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Geochemical and Mineralogical Insights into Hydrothermal Alteration in the Beruang Kanan Non-Vulcanic Area, Central Kalimantan, Indonesia

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Abstract

Previous studies have revealed significant hydrothermal alterations within the Beruang Kanan Non-Volcanic Area, Central Kalimantan, Indonesia, resulting in extensive ore mineralizations. This study aims to examine the effects of hydrothermal processes on rock alteration, delineate alteration zones, and establish their relationship to metal mineralization. The research area, situated in the Tumbang Miri district of Gunung Mas regency, forms part of the Corrugated Hills Geomorphological Unit and is traversed by the Schwaner Mountains, with elevations ranging from approximately 50 to 400 meters. Stratigraphic analysis identifies three primary rock units, ordered from oldest to youngest: the Tuffaceous Sandstone Unit, the Dacitic Tuff Unit, and the Andesite Unit. Hydrothermal alterations have resulted in three distinct alteration zones sericitic, argillic, and propylitic characterized by secondary mineral assemblages. This study provides a comprehensive framework for understanding the geological and mineralization dynamics of non-volcanic hydrothermal systems in Central Kalimantan, Indonesia

Keywords: hydrothermal; rocks; sandstone; alteration; sericitic; propylitic

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INTRODUCTION

Hydrothermal alteration plays a pivotal role in understanding the evolution of Earth's crust, particularly in relation to mineral deposits and geothermal processes. This phenomenon alters the mineralogical and chemical composition of rocks, often generating ore mineralizations critical for economic geology (Thoreau & Prayer, 2000). Research into hydrothermal systems, especially in non-volcanic regions, provides unique insights into crustal processes that differ significantly from those in volcanic environments (Henley et al., 1984).

The Beruang Kanan Non-Volcanic Area in Central Kalimantan, Indonesia, presents a compelling case study for examining hydrothermal alterations in a non-volcanic context. Situated within the Corrugated Hills Geomorphological Unit and traversed by the Schwaner Mountains, the region exhibits diverse geochemical and mineralogical characteristics that have yet to be fully explored (Nakada et al., 2019; Tongkul, 2017). Such investigations are vital to deciphering the geological history of the area and its mineralization potential.

Previous studies have revealed the significant impact of hydrothermal processes on rock alteration in this region, highlighting the development of ore deposits and associated alteration zones (Meju & Le, 2002; Saparun et al., 2022; Stone et al., 2022). These findings underscore the need for a comprehensive analysis that integrates geochemical and mineralogical data to understand the spatial distribution and genesis of these zones. The Beruang Kanan area thus serves as an ideal natural laboratory for advancing our understanding of non-volcanic hydrothermal systems (Anuar et al., 2021; Baioumy et al., 2015).

Stratigraphic observations in the Beruang Kanan area reveal a sequence of rock units, including the Tuffaceous Sandstone Unit, the Dacitic Tuff Unit, and the Andesite Unit. This stratigraphy, combined with the area's structural and geomorphological features, offers a unique framework for exploring hydrothermal alterations (Hartmann et al., 2024; Mibei, 2014; Stone et al., 2022). Each rock unit provides distinct evidence of alteration processes and secondary mineral assemblages, which are critical to understanding the region's geochemical evolution (Basaham et al., 2015; Wan et al., 2017).

One of the distinctive aspects of hydrothermal systems in the Beruang Kanan area is the identification of sericitic, argillic, and propylitic alteration zones (Guo & Wang, 2012; Harlaux et al., 2017; Wu et al., 2017; You et al., 1996). These zones, classified based on secondary mineral assemblages, hold key information about the temperature, fluid composition, and duration of hydrothermal activity. Their analysis could provide significant insights into the processes governing non-volcanic hydrothermal systems (Baioumy et al., 2015; P. Wang et al., 2016).

The magmatic arc of Central Kalimantan (Carlile and Mitchell, 1994) can be seen in the traces of erosion from the Late Oligocene to Early Miocene, which are volcanic centers of andesite and andesite trachyte. Many of these centers are associated with prospective copper deposits. Near the Kelian mine, volcanic rocks dating back to the Miocene (23 million years ago) are exposed (Van Leeuwen et al., 1990, cited in Carlile and Mitchell, 1994). Fresh andesite intrusions dating back 24.6 million years are exposed near Masuparia, and the andesites and basalts between Kelian and Mount Muro date back 14 to 24 million years. Magma flows from the Late Oligocene to Early Miocene in Central Kalimantan are exposed as erosional remnants of volcanic centers, some of which are andesitic to trachyandesitic and associated with gold deposits (Carlile and Mitchell, 1994).

This research aims to study the effects of hydrothermal processes on alteration, as well as determine the distribution of alteration zones and their relationship to metal mineralization in the Beruang Kanan area and its surroundings. To achieve this, we require geological, XRD and petrological data, which will be useful for interpreting magmatic activity at that time. This data can then be used as preliminary information in mineral exploration.

METHOD

Beruang Kanan is located north of Palangkaraya, the capital of Central Kalimantan **(Figure 1)**. It is about 190 kilometers away and is geographically located at the following coordinates: 768,300–768,500 UTM and 9,931,500–9,932,850 UTM. The study area covers 999,614 m^2. Physiographically, it is a mountainous area located north of the Kahayan River. The area can be reached by daily air flights from Jakarta to Palangkaraya, the capital of Central Kalimantan, which take 2 hours and 45 minutes. From there, it is an eight-hour drive (approx. 350 km) to Beruang Kanan or a 50-minute helicopter ride. Logging company roads provide access to this previously remote area (Anjarwati, 2019).

