Geology and Alteration of East Pinolosian Area, Bolaang Mongondow, North Sulawesi Province

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ABSTRACT

Bolaang Mongondow is located on the Eastern North arm of Sulawesi. This area is a Neogene-aged magmatic arc composed of plutonic and volcanic rocks that indicate mineralization-bearing host rocks. The study aimed to determine the geological setting and alteration based on geological observations and geochemical analysis. The method used is geological mapping, followed by laboratory and studio data analysis. The lithology of this area is composed of andesite, diorite, and pyroclastic breccia units. Two main faults are the Northwest-Southeast trending dextral fault and the Northeast-Southwest trending sinistral fault, which causes hydrothermal mineral alteration. Mineral alteration in the study area is divided into several zones, including the Silicification Zone (massive silica + vuggy silica), Advance Argillic Zone (illite + alunite + dickite + halloysite + kaolinite), Argillic Zone (illite + montmorillonite + pyrophyllite), Prophyllitic Zone (chlorite + montmorillonite). The presence of mineral assemblages and alteration zones shows the characteristics of High Sulfide Epithermal deposits with the highest level of 0.47/ppm in the Advance Argillic Zone.

Keywords: Bolaang Mongondow, geology, alteration, geochemical, epithermal high sulfidation

INTRODUCTION

The North Arm of Sulawesi is a magmatic arc formed since the Eocene [1]. The complex tectonic processes that have shaped this area make it have abundant geological resources. Since its formation, the North Arm of Sulawesi has experienced several periods of magmatism. This condition makes the area rich in economic mineral potential, like gold and copper [2].

Bolaang Mongondow is included in the eastern part of the North Arm of Sulawesi, which is composed of Neogene-aged magmatic processes in the form of plutonic and volcanic rocks which are thought to be the host rock of mineralization [3], making it interesting to conduct research related to geology and alteration in the area on a detailed scale. Previous researchers concluded that the research area is a type of high-sulfide Au-Ag mineralization with a disseminated form of vuggy silica and silica alunite alteration [4]. Several previous studies around the research site have been conducted, including on Hydrothermal Alteration in West Dumoga [5] and other areas in Bolaang Mongondow Regency and Minahasa Regency [6].

North Sulawesi is a volcanic arc separated by regional unconformities that experienced rapid uplift and magmatism-volcanism processes associated with economic minerals [5]. During the Plio-Pleistocene, the Halmahera and Philippine sea plate subduction accommodated the convergence of the Pacific-Philippines and

Eurasian plates and isolated the Maluku Basin [7]. The subduction process triggered the formation of volcanic materials and a regional structural system of sinistral faults, which began mineralization development [4].

The issues in the study area are the rock conditions that have undergone hydrothermal alteration processes and the presence of potential ore minerals in the form of Au, Ag, and Cu, which are economically valuable. This study aims to determine the geological setting and alteration based on geological mapping and geochemical analysis in the study area. The research location is in East Pinolosian District, Bolaang Mongondow Regency, North Sulawesi Province (Figure 1).

