Geology and Mineralization of Awak Mas: 
A Sedimentary Hosted Gold Deposit, South Sulawesi, Indonesia

Geologi dan Mineralisasi Awak Mas: Cebakan Emas dalam Batuan Sedimen, Sulawesi Selatan, Indonesia

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ABSTRACT
The Awak Mas project has been the object of systematic exploration reaching back from 1987 to the present. Aside from the various studies that have already been completed, drilling within Awak Mas including its satellite prospects, totals 1,012 holes with an aggregate meterage of 118,081.30 m. The Awak Mas deposit, located in the southern section of the Central Sulawesi Metamorphic Belt, is hosted within the Latimojong Formation, a thick sedimentary sequence composed of phyllites, slates, basic to intermediate volcanics, limestones, and schists overlying basement metamorphic rocks, and intruded by late-stage plugs and stocks. East of the metamorphic block is the Mesozoic Lamasi Complex composed of basic intermediate intrusives, pyroclastics, and volcanogenic sediments. Gold at Awak Mas 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. Wall rock alteration consists of albite+quartz+carbonate with the original foliation often preserved. Lawsonite-albite-tremolite-chlorite-epidote mineral assemblages observed from samples define a divariant field stretching from 240° at 3 kb to 360° at 10 kb, conforming to general observations in melange deformation wherein high strain is accompanied by low temperature ranges. This temperature-pressure regime suggests an environment related to either subduction or massive thrusting. Oblique normal faults, extensional shears, and fractures formed in response to extensional deformation, serve as local controls to mineralization. Mineralization styles formed in conjunction with the kinematic framework comprise 1) broad, shallow dipping zones of sheeted and stockwork quartz veining and associated alteration that conform to the shear fabric and 2) steeper dipping zones of quartz veining and breccias associated with high angle faults and/or shear zones cutting both the flyschoid cover sequence and basement metamorphic rocks. These steeply dipping mineralized structures are inferred to represent the main feeder zones to mineralization. The Awak Mas deposit has been subdivided into 5 discrete domains based on the nature and orientation of mineralization and structural boundaries. These mineralized zones have been designated as the Ongan, Mapacing, Lematik, Tanjung, and Rante domains. Current mineral resources for Awak Mas total approximately 2 million ounces gold. The Tarra and Salu Bulo prospects confirm the regional prospectivity of the Latimojong Formation for low-grade, structurally controlled, mesothermal deposits. Anomalous gold geochemistry has been identified within a 5 by 13 kilometer zone extending from north to south of the Awak Mas deposit. Identification of additional mineral resources along this zone is subject to ongoing exploration.

Keywords: geology, mineralization, gold deposit, metamorphic belt, Awak Mas, South Sulawesi

SARI
Proyek Awak Mas merupakan suatu objek eksplorasi sistematis yang berlangsung dari 1987 sampai saat ini. Selain dari berbagai kajian yang telah lengkap, pemboran di kawasan Awak Mas yang meliputi prospek satelitnya, total 1,012 lubang dengan keseluruhan kedalaman 118,081,30 m. Cebakan...
INTRODUCTION

The Awak Mas Project is located in the Luwu District of southern Sulawesi, Indonesia. It is centered at coordinates 120°5' E and 3°20' S lying adjacent to the coast at the head of the Gulf of Bone. The coastal port of Palopo, which is the nearest major town to the project, lies 67 km to the northeast (Figure 1). From Makassar, the provincial capital of South Sulawesi, the road distance is 367 km to the town of Belopa and from thereon, another 41 km to the project site. The project area is generally characterized by moderate to rugged topography with elevations in the range of 800 to 1,400 m asl (Figure 2). Slope gradients are steepest within the southern to western portions grading to moderate towards the northern and eastern sections (Figure 3).

PROJECT HISTORY

New Hope Consolidated Industries Pty Ltd (NHCI) and PT Asminco Bara Utama represent the original partners in the Awak Mas joint Venture. In September 1991, Battle Mountain Gold Company (BMGC) concluded a farm-in agreement with NHCI thereby earning a 60% equity in the project. In 1994, Lone Star Exploration NL (LSE) negotiated the right to acquire the equity of both BMGC and NHCI. Prior to this, Gasgoyne Gold Mines NIL (GGM) and JCI Limited (JCI) had already structured an agreement to combine the various equities (LSE - 45%, GGM - 45%, JCI - 10%) in the project under the single corporate entity of Masmindo Mining Corporation Limited (MMC). In January 1998, LSE purchased the 45% interest of GGM in the project.


