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Mineralogy and Fluid Inclusion Microthermometry of Epithermal Gold-Base Metal Mineralization at Anggai, Obi Island, Indonesia

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Abstract: Epithermal gold-base metal mineralization at Anggai village, Obi island, Indonesia has been identified through an exploration program by Broken Hill Proprietary Company during 1995 to 1996. This paper describes a preliminary study on the prospect which focused on its ore and gangue mineralogy, hydrothermal alteration, fluid inclusion microthermometry as well as geochemistry, to elucidate the formation conditions and ore grades. Fresh and altered rocks and mineralization samples were collected from field work to be studied using petrography and ore microscopy, X-ray diffraction analysis, atomic absorption spectrometry, and fluid inclusion microthermometry. The study resulted that host rocks of the mineralization are fine-grained porphyritic basalt and andesite of the Oligocene to Early Miocene Bacan Volcanics. Hydrothermal alteration mineral assemblages include quartz, chlorite, epidote, albite, less biotite, sericite, and pyrite. Mineralization styles are crustiform quartz vein and dissemination, where sulphides clustered and disseminated in closed-space either in quartz gangue and in strongly altered host rocks. Under the microscope, main hypogene ore minerals identified include galena, sphalerite, chalcopyrite, and pyrite which hosts fine-grained gold. Fluid inclusion microthermometric study on the vein quartz resulted homogenization temperature of 220 to 230°C and salinity of 2.0 to 2.5 wt.% NaCl equivalent. Chemical analysis of nine selected samples indicated highest grades of 98 g/t Au, 275 g/t Ag, 0.61% Cu, 48% Pb, and 5.35% Zn.

Keywords: Obi; epithermal; gold; mineralization; fluid inclusion

1. INTRODUCTION

Epithermal gold prospect at Anggai Village, Obi Island, South Halmahera Province, Indonesia, has been worked by hundreds of artisanal and small-scale gold miners by digging over 200 pits, shafts and adits, since 1994. The Anggai gold prospect was first explored during 1995 to 1996 by PT. Obi Minerals, a subsidiary company owned by Broken Hill Proprietary (BHP) Minerals Sulawesi Inc. and PT Aneka Tambang (Indonesian mining company). The company performed 10 holes diamond drilling and gained a range of 6.13 to 26.25 g/t gold from depths of 38.0 to 78.6 m [1,2].

In 2007, The Centre Bureau of Geological Resources of Indonesia conducted a preliminary survey in the prospect, and reported that the mineralization which hosted in andesitic lava is characterized by sugary and vuggy quartz veins and stockworks that contain pyrite, chalcopyrite and galena. The veins are generally north-south striking with 30 to 50° dipping to east, and 2 to 5 cm in thickness. Hydrothermal alteration includes silicic, sericitic, and argillic. Chemical analyses resulted highest grades of 5 gr/t Au and 4 g/t Ag in stream sediment, and 1 gr/t Au and 1 gr/t Ag in soil samples [3].

Later, during 2010 to 2011, Ashburton Minerals Ltd., an Australian mining company performed a surface exploration program covering an area of 77 km² in and around the artisanal goldfield. Some results of the project are briefly described here. The mineralization style is epithermal Au-Ag vein breccia. The
artisanal workings are closely distributed within an area of about 300 ha, following the strike corridor (about 200 m wide) of the mineralization which extending southward. Some of the larger veins appear to be continuous along strike for several hundred meters; the mineralization trend is about 10 km north-south. At least five separate veins are noted across strike of the main zone, with individual veins occasionally worked to depths in excess of 50 m. Assay of 15 run-of-mine random samples indicated average grades of Au is 16 g/t (from a range of 4.35 to 42.30 g/t), Ag 11 g/t (2.30 to 32.30 g/t), Cu 0.10% (0.04 to 0.29%), Pb 0.56% (0.18 to 1.90%), Zn 0.46% (0.10 to 2.27%), and As 149 ppm (43 to 420 ppm); which beside gold and silver, also indicates significant concentration of base metals and low concentration of arsenic [1,2].