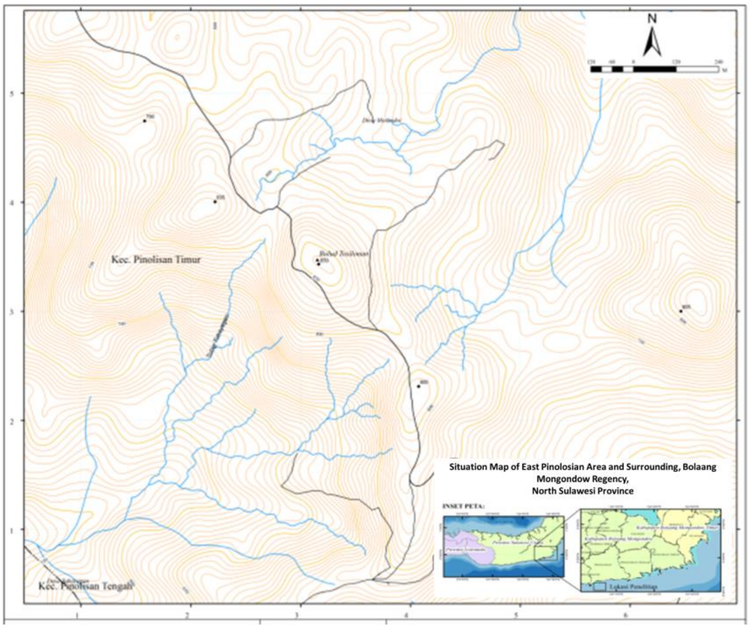

Figure 1. Research location in Bolaang Mongondow.

METHODOLOGY

This research used a multi-method approach, including geological mapping and laboratory analysis. Geological mapping includes data collection of lithology, geomorphology, geological structure, and alteration data in the field. Observations were made randomly on in-situ rock outcrops that could be observed in the field.

Laboratory analysis includes petrographic observations on thin section samples, mineragraphic observations on polished section samples, and geochemical analysis using the Atomic Absorption Spectrophotometry (AAS) method. Meanwhile, spectral analysis using Analytical Spectral Device (ASD) was conducted to determine the alteration zonation in the study area.

RESULTS AND DISCUSSION

Geomorphology

Exogenic processes generally influence geomorphology in the study area in the form of weathering and erosion, which are relatively high. In addition to exogenous processes, the study area is influenced by regional structures, as seen in the interpretation of straightness on topographic maps and Digital Elevation Model images (Figure 2). The structures that develop in the study area form a relatively northeast-southwest oriented alignment pattern.

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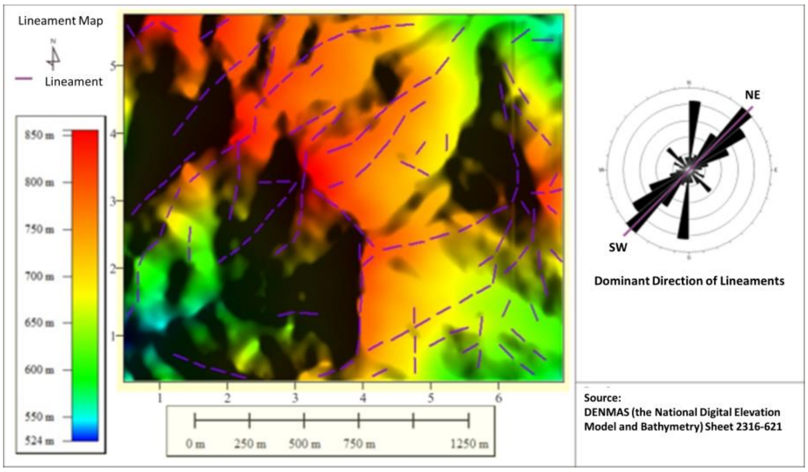

Figure 2. Lineament pattern and direction is showing relatively northeast-southwest oriented in the area.

The geomorphic units of the study area are divided using the classification of Landforms [8], which is genetically controlled by structure and lithology and morphographic, morphometric, and morphogenetic characteristics of each geomorphic unit. The geomorphic units of the study area consist of intrusion hill units and volcanic hill units.

A relatively dense pattern characterizes the intrusion hill unit, which has an overall slope of 17-35% with an altitude of about 700-800 meters above sea level. In general, the pattern of slopes leads in all directions with a "V" shaped valley in the morphology of the intrusion hill unit. It has low erosion and weathering rates, usually found in steep valleys. The lithology of this unit is diorite intrusion which occupies the eastern part with an area of approximately 2.15 Km^2 of the total study area and appears to be high-rise mountains caused by the intrusion process from the subsurface.

