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Mineralogy of Granites from Hukurila Area, Ambon Island, Indonesia: An Insight into Petrogenesis

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Abstract

The Hukurila area in the Leitimor region of Ambon Island hosts one of the granite bodies. The granite is surrounded by Jurassic-Cretaceous peridotites. Although granites in Ambon Island have been intensively investigated, their origin remains interesting to study. This work offers petrography and X-ray diffraction data of granite from Hukurila area and contributes to understanding petrogenesis in Ambon Island. Granites from Hukurila area are white to light brown and have a medium- to coarse-grained holocrystalline texture, with quartz, potassium feldspars, plagioclase, biotite, and muscovite being the most common minerals. Potassium feldspars are sometimes found in aggregated larger crystals in the outcrops. While cordierite, zircon, apatite, and mullite were also observed as accessory minerals under the microscope. Mullite in granites from Hukurila area indicates that the rocks were subjected to high temperatures. Aluminium-rich minerals (i.e., cordierite and mullite) in granites from Hukurila area suggest S-type granite with significant crustal contamination during their formation.

1. Introduction

Geographically, Ambon Island is located in the eastern part of the Indonesian archipelago (Figure 1). This island hosts several granite bodies that cropped out particularly in the Leitimor region (i.e., Hukurila, Seri, and Soya) and Leihitu region (i.e., Allang) (Figure 2). However, the large granite body in the Leitimor area, also known as Latimor granite in Pownall et al. (2013), was unmapped on the Regional Geological Map of Ambon Sheet, Maluku, by Tjokrosapoetro et al. (1993). Granite bodies are also found in the western part (i.e., Kaibobo Peninsula) and the central part (i.e., Kobipoto Mountain) of Seram Island (Linthout and Helmers, 1994; Linthout et al., 1996; Pownall et al., 2013, 2014; 2017b).

Granite in Ambon and Seram Islands has been regionally studied to understand their genesis during the tectonic evolution of Banda Arc in the Cenozoic age (e.g., Linthout and Helmers, 1994; Honthaas et al., 1999; Pownall et al., 2013, 2017a; Titawael, 2019). Those granites are field-related to Jurassic-Cretaceous ultra-mafic rocks and formed through an assimilation process due to plate subduction or anatexis processes due to the obduction or exhumation of mantle materials due to the rollback of Banda embayment (Linthout and Helmers, 1994; Honthaas et al., 1999; Pownall et al., 2013; Titawael, 2019; Figures 2-3). On the other hand, the occurrences of granite in Ambon Island as observed in several areas (i.e., Allang, Seri, Soya, and Hukurila) (Figures 2 and 3), show their slightly different characteristics (Figure 2). The previous studies regionally discussed the Ambon granite without focusing on its locality (Linthout and Helmers, 1994; Honthaas et al., 1999; Pownall et al., 2013). This study focused on the mineralogy of granites from Hukurila area of Leitimor region, Ambon Island, using petrography and X-ray diffraction analyses, allowing a further understanding of petrogenesis of granite exposed in Ambon Island.