The methodology comprises four main parts: a desk study, fieldwork, laboratory analysis, and data analysis and interpretation. Pre-field study involves a literature review and the use of secondary data. Fieldwork will involve mapping, data collection, and sampling. Petrographic analyses will be carried out in the laboratory to fulfill the research objectives. Rock observation and sampling consist of three parts: fresh rock samples (host rock) to determine the lithology of the study area; rock samples that have undergone alteration to determine the type of alteration and mineralization occurring in the study area; and mineral samples to determine the mineralogy of the study area. Samples used for petrographic analysis are fresh and altered rocks. For microscopic analysis of polished incision ore, samples are taken from rocks containing ore minerals (i.e., altered rocks). For XRD analysis, samples of soft, clay-rich altered side rocks are taken.

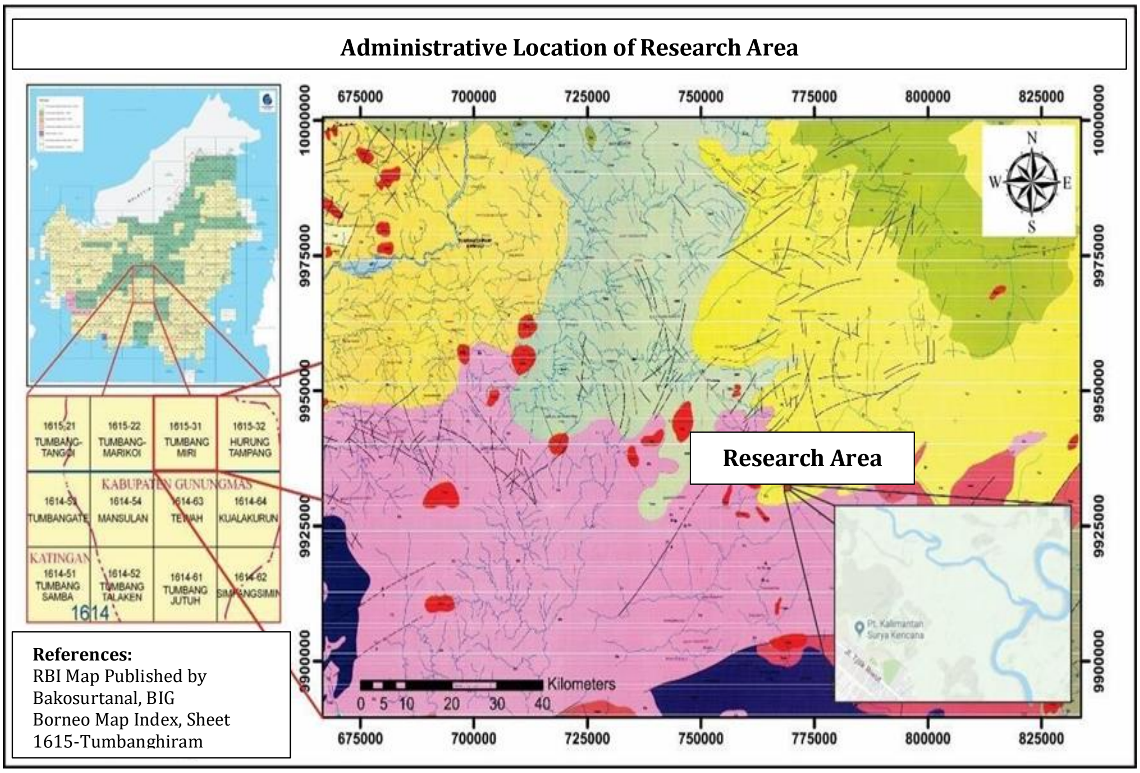

Figure 1. Administrative location of the research area

RESULTS AND DISCUSSION

In general, the stratigraphy of the study area consists of three rock units, as shown on the geological map, and they are arranged from oldest to youngest: the Tuffaceous Sandstone Unit, the Dacitic Tuff Unit, and the Andesite Unit **(Figure 1)**. Hydrothermal alteration is prevalent throughout the study area and affects all rock units, including the Tuffaceous Sandstone, Dacitic Tuff, and Andesite. The identification and classification of hydrothermal alteration in this region are based on alteration mineral groups, determined through the examination of hand specimens, thin sections, and XRD analyses (Guo & Wang, 2012; Harlaux et al., 2017; Hartmann et al., 2024; Mibei, 2014; Stone et al., 2022).

Field observations, petrographic analyses, and XRD results indicate that the altered rocks are evenly distributed across the study area. They exhibit physical characteristics ranging from hard to very soft and from coarse-grained to very fine-grained. The intensity of alteration varies, generally ranging from weak to strong. The alteration zones in the study area are categorized into three distinct types based on the presence of secondary mineral assemblages in the analyzed rocks (Arnorsson et al., 1983; Aryanto & Kamiludin, 2016; Kusuhara et al., 2020; Yuhara & Seno, 1969): Sericite-Quartz-Smectite-Pyrite Alteration (Sericitic Alteration); Illite-Smectite-Hyalosite Alteration (Argillic Alteration); and Chlorite-Illite-Smectite Alteration ± Epidote (Propylitic Alteration). These three types of alteration are clearly illustrated on the alteration map of the Beruang Kanan area **(Figure 2)**.