The volcanic hills unit is characterized by a relatively loose to tight contour pattern with the morphographic form of elongated hills. The elongated shape of the mountains is thought to be the result of deposits caused by the volcanic eruption process. This unit has a slope ranging from 9-16% at an altitude of 500-850 meters above sea level and has a steep slope relief with a steep and narrow valley shape and is controlled by faults and joints. The lithology of this unit is dominated by pyroclastic breccia and pyroclastic rocks, which are flow products from past volcanic eruptions distributed generally in all directions with an area of approximately 8.25 Km^2.

Lithologies

Based on field observations and petrographic analysis, the lithology of the study area is composed of andesite, diorite, and pyroclastic breccia units. The andesite unit is considered to be the oldest rock unit that is broken by the diorite unit. The pyroclastic breccia unit is the youngest in this area.

The andesite unit is megascopically seen as a light-dark gray, massive structure, hypocrystalline, porphyritic, phenocrysts measuring 0.2 mm-1 mm, euhedral-subhedral, composed of 20% plagioclase, 5% hornblende, and secondary minerals present as phenocrysts in the form of 5% chlorite and 3% calcite (Figure 3). Petrographic observations show that the andesite rock has undergone alteration to form 40% secondary minerals. The rock shows a porphyritic texture comprising 60% phenocrysts and 40% groundmass. The phenocrysts consist of 20% plagioclase, 20% k-feldspar, 10% hornblende, 2% biotite, and 1% quartz with size of 0.2-1.5 mm (Figure 4). Petrographic analysis shows that the andesite rock is classified as a hypabyssal rock group [9].

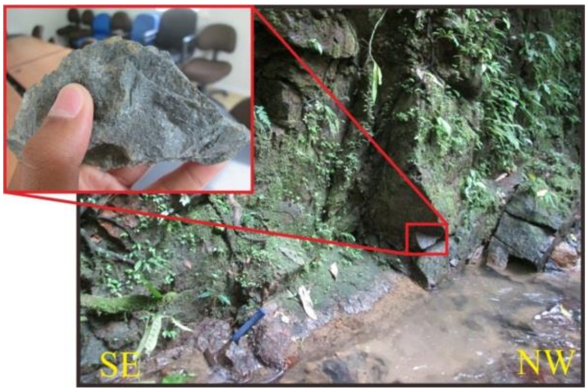

Figure 3. Andesite unit outcrop.

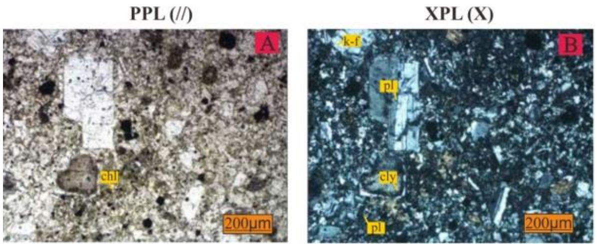

Figure 4. Andesite unit thin section on polarimetry microscope.

The diorite unit is dark to light gray, massive, holocrystalline, phaneritic, euhedral-anhedral, with a mineral composition of 20% plagioclase, 10% hornblende, 10% quartz, and contains magnetite and a small number of clay minerals (Figure 5). Microscopic observation of the thin section shows that the porphyry diorite rock has undergone alteration and formed secondary minerals by 80%. The rock is dominated by brown fine grains of clay minerals and black grains of opaque minerals, porphyritic rock texture with 20% plagioclase, 20% k-feldspar, 5% quartz, 10% hornblende, 2% biotite, 3% magnetite as phenocrysts. The 60% glassy groundmass is partly remnants, i.e., short and long tabular molds. Phenocrysts measuring 0.5-1 mm are embedded in the altered groundmass. Secondary minerals consist of clay minerals 25%, opaque minerals 5%, and sericite 35% (Figure 6).