This paper describes an update study of the prospect based on recent field and laboratory data, which focused on its ore and gangue mineralogy, hydrothermal alteration, fluid inclusion microthermometry as well as geochemistry, to elucidate the formation conditions and ore grades of the mineralization.

2. GEOLOGY OF OBI ISLAND

Obi island is one of the northern Molucca islands of Indonesia (Halmahera, Bacan, Obi, Waigeo, and several small islands surrounding Halmahera) which bounded on the south by the strike-slip Sorong fault system; on the west by north Molucca Sea; on the northeast by south end of the Philippine Trench; and on the east by a northwest-trending member of the Sorong fault system [4] (Figure 1).

This study consists of two main stages, field works and laboratory works. The field works were conducted in and around the artisanal goldfield, where fresh and altered rock and mineralization samples were collected from outcrops as well as from the artisanal workers run-off mine. The laboratory works include petrography, ore microscopy, X-ray diffraction (XRD) analysis, fluid inclusion study, and chemical analysis. For the XRD analysis, powdered altered rock and mineralization samples were scanned using a RIGAKU-Multiflex machine, and all data recorded were further analyzed using PDF-2 program issued by Mineral Data Institute (MDI) combined with Impact Match! version-2 software, to identify mineral species in the samples. For fluid inclusion study, mineralized vein quartz samples were prepared in 100 µm doubly polished wafers to be observed under transmitted light microscope, and then the temperatures were measured using a heating-freezing stage of LINKAM 10035. For determination of salinity, the ice melting temperatures of fluid inclusions resulted from the microthermometry were then converted using the equation of Bodnar [11]. Both the XRD and fluid inclusion microthermometric works were performed at the Economic Geology Laboratory, Akita University, Japan. For chemical analysis, mineralization samples were sent to be prepared and analyzed by atomic absorption spectrometry (AAS) method in a commercial research laboratory, PT. Intertek Utama Services, Jakarta, Indonesia.

4. RESULTS AND DISCUSSIONS

Field and microscopic observations revealed that host rocks of the mineralization in the study area are fine-grained porphyritic basalt and andesite. Physical, mineralogical and textural characteristics indicated that the rocks are members of the Bacan Volcanics which Oligocene to Early Miocene in age [10]. Most of the rocks are hydrothermally altered, indicated by light green to green in color which related to the presence of chlorite and epidote that generally observed in the field and Obi island has a similar geological characteristics with Halmahera island where the high-grade gold-silver (27 g/t Au, 38 g/t Ag) Gosowong epithermal deposite lies [9].

Locally, Obi island is arranged by Pre-Tertiary ultramafic, metamorphic, and metasedimentary rocks; Tertiary volcano-sedimentary, clastics and carbonaceous sedimentary, volcanic and intrusive rocks; and Quaternary sediments of reef limestone, terrace and lake deposits, as well as aluvium. One of the Tertiary volcano-sedimentary units is the Oligocene to Early Miocene Bacan Formation, where the Anggai gold prospect (study area) located. This consists of breccia and lava which intercalated by tuffaceous sandstone and claystone. The breccia is composed by andesite, basalt, and red chert fragments; while the lava is greenish grey in color, andesitic, propylitized, and contains calcite and quartz veinlets. This unit is widely distributed in the northern and central parts of the island. Major geological structures in Obi island are north-northwest normal faults which mainly distributed in the north (particularly in the Bacan Formation), and east-west trended anticlines and synclines which mainly distributed in clastic sedimentary units in the south [10].
hand specimen samples. Detailed alteration study (microscopic and XRD analyses) showed that proximal hydrothermal alteration mineral assemblages include quartz, chlorite, epidote, albite, biotite, sericite, and pyrite. Under the microscope, it was observed that in samples of strongly altered hostrock, the alteration were generally developed in three stages: (1) coarse-grained quartz and less chalcedony in banded texture, (2) fine-grained quartz ± clay, sericite, chlorite, epidote, less albite and secondary biotite, and opaque, and (3) opaque in veins and disseminated. The opaques were further identified by XRD, dominated by pyrite. This figures suggested that in general the distal hydrothermal alteration is propylitic type, which indicated by dominant appearance of chlorite and epidote, whereas in the more proximal, silicic and argillic (indicated by the dominance of quartz and clay minerals) are the main alteration types.