Kata kunci: geologi, mineralisasi, cebakan emas, jalur malihan, Awak Mas, Sulawesi Selatan
In September 1998, Placer Dome Incorporated (PDI) entered into a joint venture agreement with MMC to acquire 51% interest in the project after spending US$ 10 million. However, in June 1999, after spending US$ 1 million, PDI elected to withdraw from the joint venture stating that the project provided only limited opportunity to host a resource that would satisfy the company’s internal objectives. By October 1999, MMC signed an agreement with JCI, which basically amounted to a debt for equity swap, wherein JCI acquired 66.6% interest in the Awak Mas project. MMC eventually purchased the interest of JCI in the project thereby again assuming full interest until November 2004, when MMC executed an option to purchase agreement with Vista Gold Corporation (Vista). In December 2009, Vista announced that
its wholly-owned subsidiary, Vista Gold (Barbados) Corporation, has signed a joint venture agreement with One Asia Resources Limited (One Asia) with respect to the development of the Awak Mas project. The agreement provides One Asia the opportunity to earn 80% interest by completing an environmental impact assessment and feasibility study (in compliance with NI 43-101 standards).

**RECENT EXPLORATION**

In 1987, initial exploration at Awak Mas commenced under a SIPP, which predated the execution of the Contract of Work (CoW). Initial reconnaissance sampling was completed during this time. From 1988 to 1990, during the two year exploration period associated with the CoW, exploration included regional stream sediment geochemistry, photogeological mapping, airborne geophysical survey, GIS database development, follow-up mapping and stream sediment surveys, regional soil geochemistry, scout drilling programs, detailed structural and geological mapping, and establishment of survey control.

Further sampling, geological mapping, and extensive survey work were conducted in 1991. Soil sampling using Wacca drills were likewise completed. During this time, BMGC conducted a 77 drillhole program directed principally at the Awak Mas target. The feasibility period started in October of
Since 1991, over 150 individual studies have been conducted by external consultants covering geology, resource estimation, pit optimisation, geotechnical parameters, groundwater, pit design, mining method, production schedule, earthworks and civil works, metallurgical testwork, process plant design, infrastructure, social impact studies, and environmental management. These studies culminated in a definitive feasibility study, based on a 3 million tonne per annum mining and milling rate, conducted by Minproc Engineers Limited (Minproc). In August 1996, the feasibility study was approved by the Director General of the Department of Mines and Energy. In October of the same year, the environmental management plan (AMDAL) was submitted in support of the feasibility study. In January 1997, official government questions were raised and, in February of the same year, the revised AMDAL was re-submitted along with an updated feasibility study.

In late 1997, MMC requested for an extension of the Construction Period due to a fall in gold prices at the time. An extension was granted whereby MMC was given an opportunity to identify additional higher grade resources and to submit a revised feasibility study and environmental management strategy. Extensive additional regional exploration was thus carried out in 1998. The strategy involved the review of initial stream sediment and float geochemistry, follow-up of additional anomalies, mapping, and diamond drilling. The exploration was aimed primarily towards the Tarra, Kandeapi, and Salu Bulo Prospects.

In 1998, PDI continued regional exploration with Salu Bulo selected as the highest priority target. This program resulted in the identification of an estimated potential mineralization of approximately 160,000 to 230,000 ounces of gold in the ground. Additional exploration was also completed in the Tarra Prospect, comprising traverse mapping, trenching, channel sampling, mapping, and diamond drilling totalling 43 holes with an aggregate meterage of 4,517.90 meters.

In 1999, JCI completed a comprehensive review of the GIS database thereby generating several targets for further assessment including Rutuk, Salu Kanan, and Lelating areas. JCI then conducted grid mapping, trenching, and sampling thereby delineating a broad area of alteration and mineralization within the Rutuk area measuring 600 by 300 m.