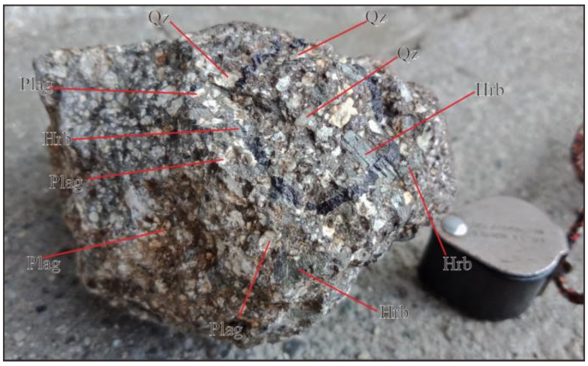

Figure 5. Diorite unit hand specimen.

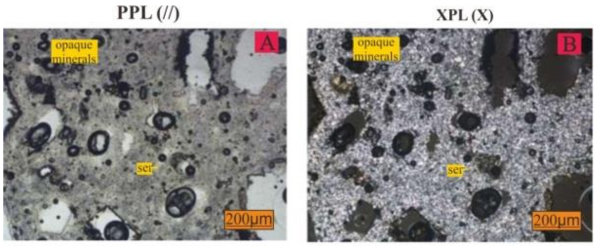

Figure 6. Diorite unit thin section on polarimetry microscope.

The pyroclastic breccia in megascopic is light gray to brownish, massive with grain size from lapillus to block size (2mm-64mm), moderately angular, poorly sorted, open packed, monomic–polymictic. Rock composition is quartz, hornblende, and additional minerals (fine tuff to altered minerals), as seen in Figure 7. There are fragments of dacite embedded in the tuff matrix and other strongly altered rocks with a vuggy quartz mineralization structure. Alteration minerals such as clay 2%, pyrite 5%, hematite 10%, and alunite 2% are present. Microscopic observations show the appearance of fragments of dacite rock that form secondary minerals by 80%. These fragments cause brown fine grains of sericite, clay minerals, and black grains of opaque minerals to dominate. The rock texture is

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porphyritic, with 25% plagioclase, 10% k-feldspar, 5% quartz, and 5% pyroxene/hornblende as phenocrysts. Phenocrysts measuring 0.5-2 mm embedded in 45% altered ash groundmass. Secondary minerals consist of clay mineral 20%, opaque mineral 30%, sericite 15%, quartz 10%, and chlorite 5% (Figure 8).

Figure 7. Pyroclastic breccia unit outcrop

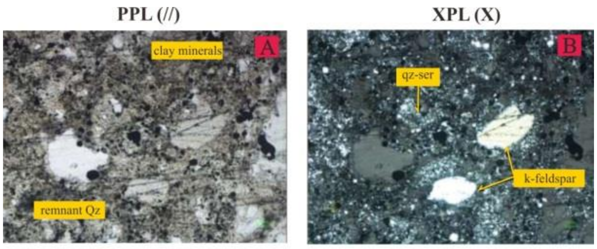

Figure 8. Pyrocalstic breccia unit thin section on polarimetry microscope.

Geological Structures

The geological structures observed in the study area are faults characterized by fault planes, slicken-side, and joints in the outcrops. There are two main directions of faults in the study area: the Northwest-Southeast trending fault, a dextral fault, and the northeast-southwest trending fault, a sinistral fault. The structure is a fault structure that crosses the island arc. The northeast–southwest oriented structure is interpreted as the carrier structure of mineralization in the study area [5].

Alteration Zones and Mineralization Potency

The study area indicates a high sulfidation epithermal deposit system by comparing the similar characteristics of medium sulfidation epithermal and low sulfidation epithermal [10]. Alteration zonation is based on field observations on rock outcrops that have undergone alteration and correlated with data from spectral analysis. The alteration zones are grouped into silicified zone (massive silica + vuggy silica), advanced argillic zone (illite + alunite + dickite + halloysite + kaolinite), argillic zone (illite + montmorillonite + phyropilite), and propylitic zone (illite + montmorillonite + phyropilite) (Figure 9 and Figure 10).

