ORE MINERALIZATION, ALTERATION AND MINERALIZING HYDROTHERMAL FLUID CHARACTERISTICS OF THE AWAK MAS MESOTHERMAL GOLD DEPOSIT, SOUTH SULAWESI, INDONESIA

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ABSTRACT
Awak Mas is a mesothermal, sedimentary hosted gold deposit in Luwu, South Sulawesi, eastern part of Indonesia with an approximate measured resources of 2.13 Mio Oz. Drilling within Awak Mas including its satellite prospects, now totals 1,012 holes with an aggregate meterage of 118,081.30 meters. The Awak Mas deposit, located in the southern section of the Central Sulawesi Metamorphic Belt, is hosted within the Latimojong Formation. Predominant lithology is composed of a thick sedimentary sequence (flisch), slate, phyllites, metasandstone, metasilstone and metaclaystone, overlying basement metamorphic rock, and intruded by stocks, granite, granodiorite and diorite. Mineralization styles in Awak Mas formed in sheeted, stockwork and brecciated quartz vein, open space filling in fracture or disseminated in host rock. Gold at Awak Mas is associated with sulphur-poor, sodic-rich fluids introduced at a relatively late stage in its tectonic history. Gold at Awak Mas, can occur as inclusion in pyrite and disseminated as native gold in wall rock. Wall rock alteration consist of 3 type of alterations including quartz – sericite - pyrite (sericitization), albite – sericite ± carbonate ± chlorite (albitization), and carbonate – quartz ± chlorite ± tourmaline (carbonatization). Fluid inclusion formed in 2 phases i.e. liquid – rich, L + V where L > 30%, formed at temperature in quartz vein range of 194°C to 320°C, low salinity, approximately 3 to 1.2 wt.% NaCl eq. formed at depth of minimum about 390 to 1,100 m below paleowater table. CO₂ – rich inclusions are commonly taken into indication of a non – igneous origin and typical of orogenic (mesothermal) gold deposits formed during accretionary tectonic events.

I. INTRODUCTION
The Awak Mas Project is located in the Luwu District of southern Sulawesi, Indonesia, at coordinates 3⁰21'30" - 3⁰22'15" S dan 120⁰6'45" - 120⁰7'45" E lying adjacent to the coast at the head of the Gulf of Bone. From Makassar, the provincial capital of South Sulawesi, the road distance is 367 km to the town of Belopa and from the Belopa, another 41 km to the project site. (Figure 1).

II. GENERAL GEOLOGY
Deposits occur in rugged tropical rainforest country in the foothills of Latimojong Mountains. The bottom of the deposits is at 800 metres above sea level with slope up to 30° and which rises up to 1,500 metres. Latimojong Mountains composed of basement metamorphic rocks and younger sediments in geological area of Western Sulawesi. The main lithologic unit overlying the area is the Late Cretaceous Latimojong Formation, which consists of phyllites, slates, basic to intermediate volcanics, limestones, and schists representing a platform and/or fore arc trough, flysch sequence (Figure 2). This formational unit overlies basement metamorphic rocks composed of phyllites and slates. Intruding the older sequences are late-stage diorite, monzonite and/or syenite plugs and stocks. East of the metamorphic block is the Mesozoic Lamasi Complex, which is composed of basic intermediate intrusives, pyroclastics, and volcanogenic sediments.