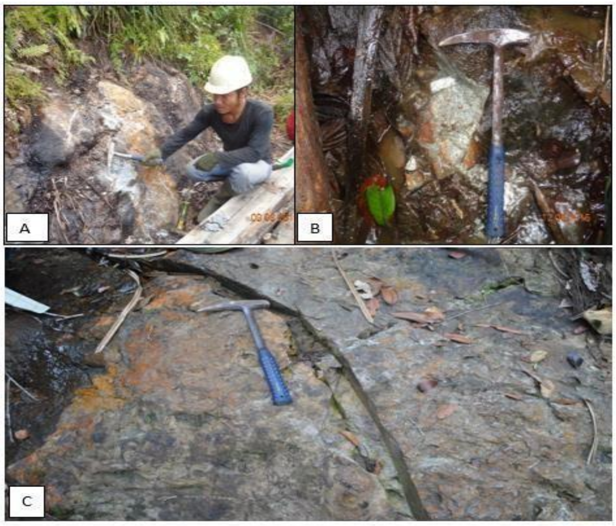

Figure 2. The dacitic tuff unit changes color from yellowish-brown to reddish-brown when altered (A). In terms of composition, the argillic altered dacitic tuff unit is harder and contains quartz veins and veinlets, as well as quartz and oxide veinlets (B). In terms of texture, argillic alteration makes the dacitic tuff unit harder (C).

Quartz, Illite, Smectite, and Sericite (Argillic Alteration)

Argillic-type hydrothermal alteration is characterized by the presence of clay minerals due to H^+ metasomatism and intense acid dissolution in the temperature range of 100–300 °C. Secondary clay minerals form through the replacement of Plagioclase and mafic silicate minerals, such as biotite and hornblende. Argillic intermediate alteration is characterized by the presence of Montmorillonite, Illite, Chlorite, and Kaolinite, as well as minor sericite. Advanced argillic alteration is characterized by Kaolinite, Dickite, Pyrophyllite, Barite, and Alunite, as well as several other minor hydrothermal alteration minerals (Kusuhara et al., 2020). Argillic alteration is the outermost zone of hydrothermal alteration in the study area. This zone has the most extensive coverage at about 20%. In general, this alteration is found in the Dacitic Tuff unit.

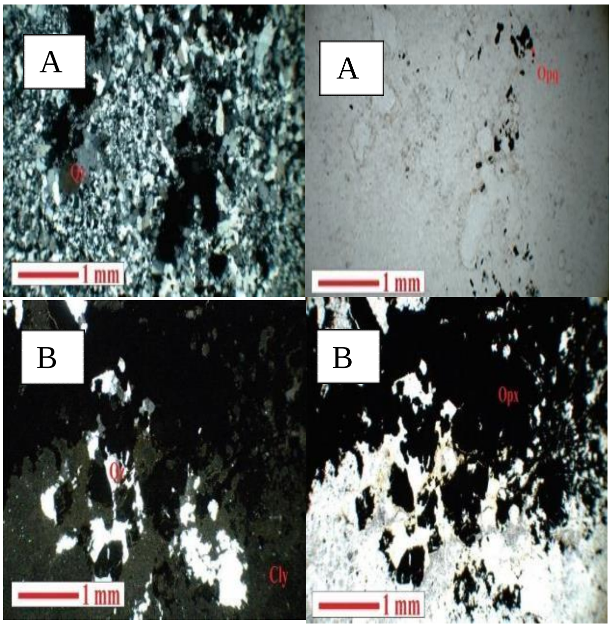

Figure 3. (A) Quartz on PPL observation has colorless colour, low relief, no pleochroism, Clay minerals with PPL observation are colorless, low relief, no pleochroism, Limonite with PPL observation yellowish brown, high relief, no pleochroism LP 15. (B) Quartz on PPL observation has colorless colour, low relief, no pleochroism. Clay minerals with PPL observation are colourless, low relief, no pleochroism. Opaque minerals, on PPL and XPL observations, are black in colour, with high relief and no pleochroism. LP28.

According to Carlile and Mitchell, 1994), based on the mineral composition of quartz-hematite-clay minerals, it can be included in the argillic alteration type **(Figure 3)**. This is also evident in the X-ray diffractogram of the argillic rock shown in **Figures 4**. XRD analysis shows that the argillic alteration is dominated by Illite, Smectite, Kaolinite, Pyrite, And Quartz.