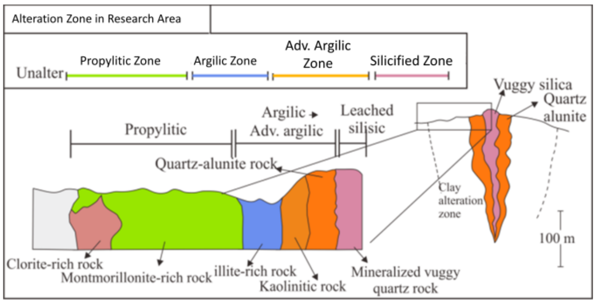

Figure 9. Schematic of high sulfidation epithermal system in the area

The silicified alteration zone is the central part of the formation of the high sulfidation epithermal system. The presence of massive silica and vuggy silica textures can characterize the genesis of the silicification zone. Mineragraphic observations indicate the presence of oxidized minerals, hematite, and limonite. The silicification zone in the study area is formed in pyroclastic breccia lithology.

The advanced argillic zone is generally formed in the proximal zone of the formation of high sulfide epithermal deposits. Minerals observed in the field are clay minerals 10%, silica 80%, alunite 5%, and quartz 2% distributed in pyroclastic breccia lithology.

Based on ASD laboratory analysis, there is a set of alteration minerals in the form of illite + alunite + dickite + halloysite + kaolinite which has a relatively wide distribution in the study area.

The argillic zone has a crumbly characteristic with observable mineral occurrences of 2% quartz, 10% feldspar, 2% kaolin, and 80% clay minerals. The argillic alteration zone has an analyzed set of alteration minerals in the form of illite + montmorillonite + pyrophyllite.

The propylitic alteration zone is far from the center of the epithermal high sulfidation deposit system. The megascopic appearance observed in the field is the mineral chlorite 2% and calcite 5% in andesite lithology. The results of ASD analysis show that the alteration mineral is chlorite + montmorillonite.

