination (Streck, 2008; Suhada and Hastuti, 2019). The zoning pattern is a characteristic stage of crystallization which imply that the core is more calcic than the outermost part and each layer growth shows a resorption period (Vernon, 2010; Maulana *et al.*, 2019). According Vernon (2010), a partly euhedral and indented crystal pattern is forming due to collision between adjacent grains during growth. Another special texture found in the lava of Mount Gamalama is the sieve texture depicted as show in Figure-4F. The formation of sieve textures according to Nelson (1992) and Renjith (2014) is influenced by the diffusion of magma mixing in the crystals, causing decompression and changes in crystal composition.

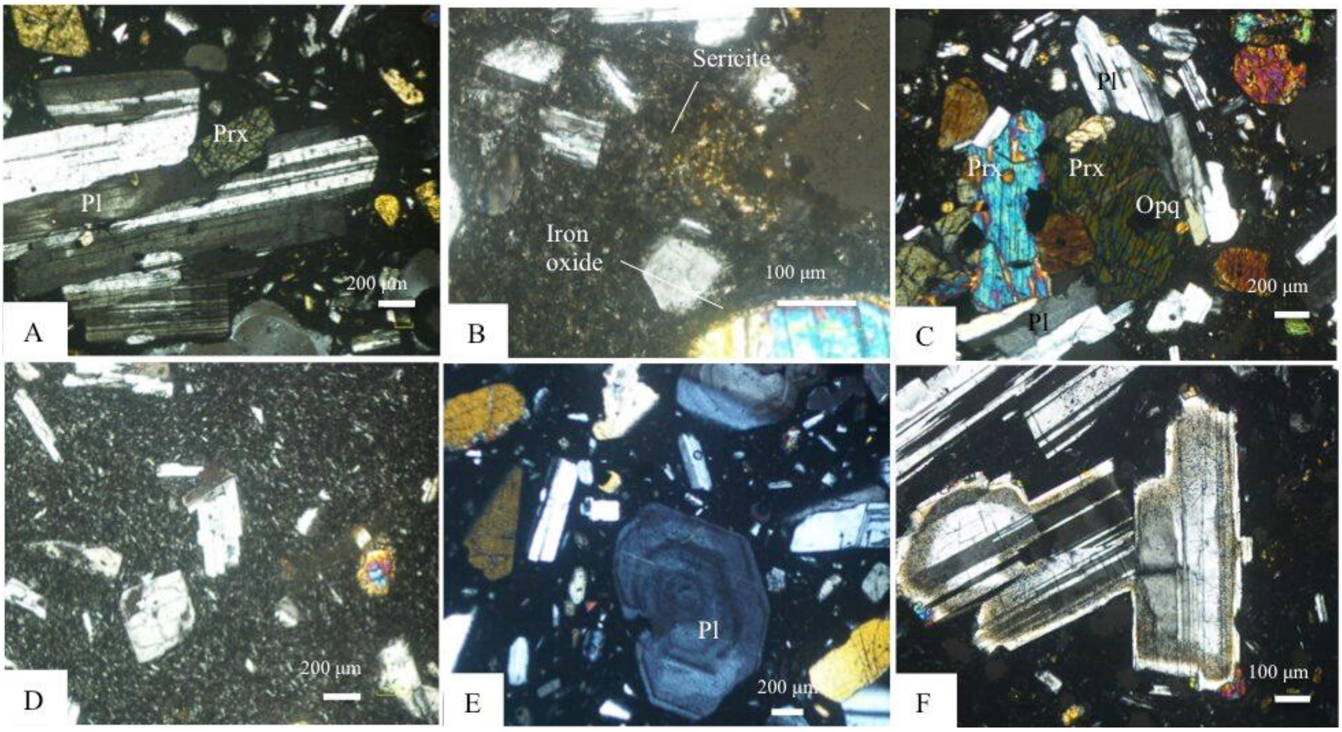

Figure-4. Microphotograph of basalt lava under cross-polarized Nicol microscope. A, Pyroxene (Prx) growing together with plagioclase (Pl) which showing carlsbad-albite and polysynthetic twins; B, Iron oxide minerals transformed from pyroxene and magnetit; C, plagioclase (Pl) and pyroxene (Prx) forming a glomeroporphyritic texture D, groundmass that faintly forms a hyalopilytic texture; E, plagioclase phenocryst showing oscillatory zoning texture; F, sieve texture on plagioclase.

CONCLUSIONS

Petographical analysis shows that the lava that makes up the Mount Gamalama Batu Angus rocks is basalt. Petrographic features include microaphanitic porphyry, inequigranular, and vesicular. The primary minerals that make up the Mount Gamalama Batu Angus rocks are plagioclase and pyroxene in the groundmass. The groundmass consists of plagioclase microlites, mafic pyroxene minerals, opaque minerals (iron oxide), and volcanic glass. The main textures are micro aphanitic porphyry, inequigranular, and vesicular, while other special textures include hyalopilytic, glomeroporphyritic, oscillatory zoning and sieve. These textures prove that the Batu Angus lava rocks were formed from the mixing of magma which came out onto the surface through the process of lava flows.

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