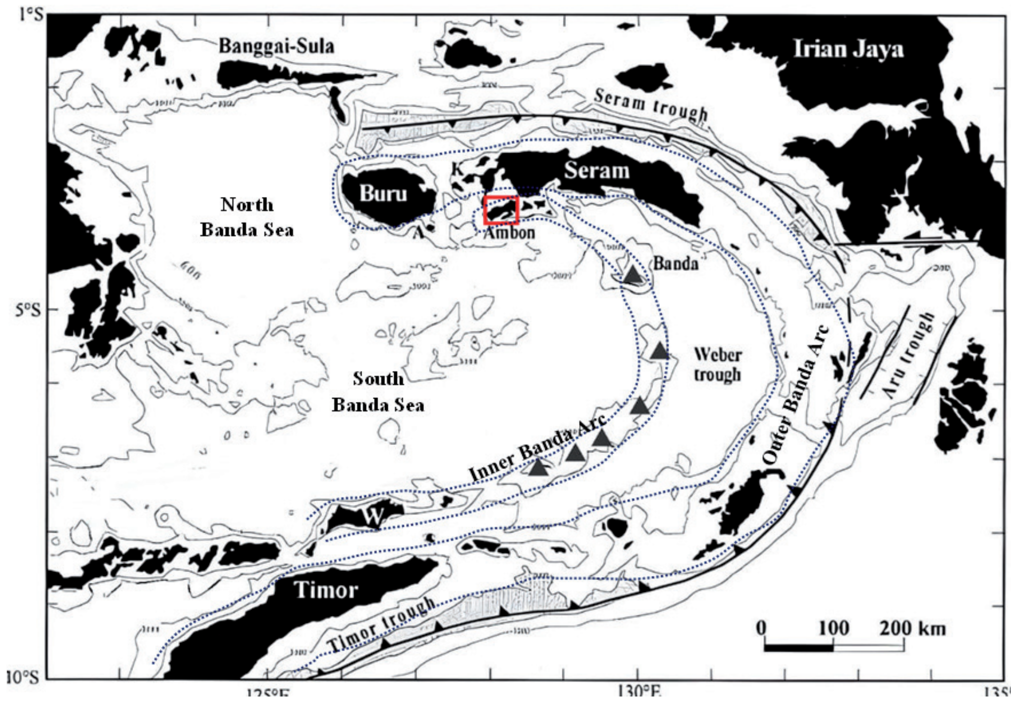

Figure 1. Tectonic setting map of eastern Indonesia (Adopted from Honthaas et al., 1999).

2. Geologic setting

Eastern Indonesia is one of the most geologically complex regions in Southeast Asia. Interaction among Eurasian, Australian, Pacific, and Philippine Sea plates produced a unique curving geometry of the Banda Arc that consists of inner and outer arcs (Figure 1). The inner Banda arc is a volcanic arc extending from Bali to Ambon Island and has been active since the Late Miocene, while the outer Banda arc is a non-volcanic imbricated rocks that extends from Roti-Timor to Seram-Buru Islands (Katili, 1975; Hamilton, 1979; Pairault et al., 2003; Figure 1). However, Honthaas et al. (1999) proposed Ambon Arc as a Plio-Quaternary Island arc extending west-east from Ambelau to the Banda Archipelago as a product of subduction of western Irian Jaya plate along Seram trough (Figure 1).

Based on the regional geological map by Tjokrosapoetro et al. (1993), Ambon Island consists of Late Triassic to Jurassic sedimentary rocks of Kanikeh Formation, Jurrasic to Cretaceous ultramafic rocks (i.e., lherzolites, dunit, and hazburgite) and a few gabbro dykes, Pliocene Ambon volcanic rocks, intrusive rocks (i.e., granites), and quaternary deposits that spread along lowland and coastal areas (Figures 2). Kanikeh Formation is less commonly cropped out on Ambon Island than on Seram Island (Gibran and Kusworo, 2020). The Ambon volcanic rocks are the predominant rocks in Ambon Island consisting of andesite, rhyolite, dacite (known as ambonites), volcanic breccia, associated tuff, and agglomerates (Tjokrosapoetro et al., 1993; Honthaas et al., 1999; Pownall et al., 2013; Figure 2). Ambonites or cordierite-garnet-bearing dacites, which are mainly found in the Leihitu region and the northern

Leitimor region, are genetically associated with intrusive granites in Ambon Island based on their petrologic, geochemical, and age features (van Bemmelen, 1949; Tjokrosapoetro et al., 1993; Linthout and Helmers, 1994; Pownall et al., 2013; Figures 2 and 3). However, Ambon granites contain significantly less cordierite than ambonites (Honthaas et al., 1999).