The mineralization styles are crustiform quartz vein and dissemination, where sulphide ore minerals clustered and disseminated in closed-space either in quartz gangue and in strongly altered host rocks. Beside quartz, crystals of amethyst were also observed as gangue. In hand specimens, the quartz veins (1 to 8 cm thick) and veinlets (0.1 to 0.9 cm) were generally characterized by crustiform banded, crystalline (mostly hexagonal, maximum 1.5 cm to fine-grained saccharoidal quartz), comb, and vuggy textures. Fine to coarse grains of pyrite, chalcopyrite, galena, and sphalerite were the main sulphides identified in hand specimen samples (Figure 2). Crystals of galena and sphalerite were observed occurred in disseminated coarse grains, 1.3 cm for galena and nearly 1 cm for sphalerite; in one sample a sulphide band of galena also found. Under the microscope, hypogene ore minerals identified include galena, sphalerite, chalcopyrite, pyrite, and less tennantite and tetrahedrite. Fine-grained electrum (20 µm) was observed as an inclusion in euhedral pyrite (Figure 3), from a highly mineralized quartz vein sample. Supergene minerals covellite and goethite were also identified in polished sections, where covellite generally distributed around the fringe of chalcopyrite, and some totally replaced chalcopyrite, while goethite mostly replaced pyrite.

Nine selected mineralization samples were assayed using AAS method to measure their Au, Ag, Cu, Pb and Zn grades. The result is shown in Table 1. The highest grade of each element is as follow: 98 g/t Au, 275 g/t Ag, 0.61% Cu, 48% Pb, and 5.35% Zn. Sample with code ST.12.B that contains the highest gold grade, is a strong silicified quartz vein sample which having an intensive vuggy (0.1 to 0.3 cm) and saccharoidal quartz texture. Medium to coarse grained sulphides were clustered in the vein, with dimension of each cluster is 1.7 to 2.0 cm. Galena, chalcopyrite, sphalerite and pyrite were disseminated in very closed-space in each cluster. Single crystals of galena was up to 5 mm, and sphalerite 2 mm. Hand specimen and microscopic photographs of this sample were shown in Figure 2 and Figure 3, respectively.

**TABLE I. ORE GRADES MEASURED BY AAS**

<table>
<thead>
<tr>
<th>Sample code</th>
<th>Au (ppm)</th>
<th>Ag (ppm)</th>
<th>Cu (%)</th>
<th>Pb (%)</th>
<th>Zn (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST.04.B</td>
<td>1.36</td>
<td>2</td>
<td>0.03</td>
<td>0.02</td>
<td>0.06</td>
</tr>
<tr>
<td>ST.07.B</td>
<td>30.80</td>
<td>13</td>
<td>0.16</td>
<td>2.12</td>
<td>5.35</td>
</tr>
<tr>
<td>ST.08.B</td>
<td>2.62</td>
<td>17</td>
<td>0.61</td>
<td>0.34</td>
<td>1.33</td>
</tr>
<tr>
<td>ST.09.B</td>
<td>13.60</td>
<td>275</td>
<td>0.21</td>
<td>48.00</td>
<td>0.16</td>
</tr>
<tr>
<td>ST.10.B</td>
<td>2.59</td>
<td>7</td>
<td>0.16</td>
<td>0.87</td>
<td>1.04</td>
</tr>
<tr>
<td>ST.10.P</td>
<td>4.62</td>
<td>4</td>
<td>0.06</td>
<td>0.14</td>
<td>0.52</td>
</tr>
<tr>
<td>ST.11.B</td>
<td>5.72</td>
<td>10</td>
<td>0.11</td>
<td>0.37</td>
<td>0.61</td>
</tr>
<tr>
<td>ST.12.B</td>
<td>98.00</td>
<td>33</td>
<td>0.54</td>
<td>1.33</td>
<td>1.40</td>
</tr>
<tr>
<td>ST.15.B</td>
<td>3.10</td>
<td>3</td>
<td>0.02</td>
<td>0.03</td>
<td>0.06</td>
</tr>
</tbody>
</table>