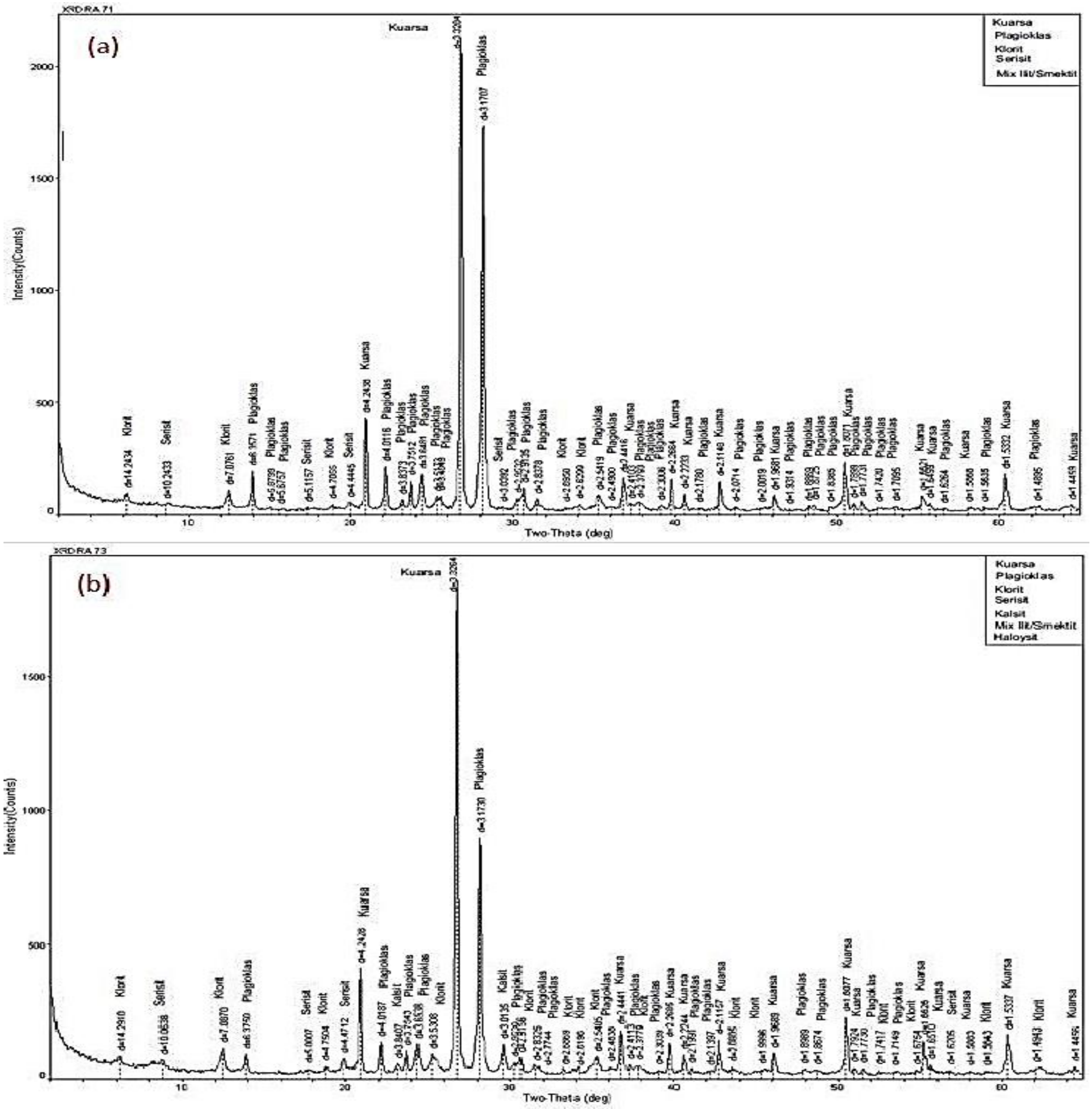

Figure 4. X-ray diffractogram of argillic rock, showing the minerals present are quartz minerals, illite minerals, smectite, hylosite, calcite, and sericite.

Alteration of Chlorite, Pyrite, Smectite±Epidote (Propylitic)

Propylitic alteration is characterized in particular by the presence of actinolite, chlorite, epidote, and magnetite at the margins of hydrothermal systems (Thoreau & Prayer, 2000). There is equigranular K feldspar and plagioclase-rich basement. Chlorite appears as a prograde and retrograde hydrothermal/metasomatic transition in paragenesis (Amita et al., 2014, 2014).

The outer propylitic alteration zone is the least altered. This zone still preserves the original texture of the host rock. It is characterized by Chlorite and Illite, as well as Smectite ± Epidote, which are mostly observed around the margins of the deposit. Pyrite is also frequently present, albeit in lower quantities than in other alteration zones. Zeolite (the lowest mineral) is occasionally found in propylitically altered andesite (Chen et al., 2020; Czinder & Török, 2021; Nugraha et al., 2019).