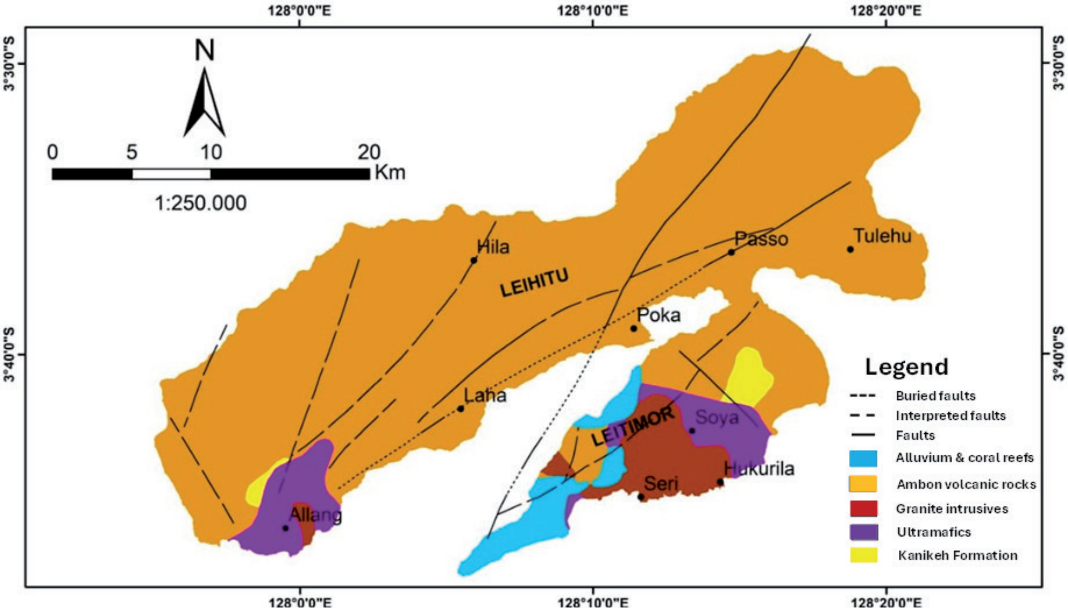

Figure 2. Geological map of Ambon Island showing granite locations and associated rocks (Compiled from Pownall et al., 2013 and Tjokrosaputro et al., 1993). Location of the Ambon Island is indicated in Figure 1.

3. Data and methods

Three samples (i.e., ST01, ST02B, and ST03) of granite, and one sample (i.e., ST02A) of aplite were collected during fieldwork along Wairuhung and Hukurila Beaches, where the granites are well-exposed in the Hukurila area. Those samples were later prepared into small pieces for thin sections, and a part of them were powdered using jaw crusher and vibrator disk mill, then sieved into size of 270 mesh for X-ray diffraction analysis. The petrographic analysis used an Olympus Polarization microscope at National Research and Innovation Agency (BRIN), Ambon, focusing on mineral compositions of granites and aplite. Mineral percentages are average values calculated by determining their occurrence in thin sections during petrography analysis. X-ray diffraction analysis was conducted at Integrated Mineral Laboratory Lampung, National Research and Innovation Agency (BRIN), using a Panalytical type X'pert3 Powder X-ray diffractometer. The powder samples were scanned between 2° to 80° (2θ) and maintained at 40kV operating voltage and 20mA current to obtain X-ray diffraction patterns of minerals.

4. Results

Field observations

Granites in the Hukurila area were observed within peridotites. The granite bodies are intensively fractured, yielding boulders of various sizes that spread along the beach and road in the Hukurila area (Figure 3). The intensive fracturing facilitates water infiltration to form a thick weathered crust above the fresh granite rocks in the hill area. Megascopically, granites exhibit white to light brown color, holocrystalline, medium to coarse-grained, and mainly consist of quartz, potassium feldspar, plagioclase, and biotite. Potassium feldspar is occasionally observed as an aggregated larger crystal up to 2.5 cm in length (Figure 3c). While mafic enclaves were also observed as single isolated rocks (Figure 3d). In addition, a white fine-grained aplite shows an equigranular texture with less mafic minerals occurring as dyke in granite (Figure 3e).