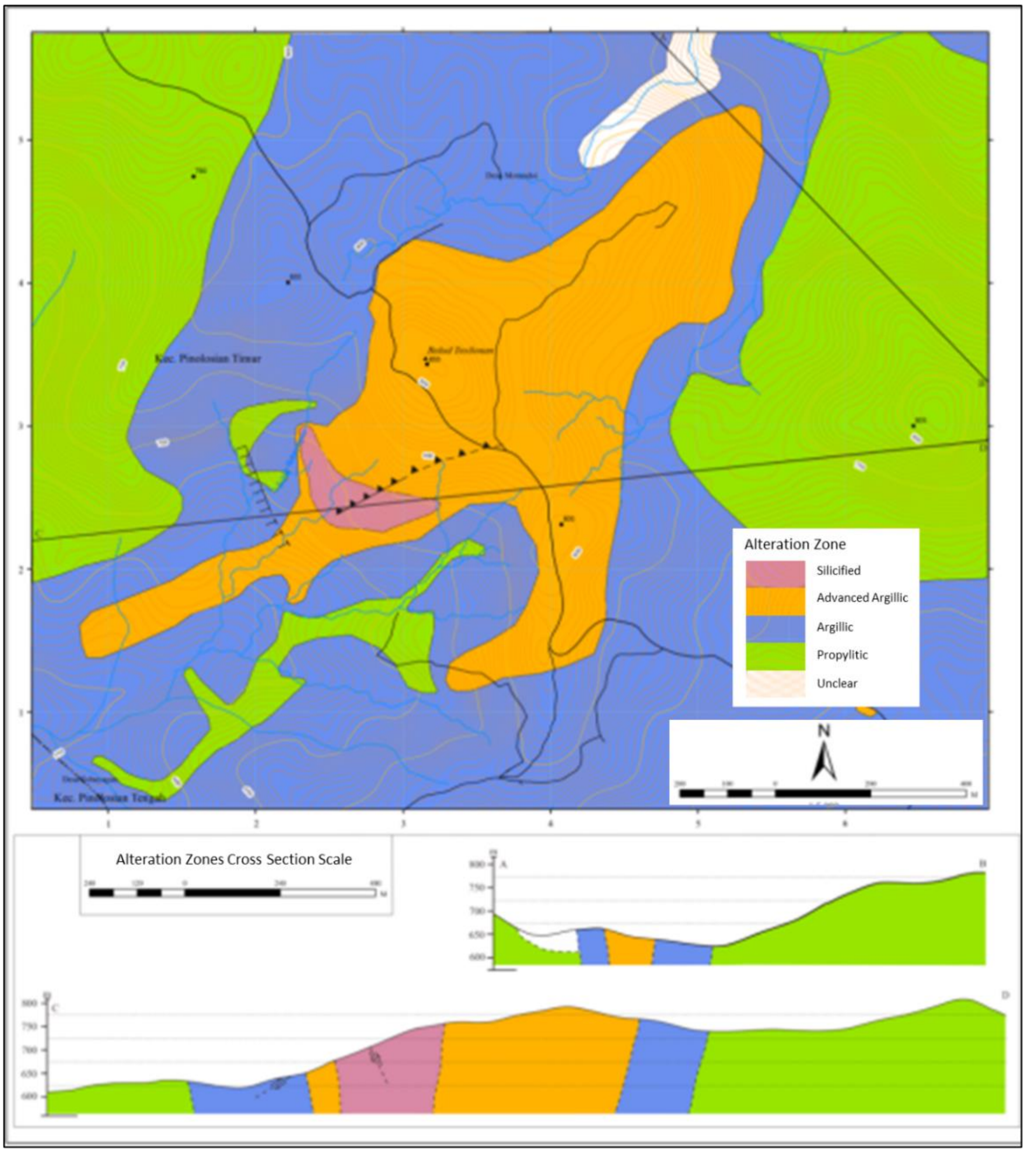

Figure 10. Alteration zones map in the research area.

The AAS analysis was conducted to determine the distribution of Au content in the alteration zone. The results of AAS analysis have an average Au content value of 0.03-0.19/ppm in the silicified zone, 0.01–0.47/ppm in the argillic advan zone, and 0.01–0.03/ppm in the argillic and propylitic zones (Figure 11).

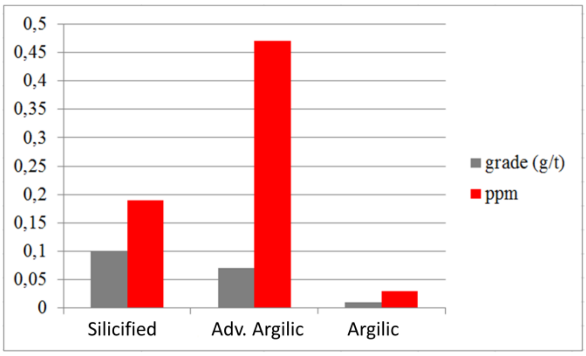

Figure 11. Graph of grade/ppm in alteration zones shows the highest Au content in the advanced argilic zone.

Alteration minerals in the study area indicate the temperature conditions for high sulfidation epithermal deposits. Based on alteration minerals, it is known that the degree of acidity is dominant at acidic pH with temperature conditions ranging from <100°–200°C caused by leached activities from gas removal due to reactions in the alteration process in the zone. Minerals with acidic pH in the study area are alunite, halloysite, kaolinite dickite, and pyrophyllite.

CONCLUSIONS

The geological setting of the study area is composed of andesite units which are then intruded by diorite intrusions. Pyroclastic breccia rocks were formed during the Pliocene age. At the same time, sinistral faults were formed, which are believed to be the host of mineralization. The study area is a complex system of the formation of epithermal high sulfidation deposits. The alteration zones of the study area are divided into silicified, advanced, argillic, and propylitic zones. The highest Au levels were observed in the Argillic Advanced alteration zone with 0.01–0.47/ppm levels. This area is considered to have potential economic mineral reserves.

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