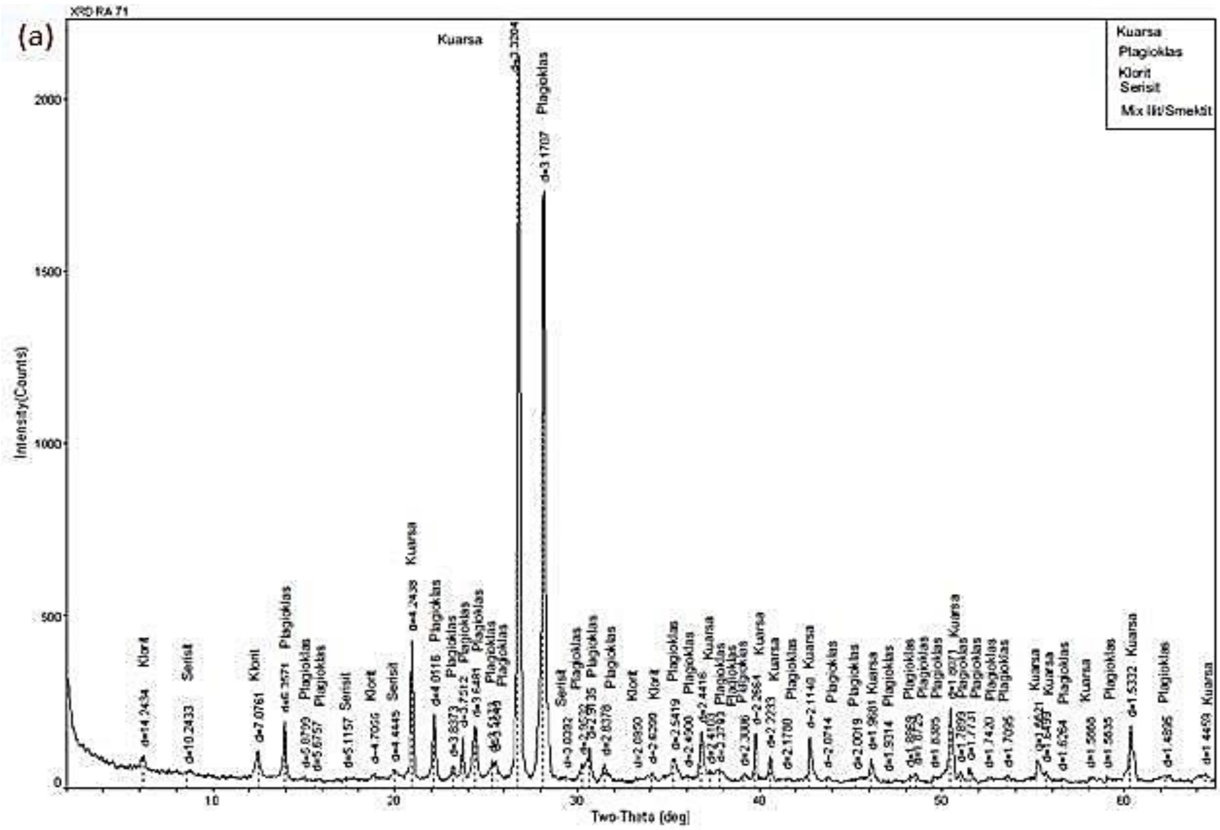

Figure 5. X-ray diffractogram of propylitic rock, showing the minerals present are chlorite, smectite, and quartz.

Sericite alteration involving Smectite, Quartz, And Pyrite.

Sericitized hydrothermal alteration is characterized by the presence of Sericite and Quartz. Sulfide minerals, particularly pyrite, often accompany sericitization alteration. This hydrothermal alteration is therefore referred to as Quartz (Q) + Sericite (S) + Pyrite (P) alteration, or QSP (Guo & Wang, 2012; Stone et al., 2022; L. Wang et al., 2024).

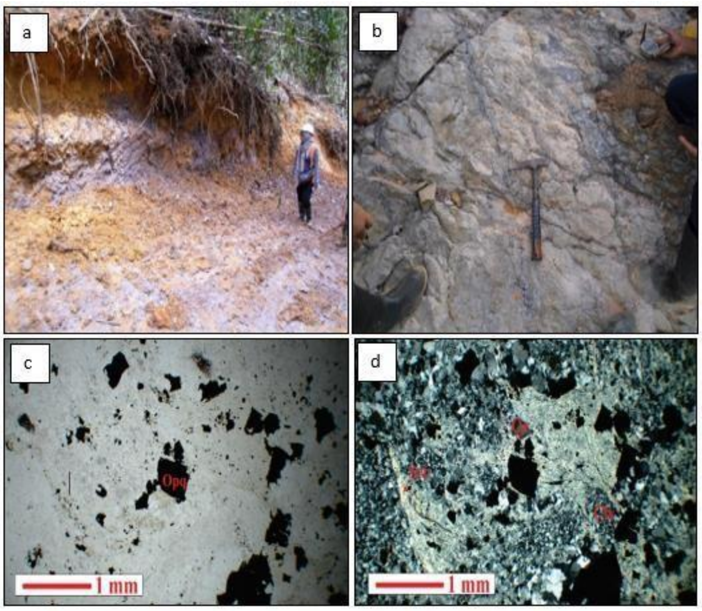

Figure 6. Appearance of sericite-altered rock outcrop LP 66 (a) Appearance of sericite-altered rock outcrop where there is a quartz vein (b), and sericitic thin section of sample RA 34 showing the composition of sericite, quartz, clay minerals, PPL (c), and XPL (d).

Sericitic alteration occurs when feldspar and mica are completely replaced by sericite, and mafic minerals are replaced by secondary quartz. The sericite alteration zone is a hydrothermal alteration zone covering the outer part of the silicification alteration zone in the study area. Sericitization alteration occurs in the dacitic tuff unit. It is the hydrothermal alteration zone covering the smallest area (about 35% of the total study area). It is characterized by the presence of sericite minerals replacing feldspar and mica **(Figures 6)**. There are veins in the rock in the form of sericite veins. Mineral composition of the rock, namely secondary minerals in the form of quartz, sericite, clay minerals, and opaque minerals. Opaque minerals, in PPL and XPL observations, are black, with high relief, no pleochroism, subhedral mineral relationships, mineral size 0.04-0.5 mm, tabular shape, and 15% abundance. Brown biotite is mostly present together with magnetite and K-feldspar. Very little pyrite and chalcopyrite.