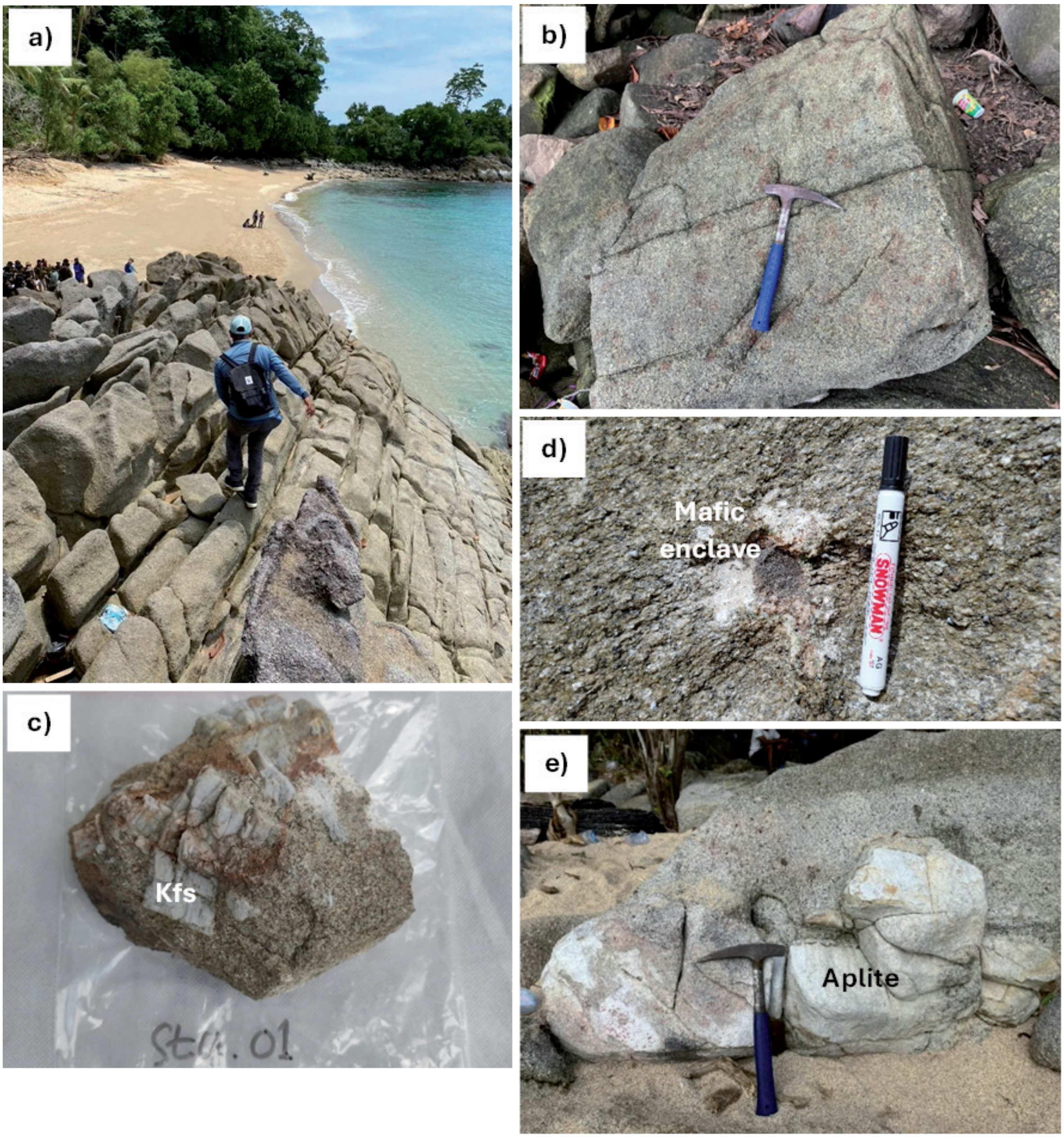

Figure 3. Photographs of granite outcrops along Wairuhung and Hukurila Beaches in the Hukurila area. (a-b) Hukurila granitoid rocks are systematically fractured showing medium-coarse grained equigranular texture. (c) Potassium feldspar (Kfs) was observed to be aggregated with size of single mineral ranging from 1 to 2.5 cm. (d) Mafic enclave occurs as a single isolated rock. (e) A white fine-grained aplite was intruded granite in Wairuhung Beach.