After acquiring the project in 2004, Vista completed re-centralizing and re-cataloguing historical data, implementing environmental assessments and management plans, re-estimating contained geologic resources in accord with CIM compliant definitions, and initiating an exploration drilling program. The 2006 program conducted by Vista entailed drilling 10 holes within the Rante area with an aggregate meterage of 2,102.10 m and 3 holes within the Lematik area with an aggregate meterage of 470.20 m.

In late 2009, after having assumed the development for the Awak Mas project, One Asia immediately conducted additional mapping, trench and channel sampling, civil works, and in-house mineral resource calculations prepared prior to technical auditing by an Independent Qualified Person. A drilling program was likewise undertaken with the objective of upgrading the inferred resource category into a measured and/or indicated category. Aside from in-fill drilling, the program likewise included metallurgical
sampling and geotechnical assessments. To date, One Asia has completed drilling 75 holes with an aggregate meterage of 5,137.60 m.

In all, the total drilling that has been conducted for the Awak Mas project since 1991, including its satellite prospects, is 1,012 holes with an aggregate meterage of 118,081.30 m (Figure 4) as of September 1, 2011.

TECTONICS

Sulawesi lies at the junction of three major tectonic plates, the Eurasian Plate to the west, the Pacific Plate to the East, and the Australian Plate to the South. Its tectonic evolution reflects a history of subduction, multiple collisions, extension, and strike-slip faulting (Figure 5).

The West Sulawesi Arc, representing the western to northern segment of Sulawesi, is a volcanic arc terrane built on pre-Late Cretaceous accretionary complexes composed of high-pressure metamorphic rocks and ophiolites. Intensely folded Late Cretaceous flysch is overlain unconformably by less-deformed Eocene carbonaceous clastics. These are then overlain by widespread Late Eocene platform carbonates and capped by thick Miocene and younger volcanics. Present day Sulawesi is dominated by a few large sinistral strike-slip fault zones. These faults accommodate the NW relative movements of parts of Sulawesi (due to the continued convergence of the Pacific, Australian and Eurasian Plates) after the Middle Miocene collision of the Bangai-Sula microcontinent. The currently active NW-SE relative motion of the Sulawesi region also created young accretionary prisms/fold-and-thrust belts.
at the northern and western sections. East Sulawesi is characterized by one of the world’s largest ophiolite complexes. Age of obduction is believed to be Late Eocene to Early Oligocene. Below the relatively flat-lying ophiolite cover is a poorly known, but significant Late Triassic-Cretaceous marine sediment section. It has been suggested that East Sulawesi, Buton, Buru, and Seram were parts of a single microcontinent that separated from Australia in the Jurassic and collided with the Eurasian margin to form the Sulawesi orogen in the Oligocene (Van Gorsel, 2011).

**GENERAL GEOLOGY**

Western Sulawesi contains three major Neogene, N-S trending, tectonic domains consisting of (from west to east): (1) an active fold belt in which Pliocene and Miocene volcanogenic rocks are involved in west-vergent thrusting extending up to
the Makassar Strait; (2) a central belt composed of a deformed submarine Miocene volcanoplutonic arc built on an Oligocene-Eocene clastic and carbonate platform with Latimojong Mesozoic basement metamorphic and sedimentary rocks thrust over its eastern margin on west-vergent faults; and (3) an accreted Cretaceous-Paleogene ophiolite (Lamasi Complex) between the Latimojong basement block and Bone Bay (Bergman et al., 1996).

The Lamasi Complex ophiolite 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-alkaline to mildly alkalic, 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. Major and trace element geochemical data suggest that parental source rocks of the Miocene melts were Late Proterozoic to Early Palaeozoic crustal and mantle lithospheric assemblages which became heated and melted owing to a continent-continent collision in which west-vergent continental lithosphere derived from the Australian-New Guinea plate was subducted beneath eastern-most Sundaland.

The Makassar Strait is interpreted as a foreland basin bound on both sides by converging Neogene thrust belts, in contrast to previous models suggesting Late Tertiary oceanic spreading or continental rifting. West-vergent obduction of a pre-Eocene oceanic, primitive arc, or back-arc crust onto western Sulawesi occurred during Late Oligocene to Miocene times. The Late Miocene western Sulawesi magmatic arc is envisioned as a continent-continent collision product, contrary to previous models involving a normal ocean-continent or ocean-subduction-related magmatic arc or post-subduction rifting. The east Sulawesi ophiolite extends into western Sulawesi, suggesting that Bone Bay resulted from collapse of the over-thickened Miocene orogen.