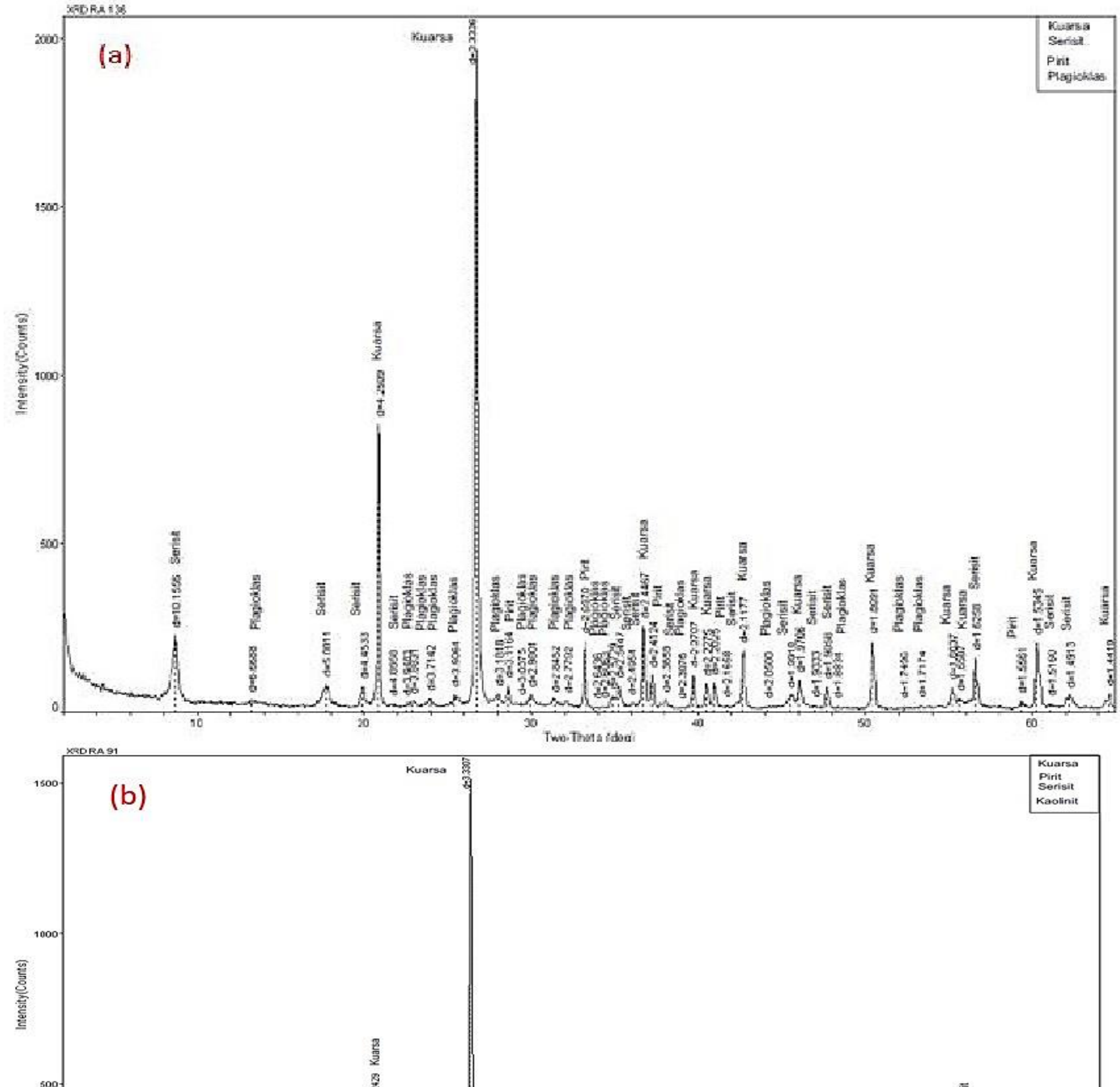

Figure 7. X-ray diffractogram of argillic rock, showing the minerals present are sericite, quartz, smectite, and pyrite. LP 43

Field observations indicate pronounced changes in the color, texture, and composition of the argillic-altered dacitic tuff unit, where white to grey clay minerals form, and the original rock composition is replaced by clay minerals and mica groups. Determining the intensity of hydrothermal alteration proves challenging, as selective alterations preserve original rock textures in certain instances, notably in porphyry andesite. The argillic zone extends outward from the initial alteration zone, predominantly characterized by Illite, Muscovite, and Illite-Smectite. Altered dacitic tuff transitions to hues of yellowish-brown or reddish-brown, accompanied by the hardening of the rock due to the development of quartz veins/veinlets and quartz+oxide veins/veinlets. The texture of the dacitic tuff unit also becomes denser as a result of argillic alteration. Petrographic analyses reveal the presence of minerals as phenocrysts within these altered rocks.

Petrographic results demonstrate that the rock is notably rich in chlorite and epidote, providing a useful reference for classifying the type of alteration observed. According to Carlile and Mitchell, 1994), the quartz-chlorite-sericite mineral composition aligns with the characteristics of propylitic alteration. In this alteration zone, secondary sulfide minerals such as hematite and goethite are also present. Actinolite is frequently identified within lithium tuffs, while epidote is observed infrequently. However, smectite and chlorite are noted as replacement products for plagioclase and other mafic phenocrysts. XRD analysis confirms that the mineral assemblages within this zone comprise Chlorite, Illite, Smectite, Pyrite, and Quartz **(Figure 7)**.