Petrography

Three thin sections of granite from Hukurila area were examined during petrographic analysis (Figures 3 and 4). Under the microscope, granite samples are light brown in color, holocrystalline, and medium to coarse-grained, composed of intergrowth quartz, potassium feldspars, plagioclase, biotite, and muscovite as the main ore-forming minerals (Figure 4). Quartz shows an anhedral shape with a percentage of about 30 to 50% of total mineral-forming rocks. Quartz occasionally exhibits undulatory extinction and recrystallization processes. Potassium feldspars mainly consist of orthoclase and rarely anorthoclase, showing euhedral to subhedral shape and occurring about 15% to 30% in the rocks (Figures 4a, d, and e). Plagioclase is lesser observed in all samples showing euhedral to subhedral shape, and occurs in about 5-10% of the rocks (Figure 4b). Feldspar minerals occasionally exhibit sieve, zoned, and myrmekite textures. Perthite texture was observed in potassium feldspar (i.e., orthoclase) and clearly shown in the larger crystals (Figure 4e). Biotite and muscovite are the main mafic minerals, with percentages of about 3 to 10% and 1 to 2%, respectively (Figure 4). Opaque minerals are less observed during petrographic analysis of about 1%, mainly within altered biotite (Figure 4).

Accessory minerals such as cordierite, zircon, apatite, and mullite were also observed in thin sections (Figures 4e-h). Cordierites exhibit twinning and are commonly altered to pinite minerals (brown) at the edge of crystals (Figure 4e). Zircons mostly occur within biotite and rarely within quartz, showing identical pleochroic halos (Figure 4f). Apatite is less observed with zircon that occurs in quartz (Figure 4g). A very small needle-like mullite crystal was rarely observed as inclusion in feldspars (Figure 4h). Secondary minerals such as sericite were commonly observed to alter plagioclase, while chlorite with radial aggregate replaced biotite. Rutile occurs within intensively altered biotite indicating a high concentration of Ti and Fe in the biotite (Figure 4h).

In addition, one aplite sample shows similar mineral compositions with granites namely quartz, potassium feldspar, plagioclase, biotite, muscovite, and cordierite, but those are relatively fine-grained in size. Compared to granites, aplite sample shows less biotite and muscovite mineral percentages in the rock (Figure 3e).

X-ray diffraction

Three samples of granite and one aplite sample from Hukurila area were also measured using X-ray diffractometer to identify their mineral composition (Figure 5). The X-ray diffraction analysis of granite and aplite samples exhibits quartz, potassium feldspar, plagioclase, mica, chlorite, apatite, and rutile (Figure 5). Those mineral compositions are similar to minerals that are observed during petrographic analysis. In addition, X-ray diffraction analysis also detected peaks of mullite, titanite, and serpentine group minerals.

5. Discussion

Granites from Hukurila area are characterized by occurrences of two mica minerals (i.e., biotite and muscovite) and cordierites suggesting S-type granite (Priem et al., 1978; Linthout and Helmers, 1994; Titawael, 2019; Figure 3). A/CNK values for granite in Ambon Island ranged from 1.16 to 1.24, classified as peraluminous (Honthaas et al., 1999; Chappell and White, 2001). During petrography and X-ray diffraction analyses, mullite was rarely identified in granite samples from Hukurila area suggesting Al-rich metasedimentary rocks contribution (Figure 4g). Mullite was commonly reported with other metamorphic minerals such as sillimanite, cordierite, corundum, and spinel in buchite, anatectic migmatite rocks, and pyro-metamorphic rocks (Markl, 2005; Prakash et al., 2017; Igami et al., 2018; da Silva et al., 2020).