Fluid inclusion microthermometric study was conducted in quartz of mineralized veins. Under the microscope, generally the size of fluid inclusions ranges from <5 to 30 µm, vary in shape, mostly angular, elongated, and prismatic. At room temperature, all fluid inclusions showed two-phase liquid-vapor (liquid rich) with range of \( V/(V + L) \) is 10 to 50% (Figure 4). The inclusions spreaded parallel and some defining the quartz crystal fringes as a cluster of inclusions and were interpreted as primary inclusions; less were found trapped along microfractures, which classified as secondary inclusions, according to the criteria of Roedder and Bodnar et al. [12,13]. Homogenization- and ice melting temperature were only measured on the primary inclusions.
Fig. 4. Photomicrographs of primary two-phase liquid-vapor (liquid rich) fluid inclusions in vein quartz (sample code ST.12.B). L: liquid, V: vapor.

Histograms of fluid inclusion microthermometric results is shown in Figure 5. As mentioned in the methods, the salinity values were determined by converting ice melting temperatures using the equation of Bodnar [11]. Based on the peaks of the histograms, it is estimated that formation temperature of the mineralization is 220 to 230°C, while salinity of the responsible hydrothermal fluid is 2.0 to 2.5 wt.% NaCl equivalent. Trend of homogenization temperature vs salinity plot of the highest gold grade sample (ST.12.B), which generally parallel to salinity axis (Figure 6), indicated that the mineralization precipitated from a hydrothermal fluid that isothermally mixed with other contrasted salinity fluid, and not related to boiling [14]. The estimated formation temperature was then used to infer formation-depth and pressure of the mineralization using the boiling point curve and P-V-T data of Haas [15]. Since the curve was constructed using P-V-T data of boiling condition, while there is no indications of boiling mechanism responsible for the precipitation, thus the formation depth estimated in this study is minimum depth. By plotting the formation temperature to the boiling point curve, the estimated minimum depth of the formation is 250 to 300 m below paleo-water table, which corresponds with 23 to 28 bar hydrostatic pressure [15].

Fig. 5. Histograms of homogenization temperature and salinity determined from fluid inclusion microthermometry (sample ST.12.B, n=33).

Fig. 6. Homogenization temperature vs salinity plot (sample ST.12.B, n=33).

5. CONCLUSIONS

Some conclusions defined in this study, include:

- Host rocks of the mineralization are members of the Oligocene to Early Miocene andesitic-basaltic Bacan Volcanics.
- Hydrothermal alteration were zoned from distal propylitic (mainly characterized by chlorite and epidote) to proximal silicic and argillic (quartz and clay).
- Mineralization styles are quartz vein and disseminated with identified hypogene ore minerals of pyrite, chalcopyrite, galena, sphalerite, less tennantite and tetrahedrite, and gold.
- The range ore grades are: 1.36 to 98 g/t Au, 2 to 275 g/t Ag, 0.02 to 0.61% Cu, 0.02 to 48% Pb, and 0.06 to 5.35% Zn.
- The mineralization is inferred to be formed in temperature range of 220 to 230°C, pressure of 23 to 28 bar, within a depth range of 250 to 300 m below paleo-water table, precipitated from hydrothermal fluid that isothermally mixed with contrasted salinity fluid (salinity range of 2.0 to 2.5 wt.% NaCl equivalent), and not related to boiling mechanism.
- The whole hydrothermal alteration characteristics, ore and gangue mineral assemblages, mineralization styles and their textural properties, fluid inclusion signatures particularly the two-phase liquid-vapor (liquid rich) dominant inclusions in vein quartz, as well as the physico-chemical conditions of the formation (temperature, pressure, depth, precipitation mechanism, and salinity of responsible hydrothermal fluid) indicated that the gold-base metal mineralization in the study area is epithermal low sulphidation.

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