Observations of the sericitic-altered dacitic tuff unit highlight significant changes in color, texture, and composition. During the sericitic alteration, the dacitic tuff unit evolves to a grey-brown color and develops a softer texture compared to rocks affected by argillic alteration. This process results in finer crystal size and granularity, driven by the transformation of secondary mica minerals into clay minerals through weathering. Consequently, the rock's texture changes significantly, leaving only resistant minerals intact within the unit.

CONCLUSION

The analyzed samples, characterized by their corresponding lithology, mineral composition, and alteration types, provide valuable insights into the geological processes of the study area. Petrography and XRD analyses reveal a variety of rock types, including dacitic tuff, tuffaceous sandstone, and andesite, each exhibiting distinct mineralogical compositions and hydrothermal alteration types, such as Sericitic, Propylitic, and Argillic. Key minerals identified in the samples include quartz, sericite, clay minerals, opaque quartz minerals, pyrite, and plagioclase, with additional minerals such as alunite, limonite, goethite, chlorite, illite-smectite, calcite, and kaolinite observed in varying amounts. These mineral assemblages reflect the chemical transformations and mineralogical changes induced by hydrothermal processes over time. The identified alteration types not only highlight the intensity and diversity of hydrothermal activity in the region but also provide a framework for understanding the spatial and temporal evolution of alteration zones. These findings contribute to a more comprehensive understanding of the area's complex geological history and its implications for mineral exploration.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest concerning the publication of this article. The authors also confirm that the data and the article are free of plagiarism.

REFERENCES

Amita, K., Ohsawa, S., Nishimura, K., Yamada, M., Mishima, T., Kazahaya, K., Morikawa, N., &

Hirajima, T. (2014). Origin of saline waters distributed along the Median Tectonic Line in southwest Japan: Hydrogeochemical investigation on possibility of derivation of metamorphic dehydrated fluid from subducting oceanic plate. *Journal of Japanese Association of Hydrological Sciences*, *44*(1), 17–38. https://doi.org/10.4145/jahs.44.17

Anjarwati, R., Idrus, A., Setijadji, L.D., 2019. Petrography and ore mineral study at Beruang Kanan Site, Gunung Mas Regency, Central of Kalimantan Province. J. Phys. Conf. Ser. 1242, 012052. https://doi.org/10.1088/1742-6596/1242/1/012052

Anuar, M. N. A., Arifin, M. H., Baioumy, H., & Nawawi, M. (2021). A geochemical comparison between volcanic and non-volcanic hot springs from East Malaysia: Implications for their origin and geothermometry. *Journal of Asian Earth Sciences*, *217*(August 2020), 104843. https://doi.org/10.1016/j.jseaes.2021.104843

Arnorsson, S., Gunnlaugsson, E., & Svavarsson, H. (1983). The chemistry of geothermal waters in Iceland . II . Mineral equilibria and independent variables controlling water compositions. *Geochimica et Cosmochimica Acta*, *47*, 547–566.

Aryanto, N. C. D., & Kamiludin, U. (2016). The Content of placer heavy mineral and characteristics of REE at Toboali Coast and its surrounding area , Bangka Belitung Province. *Bulletin of the Marine Geology*, *31*(1), 45–54.

Baioumy, H., Nawawi, M., Wagner, K., & Arifin, M. H. (2015). Geochemistry and geothermometry of non-volcanic hot springs in West Malaysia. *Journal of Volcanology and Geothermal Research*, *290*(December), 12–22. https://doi.org/10.1016/j.jvolgeores.2014.11.014

Basaham, A. S., El Sayed, M. A., Ghandour, I. M., & Masuda, H. (2015). Geochemical background for the Saudi Red Sea coastal systems and its implication for future environmental monitoring and assessment. *Environmental Earth Sciences*, *74*(5), 4561–4570. https://doi.org/10.1007/s12665-015-4477-5

Carlile, J.C., Mitchell, A.H.G., 1994. Magmatic arcs and associated gold and copper mineralization in Indonesia. J. Geochem. Explor. 50, 91–142. https://doi.org/10.1016/0375-6742(94)90022-1

Chen, X., Zheng, Y., Gao, S., Wu, S., Jiang, X., Jiang, J., Cai, P., & Lin, C. (2020). Ages and petrogenesis of the late Triassic andesitic rocks at the Luerma porphyry Cu deposit, western Gangdese, and implications for regional metallogeny. *Gondwana Research*, *85*, 103–123. https://doi.org/10.1016/j.gr.2020.04.006

Czinder, B., & Török, Á. (2021). Strength and abrasive properties of andesite: relationships between strength parameters measured on cylindrical test specimens and micro-Deval values—a tool for durability assessment. *Bulletin of Engineering Geology and the Environment*, *80*(12), 8871–8889. https://doi.org/10.1007/s10064-020-01983-9

Guo, Q., & Wang, Y. (2012). Geochemistry of hot springs in the Tengchong hydrothermal areas, Southwestern China. *Journal of Volcanology and Geothermal Research*, *215–216*, 61–73. https://doi.org/10.1016/j.jvolgeores.2011.12.003