III. GEOLOGY OF AWAK MAS
The description of geological framework of Awak Mas is based on Geological map of
Majene and Western Palopo sheet, (Djuri et al., 1998). Stratigraphically, the lithologies of the Awak Mas from the oldest to the youngest are successively occupied by Latimojong Formation (Kls), Lamasi Volcanic Formation (Tolv) and felsic intrusives rock (Tmpi). Latimojong Formation (Kls) mostly composed of low grade metamorphic rocks ranging phyllite, slate, marble, chert, and quartzite. The Lamasi Complex ophiolite or Lamasi Formation (Tolv) includes dioritic plutons, basaltic sheeted dykes, pillow lavas, greenstones, tuffs and volcanic agglomerates. Late Miocene to Pliocene extrusive and intrusive rocks form a cogenetic volcanoplutonic complex of calc-alkalic to mildly alkaline, potassic, and shoshonitic felsic and mafic magmatic rocks of bimodal composition which were erupted and intruded during a short episode of Middle Miocene to Pliocene (3 - 18 Ma) lithospheric melting consist of include granit, granodiorite, syenit, quartz monzonite, and ryholite. The predominant lithologic unit is a thick sedimentary package that has been subjected to a low-grade, greenschist facies metamorphism. The rocks are generally light to dark grayish green, foliated, typically fine-grained, with protoliths ranging from metaclaystone, metasiltstones to metafine-grained sandstones. There are Three major NNE-SSW trending, parallel to sub-parallel, sub-vertical fault zones transect Awak Mas. These have been arbitrarily designated as the Chinese, Garlic, and Discovery Faults (Figure 3). Syn- to post-mineralization movements have resulted in the displacement of mineralized zones. The earliest displacements indicate dextral sense of motions although later local kinematic indicators suggest a shift towards sinistral movements. Sheared intervals frequently occur in between major structures.

Awak Mas is a mesothermal, metamorphic-hosted gold deposit. The gold is associated with sulphur-poor, sodic-rich fluids introduced at a relatively late stage in its tectonic history. Albite-pyrite-silica-calcareous alteration generally accompanies gold deposition and overprints the ductile fabric associated with deformation and metamorphism in the older basement lithologies. The Awak Mas deposit has been subdivided into 5 discrete domains based on the nature and orientation of mineralization. These domains have been designated as the Ongan, Mapacing, Lematik, Tanjung, and Rante domains. Steep faults commonly form the bounding structures separating these domains. This paper just discusses about domain Rante.

IV. RESEARCH METHODS

This preliminary study has been carried out through several approaches including desk study, fieldwork and sampling for laboratory analysis. There are 53 rock samples from the field taken from 4 points of observation and 2 selected drill holes including AMD 682 and AMD 648 from Domain Rante. Host rocks and gold-bearing quartz vein samples were taken, and petrographically analyzed for hydrothermal alteration and ore mineralogy at Department of Geological Engineering, Gadjah Mada University and Laboratory of Mineralogy, Center of National Atomic Agency in Jakarta. Rock geochemical analyses were conducted in Center of National Atomic Agency in Jakarta. Fluid inclusion within quartz veins from various stages were microthermometrically analyzed by LINKAM THMS600 heating and freezing stage at LIPI Geotechnology Research Centre, Bandung. 28 selected samples were analysed for petrography (thin section), 26 samples for ore microscopy (polished section), 11 samples selected to fluid inclusion (double polished section) and 4 selected samples for XRF (X-Ray Fluorescence) analysis.

V. RESULTS AND DISCUSSION

Alteration and Ore Mineralogy

Awak Mas is a mesothermal, metamorphic-hosted gold deposit. The gold is associated
with sulphur-poor, sodic-rich fluids introduced at a relatively late stage in its tectonic history. Albite-pyrite-silica±carbonate alteration generally accompanies gold deposition and overprints the ductile fabric associated with deformation and metamorphism in the older basement lithologies (Gustavson, 2007 in Querubin, 2012). Hydrothermal alteration style is identified according to field observation and petrographic analysis. In domain Rante, Awak Mas consist of 3 type of alteration, there are (1) quartz – sericite – pyrit (sericitization) in Figure 4, (2) carbonate – quartz – opaque mineral ± chlorite ± tourmalin (carbonatization) in Figure 5, and (3) albite – sericite – opaque minerals +carbonate + clorite (albitization) In figure 6. Minerals alteration present in all of sample in the field with differential intensity. Commonly, sericitization present in the near to surface in DOMAin Rante, Awak Mas. Type of this alteration are content dominan sericite mineral disseminated in wallrock, associatted with quartz and pyrit, present in brown metasediment, commonly sericite mineral form from replacement feldspar mineral to sericite. Intensity of alteration commonly high (18 - 65%), with selective pervasive. Carbonatization present in dark to light grey metaclaystone, disseminated or associatated with quartz in vein or fracture (open space filling). Intensity of alteration commonly low (16 - 40%), with selective pervasive. In this type of alteration present mylonit teksture, form by active structure through the litology. Albitization, commonly take place in lower drill hole, present in green metasedimen, with disseminated and associatated with quartz in the fracture (open space filling). The intensity of alteration commonly high, selectively pervasive to pervasive (25 - 95%).