**PROJECT GEOLOGY**

The Awak Mas project area is situated within the southern section of the Central Sulawesi Metamorphic Belt, a 50 km long, north-northeast trending fault bounded block composed of basement metamorphic rocks and younger sediments. The western margin of this block is represented by an easterly dipping thrust, whereas the eastern margin is defined by a major basement structure (Rozelle, 2007). 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 6). 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.

Within the immediate vicinity or the Awak Mas project, the predominant lithologic unit is a thick sedimentary package that has been subjected to a low-grade, greenschist facies metamorphism (Archibald et al., 1996). The rocks are generally light to dark grayish green, foliated, typically fine-grained, with protoliths ranging from mudstones to siltstones to fine-grained sandstones. Included here are thin intervals of fine- to medium-grained, light reddish grey to redish brown hematitic schists. Capping this
sequence is a foliated to gneissic, coarse-grained, tuffaceous sandstone interval. These coarser-grained deposits occur as a thin veneer overlying the finer-grained sequences and are generally confined along ridge crests. Dark gray, sheared/mylonitic intervals were noted occurring as interbeds oriented parallel to sub-parallel to foliation and usually located proximal to major structural features.

A surface layer of consolidated scree and colluvium averaging 3 to 4 m and with a maximum 15 m thickness drapes the deposit. Weathering has produced a soil profile that typically grades into saprolite. The base of weak oxidation within the mineralized sequence lies within 20 m of the surface.

**STRUCTURES**

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 7). Based on local kinematic indicators, the latest displacements along these faults indicate a dextral sense of motion. This perceived movement

Figure 6. Generalized geologic map of the Awak Mas project (after Archibald et al., 1996).
correlates well with findings by previous workers suggesting that thrusting within this part of the region is directed WSW to SW (EHW, 1996 and 1977a).

However, the five domains within Awak Mas are segregated by major structures as represented by the Chinese, Garlic, and Discovery Faults. The displacement exhibited by each domain relative to its adjacent domain is in the magnitude of a few hundred meters and appear to have been sinistral. This is exemplified by the relative positions of broad, shallow dipping zones of sheeted and stockwork quartz veining and associated alteration conforming to the shear fabric within the Ongan and Mapacing Domains. In addition, the most significant mineralization at Lematik is described as being localized in N-S trending, steeply dipping shear zone segments. The configuration and orientation of vein systems within this specific area strongly resemble features similar to a dilational jog. This would suggest that extension within this domain was initially directed E-W. The steeply dipping mineralized structures in Lematik are inferred to represent the main feeder zones to mineralization at Ongan, Mapacing, and Rante.

DISCUSSION

Petrography

The petrographic analysis of samples from selected drill cores show that rocks within Awak Mas have undergone low temperatures with fairly high pressure metamorphism (England, 1992a,b). Assemblages of lawsonite-albite-tremolite-chlorite-epidote define a divariant field stretching from 240° at 3 kb to 360° at 10 kb, where glaucophane-lawsonite replaces albite-chlorite-tremolite. These pressures are equivalent to a possible depth range of from 3 to 35 km and conform to general observations in melange deformation wherein high strain is accompanied by low temperatures. This combination of intense tectonism and low geothermal gradient suggests that the environment may be
related to either a subduction zone or to massive thrusting. The albition of samples is inferred to have been caused by seawater expelled from the sediments and focussed through the melange zone.

Deposit Type and Mineralization

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).

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.

In conjunction with the kinematic framework, two main styles of mineralization have been developed. The first represents broad shallow dipping zones of sheeted and stockwork quartz veining and associated alteration that conform to the shear fabric (particularly within the mudstones), and the second consists of steeper dipping zones of quartz veining and breccias associated with high angle faults and/or shear zones cutting both the flysch cover sequence and basement metamorphics (Figures 8 to 11). The steeply dipping mineralized faults

Figure 8. Section N 9627269 across Lematik Domain showing selected mineralized intercepts.
Figure 9. Section N 9627681 across Ongan Domain.