Harlaux, M., Mercadier, J., Bonzi, W. M. E., Kremer, V., Marignac, C., & Cuney, M. (2017). Geochemical Signature of Magmatic-Hydrothermal Fluids Exsolved from the Beauvoir Rare-Metal Granite (Massif Central, France): Insights from LA-ICPMS Analysis of Primary Fluid Inclusions. *Geofluids*, *2017*. https://doi.org/10.1155/2017/1925817

Hartmann, L. A., Hoerlle, G., & Renner, L. C. (2024). Extensive two-tier structure and breccia stockwork formation by hydrothermal processes in the first Paraná lava flow covering the Botucatu paleoerg-turned-Guarani Paleoaquifer. *Journal of South American Earth Sciences*, *133*(May 2023). https://doi.org/10.1016/j.jsames.2023.104734

Henley, R., Truesdell, A. ., Barton, P. ., & Whitney, J. . (1984). *Fluid-mineral equilibria in hydrothermal systems*. Society of Economic Geologist.

Kusuhara, F., Kazahaya, K., Morikawa, N., Yasuhara, M., Tanaka, H., Takahashi, M., & Tosaki, Y. (2020). Original composition and formation process of slab-derived deep brine from Kashio mineral spring in central Japan. *Earth, Planets and Space*, *72*(1). https://doi.org/10.1186/s40623-020-01225-y

Meju, M. A., & Le, L. (2002). Geoelectromagneticexploration For Natural Resources:Models, Case Studies and Challenges. *Surveys in Geophysics*, *23*, 133–205.

Mibei, G. (2014). *Presented at Short Course IX on Exploration for Geothermal Resources, INTRODUCTION TO TYPES AND CLASSIFICATION OF ROCKS*. 1–12.

Nakada, S., Maeno, F., Yoshimoto, M., Hokanishi, N., Shimano, T., Zaennudin, A., & Iguchi, M. (2019). Eruption scenarios of active volcanoes in Indonesia. *Journal of Disaster Research*, *14*(1), 40–50. https://doi.org/10.20965/JDR.2019.P0040

Nugraha, A. S., Darsono, D., & Legowo, B. (2019). Identification of the distribution of andesite rocks in Kalirejo Village, Kokap District, Kulon Progo Regency, Special Region of Yogyakarta based on geoelectrical tomography data. *Journal of Physics: Conference Series*, *1153*(1). https://doi.org/10.1088/1742-6596/1153/1/012019

Saparun, M., Akbar, R., Marbun, M., Dixit, A., & Saxena, A. (2022). Application of Induced Polarization and Resistivity to the Determination of the Location of Minerals in Extrusive Rock Area, Southern Mountains of Java, Indonesia. *International Journal of Hydrological and Environmental for Sustainability*, *1*(3), 108–119. https://doi.org/10.58524/ijhes.v1i3.137

Stone, A., Inglis, R., Barfod, D., Ickert, R., Hughes, L., Waters, J., Jourdan, A. L., & Alsharekh, A. M. (2022). Hydroclimatic and geochemical palaeoenvironmental records within tufa: A cool-water fluvio-lacustrine tufa system in the Wadi Dabsa volcanic setting, western Saudi Arabia. *Sedimentary Geology*, *437*, 106181. https://doi.org/10.1016/j.sedgeo.2022.106181

Thoreau, H. D., & Prayer, Y. I. (2000). *Rocks & Minerals* (p. 38).

Tongkul, F. (2017). Active tectonics in Sabah – seismicity and active faults. *Bulletin of the Geological Society of Malaysia*, *64*(December), 27–36. https://doi.org/10.7186/bgsm64201703

Van Leeuwen, T.M., 1994, 25 Years of Mineral Exploration and Discovery in Indonesia, Journal of Geochemical Exploration 50, p. 13-90.

Wan, H., Sun, H., Liu, H., & Xiao, Y. (2017). Lithium Isotopic Geochemistry in Subduction Zones: Retrospects and Prospects. *Acta Geologica Sinica (English Edition)*, *91*(2), 688–710. https://doi.org/10.1111/1755-6724.13126

Wang, L., Song, J., & Yu, C. (2024). The utilization and advancement of quartz crystal Microbalance (QCM): A mini review. *Microchemical Journal*, *199*(October 2023), 109967. https://doi.org/10.1016/j.microc.2024.109967

Wang, P., Chen, X., Shen, L., Wu, K., Huang, M., & Xiao, Q. (2016). Geochemical features of the geothermal fluids from the Mapamyum non-volcanic geothermal system (Western Tibet, China). *Journal of Volcanology and Geothermal Research*, *320*, 29–39.

https://doi.org/10.1016/j.jvolgeores.2016.04.002

Wu, D., Purnomo, B. J., & Sun, S. (2017). As and Sb speciation in relation with physico-chemical characteristics of hydrothermal waters in Java and Bali. *Journal of Geochemical Exploration*, *173*, 85–91. https://doi.org/10.1016/j.gexplo.2016.12.003

You, C. F., Castillo, P. R., Gieskes, J. M., Chan, L. H., & Spivack, A. J. (1996). Trace element behavior in hydrothermal experiments: Implications for fluid processes at shallow depths in subduction zones. *Earth and Planetary Science Letters*, *140*(1–4), 41–52. https://doi.org/10.1016/0012-821X(96)00049-0

Yuhara, K., & Seno, K. (1969). Geology, geophysics and geochemistry of hot and mineral springs. In *Chijinshokan & Co., Ltd., Tokyo, Japan* (pp. 155–166).