Mineralization is typically hosted within a flysch sequence that generally dips 15° to 50° north. Gold is usually associated with abundant quartz veining and silica-albite-pyrite alteration. Oblique normal faults as well as extensional shears and fractures, formed in response to extensional deformation, serve as local controls to mineralization although the orientation of the local host foliation likewise acts as an essential component. (Querubin, 2012). Field observation and ore microscopic analysis indicates that ore mineralization is characterized by sulphide mineral and oxide mineral. There are pirit, chalcopyrite and electrum (very rare). Oxide minerals and enrichment consist of hematite, goethite magnetit, digenit.

The Awak Mas deposit has a defined ore resource with current measured and indicated resources of 45.2 million tonnes at 1.41 g/t Au at a cut-off of 0.5 g/t Au with an additional 2.6 million tonnes at 1.14 g/t Au in the inferred classification. Gold mineralization is closely related to abundant quartz veining. There are 3 type of quartz veinin in domain Rante Awak Mas, sheeted quartz vein, stockwork quartz vein and brecciated quartz vein. (Figure 8). Commonly sheeted quartz vein present in the dark metaclaystone with low alteration, commonly in carbonatization alteration and poor mineralization, stockwork quartz vein commonly present in the green - yellow metasilstone with med alteration, commonly in albitization alteration, brecciated quartz vein present in metasedimen with active structure, high mekanik pressure from the structure and break the lithology, commonly present in the brown metasedimen and associated with sericitization alteration and rich of ore mineralization. Base on XRF analysis from 4 sample selected in domain Rante Awak Mas, value of gold present in brecciated quartz vein higher than stockwork quartz vein and sheeted quartz vein, value of gold at ppm in brecciated quartz vein at 2,9 ppm/sample and sheeted vein at 1,9 ppm/sample and stockwork quartz vein at 2,3 ppm/sample.

**Mineralizing Fluid Characteristics**

Based on fluid inclusion analysis, 2 type inclusions are present in the samples including...
primary and secondary inclusions. Both of them present in the sample, but for measure the temperaure homogenisation we just take the primary fluid inclusion. Petrographic study indicates that fluid inclusions in quartz vein types consist of 2 phases including liquid – rich and L + V where L > 30%. (Figure 10). The temperature of homogenization (Th), interpreted to be the formation temperature of the of quartz vein varies from 194 °C to 320°C, temperature in parallel foliation vein is higher than across foliation vein and brecciated vein. The parallel foliation vein formed at temperature ranging from 225 to 320 °C, across foliation vein formed at temperature range from 230 °C to 270 °C and brecciated vein formed at temperature range from 194–280 °C, formed at low salinity range from 0.3 wt.% NaCl equivalent to 1.2 wt.% NaCl equivalent. Based on boiling – point curve of Haas (1971), the vein formed at depth minimum at 390-1100 m below paleowater table. The density of fluid in Awak Mas are almost near 1.0 g/cm³, approximately 0.7 g/cm³ to 0.9 g/cm³. Based on homogenization temperature–salinity diagram illustrating typical ranges for inclusions from different deposit types of Wilkinson (2001), the Awak Mas deposit is categorized into lode Au or mesothermal gold (Figure 12).

Th vs salinity diagram space due to various fluid inclusion evolution processes and precipitation mechanism (modified from Shepherd et al, 1985 and Wilkinson, 2001), the evolving fluid inclusion formed at boiling (low salinity, CO₂ – bearing), mixing with cooler, less saline fluid surface fluid dilution and isothermal mixing with fluids of contrasting salinity. CO₂ – rich inclusions are commonly taken to indicate a non – igneous origin and typical of orogenic (mesothermal) gold deposits formed during accretionary tectonic events. Gold at Awak Mas is associated with sulphur-poor, sodic-rich fluids introduced at a relatively late stage in its tectonic history.