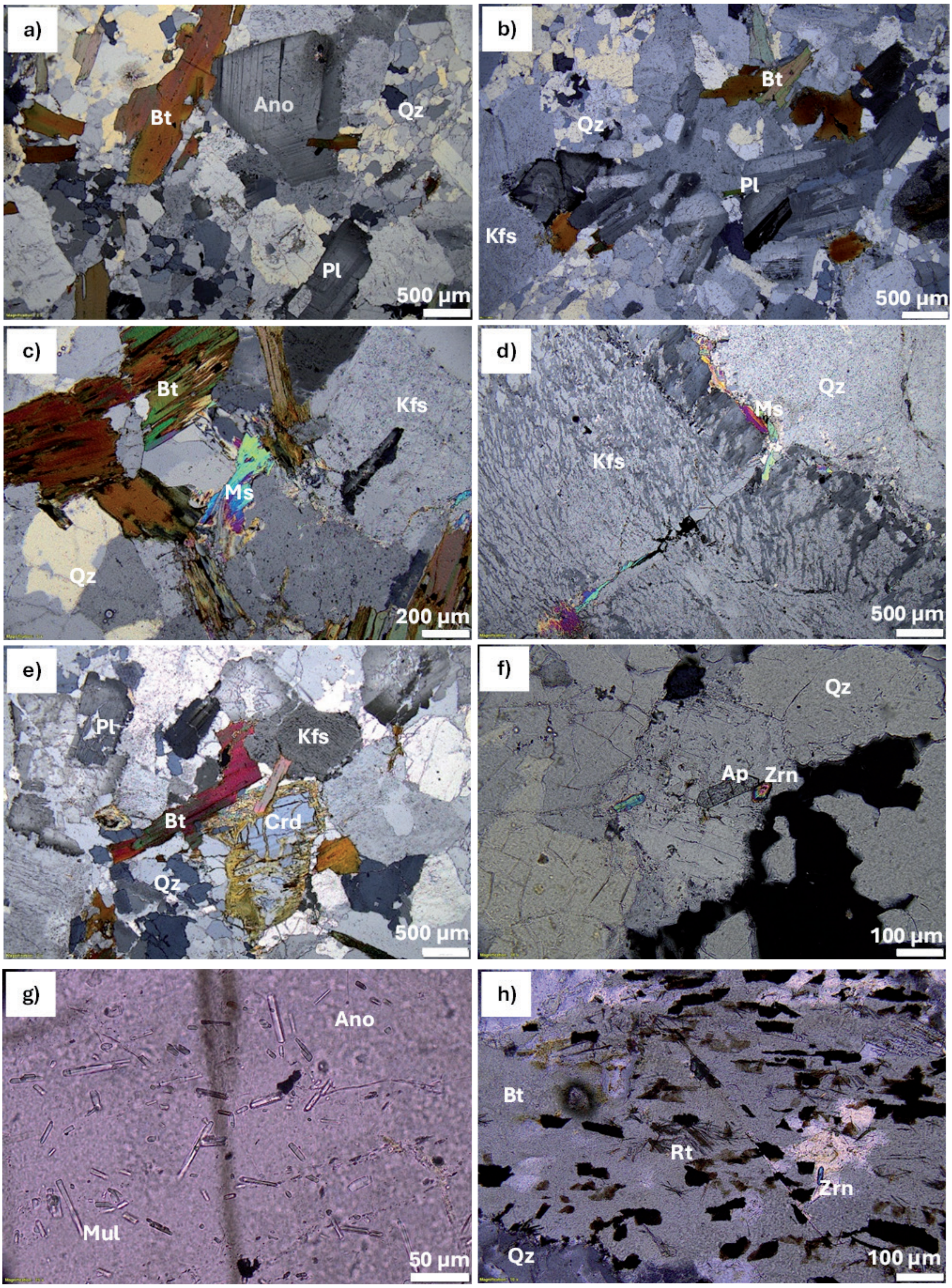

Figure 4. Photomicrographs of granite from Hukurila area showing mineral compositions. (a-c) The holocrystalline (intergrowth) texture of Hukurila granite is composed mainly of quartz, potassium feldspar, plagioclase, biotite, and muscovite. (d) Single potassium feldspar shows perthite texture along with quartz and interstitial muscovite. (e) Cordierite mineral shows lamellar twinning and is altered to pinite at the edge of the crystal. (f) Apatite and zircon are enclosed to biotite. (g) Mullite occurs as inclusion in feldspar. (h) Rutile was observed in altered biotite. Abbreviations: Ano=anorthoclase; Qz=quartz; Bt=biotite; Kfs=potassium feldspar; Pl=plagioclase; Ms=muscovite; Crd=cordierite; Ap=Apatite; Zrn=Zircon; and Mul=mullite.