Ore chemistry

Four rock samples were collected in Domain Rante area for ore geochemical (XRF ) in mineralogy Laboratory, BATAN, Jakarta for Au, Ag, As, Sb, Hg, Cu, Pb, and Zn. The samples were collected in various places, there are 2 type sample, surface sample and drill hole samples. All of the sample contain low grade gold. Sample from ST 1/R1/H contain <1,2 ppm Au, sample ST 2/R3/V contain 2,9 ppm Au. Sample from AMD 682/37/-7 contain 2,3 ppm Au and sample from AMD 682/7/8 contain 1,9 ppm Au. For the other elements e.g Ag, As, Sb, Hg, Cu, Pb, and Zn present in the sample relatively low.

VI. CONCLUSION

Awak Mas is a mesothermal gold deposit hosted in a flysch sequence (Latimojong Formation) that generally dips 15° to 50° north, with dominant lithology is metasediment consisting of metaclaystone, metasilstone, metasandstone and slate. There are 3 alteration types with different intensity, including sericitization, carbonatization, and albitization. Three quartz vein types identified consist of sheeted, stockwork and brecciated quartz veins. Ore minerals are pyrite, chalcopyrite, electrum inclusion in pyrit, and oxide mineral are hematite with goethite, form by hidration hematit minerals. The gold is associated with sulphur-poor, sodic-rich fluids introduced at a relatively late stage in the regional tectonic history. Gold mineralization is closely related to abundant quartz veining and silica-albite-pyrite alteration. Fluid inclusion formed in 2 fase, liquid – rich, L + V where L > 30%, formed at temperature in quartz vein range of 194 °C to 320°C, low salinity, CO₂ – rich inclusions are commonly taken to indicate a non – igneous origin and typical of orogenic (mesothermal) gold deposits formed during accretionary tectonic events.
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**FIGURE**

Figure 1 Location map of the Awak Mas
Figure 2. Generalized geologic map of the Awak Mas project (after Archibald et al., 1996)

Figure 3. Mineralization styles across Awak Mas, Boundary by 3 major structures, chinese, discovery and garlic fault (Querubin 2012)
Figure 4. (A) Hand specimen rock sample metasedimen with sericitization alteration, (B) Thin section photograph in crossed polarized light show quartz veinlet and seiricit minerals in metasedimen.

Figure 5. (A) Hand specimen rock sample metasedimen with carbonatization alteration, (B) Thin section photograph in crossed polarized light show quartz veinlet associated with carbonat, chlorite and tourmalin mineral in metasedimen.
Figure 6. (A) Hand specimen rock sample metasedimen with carbonatization alteration, (B) Thin section photograph in crossed polarized light show quartz veinlet associated with carbonat, chlorite and tourmalin mineral in metasedimen.

Figure 7 (a) Polish section photograph show pyrit in fracture, (b) pyrit with diagenit formed by enrichment sulphide minerals. (c) covelit inclusion in pyrit. (d) electrum inclusion in pyrit (e) goethite form by hydration hematit minerals. (f) magnetit associated with pyrit in quartz.
Figure 8 (a) Hand specimen stockwork quartz vein in green metasedimen (b) Hand specimen sheeted quartz vein in dark grey metasedimen and (c) hand specimen brecciated quartz vein in brown metasedimen.

Figure 8. Profile of alteration zone along the drill hole AMD 682 and AMD 648 of Domain Rante in Awak Mas prospect.
Figure 9. Alteration zone correlation along drill hole AMD 682 and AMD 648 of Domain Rante, Awak Mas prospect.
Figure 10. (a) Hand specimen selected sample in Domain Rante Awak Mas show stockwork quartz vein (b) Double polish section photograph show elongated fluid inclusion with liquid and vapour composition. (c) Double polish section photograph show subhedral fluid inclusion with liquid and vapour composition. (d) Double polish section photograph show anhedral fluid inclusion with liquid and vapour composition.

Figure 11. Temperature–salinity plot showing densities g/cm³ of vapour-saturated NaCl–H₂O solutions formed in Domain Rante, Awak Mas area. (modified from Wilkinson, 2001).
Figure 12. Homogenization temperature–salinity data of Awak Mas plotted on lode Au area (Plotted on diagram of Wilkinson, 2001).