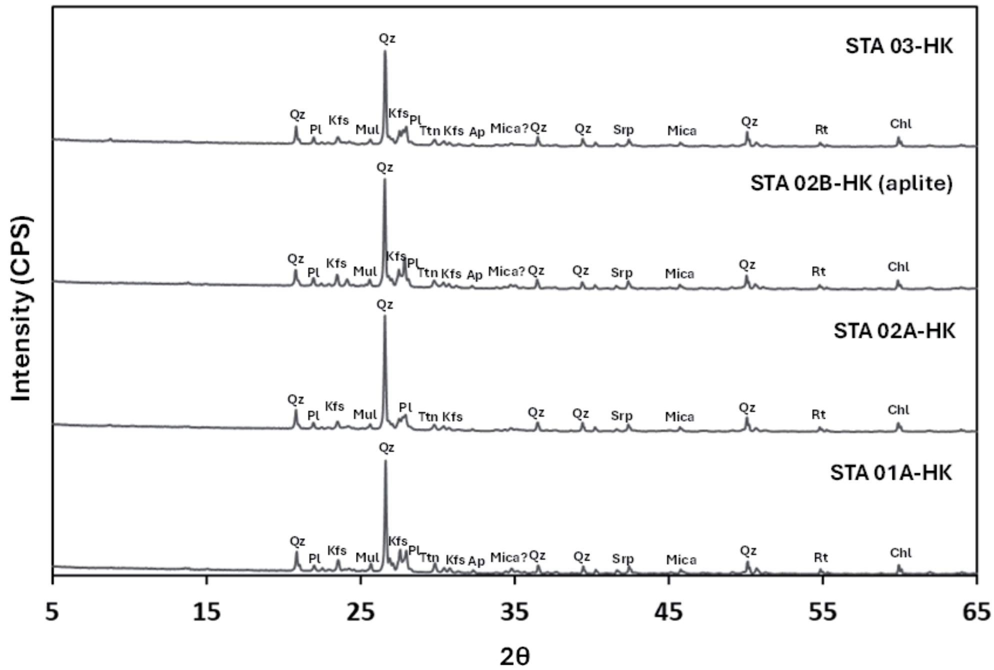

Figure 5. X-ray diffraction result of bulk analysis of Hukurila granites. Abbreviations: Qz=quartz; Pl=plagioclase; Mul=mullite; Kfs=potassium feldspar; Ttn=titanaite; Ap=apatite; Srp=serpentine; Rt=rutile; and Chl=chlorite.

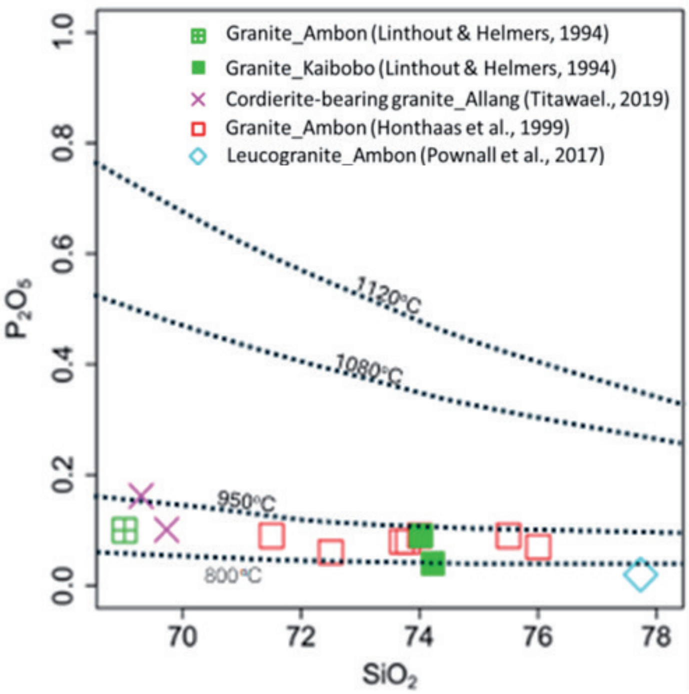

Figure 6. Bivariate diagram of SiO_2 versus P_2O_5 from Ambon and Seram granites plotted with experimentally determined isotherms (Modified from Green and Watson, 1982).

The occurrences of cordierite and mullite in granite samples from Hukurila area indicate that the rocks were subjected to high temperatures. This high-temperature condition is confirmed by the concentration of P_2O_5 from granites in Ambon and Seram Islands which are plotted within 800-950°C in the apatite solubility isotherm by Green and Watson (1982) (Figure 6).

Partial anatexis of the Palaeozoic continental crust induced by the obduction of very hot mantle peridotite during 5.65–5.4 Ma was proposed to form intrusive granites in Ambon and Seram Islands (Linthout and Helmers, 1994). This condition is related to the field association of granites and peridotites commonly found in Ambon and Seram Islands (Figure 2). X-ray diffraction analysis detected peaks of serpentine group minerals indicating their association (Figure 5). Xenoliths of serpentinite and veins that contain serpentine and chlorite were respectively reported to be trapped and filled fractures in chloritized leucogranite from Seri, Leitimor region of Ambon Island (Pownal et al., 2013). The obduction of very hot mantle also formed a metamorphic sole at Kaibobo, Seram Island, with peak metamorphism reached about 740^{o}C at 4–5 kbar (Linthout et al., 1996). However, the extensive lherzolites observed in Ambon and Seram Islands are not characteristic of an ophiolite, yet more likely the missing units of an ophiolite sequence (Pownall, 2013).

The exhumation of lherzolite in an extensional tectonic environment triggered by the proto-Banda Sea's subducting slab rollback of Banda embayment heated and metamorphosed overlying continental crust developed residual granulite (T=~950^{o}C), consisting of Al–Mg-rich garnet + cordierite + sillimanite + spinel + corundum (Pownall et al., 2013; 2014; 2017b). The granulite is well-exposed together with cordierite granites in the Kobipoto Mountains, Kaibobo Peninsula, and is associated with the cordierite granites which crop out on Ambon Island as observed in Hukurila area (Pownall et al., 2013; 2014; 2017b). However, Linthout and Helmers (1994) identified chemical differences in cordierite-bearing granites from Kaibobo and Ambon Island due to local variations in source rock chemistry. Partial melting of granulitic residue caused by basaltic magma emplacement, as well as localized anatexis of granulite metamorphic rocks, have also been proposed as sources of late-stage peraluminous biotite-muscovite granite in South China and granitic pegmatites in Sri Langka, respectively (Chen et al., 2021; Dharmapriya et al., 2021).

On the other hand, the Ambon high-K suite rocks, such as cordierite-bearing dacites (ambonites) and granites, are most likely derived from low-K mafic magmas linked to subduction along the Seram trough through massive assimilation of the Seram-Ambon continental crust (van Bemmelen, 1949; Priem et al., 1978; Honthaas et al., 1999). Geochemistry of these high K-suites of the Plio-Quaternary Ambon arc (i.e., Ambelau, Ambon, Saparua, and Haruku Islands) exhibits rather high MgO, compatible elements, and SiO_2 contents suggesting they are derived from a mafic source (Honthaas et al., 1999). According to Priem et al. (1978), the granite age in Ambon Island is 3.8 Ma (based on K-Ar on biotite separate) and 3.3 Ma (based on R/Sr on whole-rock/biotite). Similar findings were made by Honthaas et al. (1999), who reported 4.1 to 3.4 Ma obtained by $^{40}K–^{40}Ar$ on biotite separates, but the age more reflects the cooling of Ambon granitic bodies down to approximately 300^{o}C. However, the exhumation of the migmatite Kobipoto Complex in Ambon was claimed to have occurred at 3.4 Ma by 40Ar/39Ar (Pownal et al., 2017a). In order to better understand the tectonic evolution of granites on Ambon and the adjacent Seram Island, zircons identified in granite from the Hukurila area could be used for U-Pb geochronology in combination with Sr-Nd-Pb isotopes in the future.

6. Conclusions

Granite exhibits along roads and beaches in the Hukurila area consist of quartz, potassium feldspar, plagioclase, biotite, and muscovite. Potassium feldspar occasionally occurs as large crystals in the field. Two-mica minerals (i.e., biotite and muscovite) and cordierite suggest granite from Hukurila area as S-type granite. High-aluminum minerals (i.e., cordierite and mullite) indicate crustal contamination during their formation. Furthermore, geochemistry and geochronology investigations will still be needed to support the conclusion and better understand the tectonic evolution of Ambon Island.

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