Figure 10. Section N 9627481 across Mapacing Domain.
and shear zones, which are associated with repeated silica flooding and brecciation, possibly represent the main feeder zones to mineralization where higher grade gold intercepts are closely related to elevated values of silver and other metals.

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 (Figure 12).

**Resource Estimate**

The gold resources for the Awak Mas deposit (Figure 13) were estimated using normal, whole-block kriging procedures. These gold resources were then classified into measured, indicated, and inferred categories. Based on evaluations made, the Awak Mas deposit was estimated to contain a current Measured and Indicated Mineral Resource amounting to 45.1Mt at 1.30 g/t Au utilizing a cut-off grade of 0.50 g/t Au, and additional Inferred Mineral Resources of 6.5Mt at 1.13 g Au/t based on the same cut-off grade for a total resource of 2.13 Moz gold (Kirchner and Gossage, 2004). The resource estimate is reported in accordance with JORC code (Tetra Tech 2011).

**Resource Potential**

Aside From Awak Mas, the Salu Bulo prospect located approximately 2 km ESE on-trend from Awak Mas, represents the most advanced exploration area within the CoW (Cox, 1998). This area lies adjacent to a major tectonic feature as represented by the NW-SE trending suture between the
Lamasi Complex and the Latimojong Formation. From 1998 to 1999, Placer Dome conducted an exploration program which entailed 2,956 m of channel sampling and trenching including 4,517.90 m of diamond drilling. From the results obtained from this program, Placer Dome estimated the potential mineralization to be in the range of from 160,000 to 230,000 ounces of gold in the ground (Gustavson, 2007). Drill results at Salu Bulo include 26m@2.78 g/t Au, 30m@2.95 g/t Au and 72m@1.95 g/t Au.
The Tarra prospect, located approximately 3 kilometers N-NW of Awak Mas, represents another area exhibiting considerable potential. In a review conducted by Etheridge, Henley, and Williams (1997b,c) of data from drillcores and surface exposures, it was estimated that approximately 1Mt with a tenor of 2.20g Au/t occurs in a zone above a planar basal fault sitting underneath 100 to 150 m of relatively un-mineralized rock. Preliminary drill results from Tarra have returned up to 56m@2.54 g/t Au. Additionally, the potential for mineralization is present in a shallow plunging shoot at depths approximately 40 m from the surface. Determining the continuity of mineralization within this particular area, however, requires further drilling.

**Exploration Potential**

The Tarra and Salu Bulo prospects confirm the regional prospectivity of the Latimojong Mountains for low-grade, structurally controlled, mesothermal deposits. A regional stream sediment sampling completed over the majority of the CoW has identified a broad area of anomalous gold geochemistry, which is 5 km wide and extends to a length of over 13 km to the north and south of the Awak Mas deposit (Figure 14).

The majority of currently identified resources and prospects lie within the northern 40% of this anomalous area. However, little follow-up exploration has been undertaken within the remaining 60%. It is considered highly likely that additional mineralized oc-

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**Figure 14. Location of Awak Mas deposit and principal regional prospect areas.**
currences will be identified within this area with further systematic exploration.

**CONCLUSION**

Awak Mas is a mesothermal gold deposit hosted in a flysch sequence (Latimojong Formation) that generally dips 15° to 50° north. 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.

Lawsonite-albite-tremolite-chlorite-epidote mineral assemblages define a divariant field stretching from 240° at 3 kb to 360° at 10 kb, conforming to general observations in melange deformation wherein high strain is accompanied by low temperature range. This temperature-pressure regime suggests an environment related to either subduction or massive thrusting.

Oblique normal faults as well as extensional shears and fractures formed in response to extensional deformation, serve as local controls to mineralization. Mineralization styles formed in conjunction with the kinematic framework are 1) broad shallow dipping zones of sheeted and stockwork quartz veining and associated alteration that conform to the shear fabric, and 2) steeper dipping zones of quartz veining and breccias associated with high angle faults and/or shear zones cutting both the flyschoid cover sequence and basement metamorphic rocks. These steeply dipping mineralized structures are inferred to represent the main feeder zones to mineralization.

Based on the nature and orientation of mineralization as well as structural boundaries, the Awak Mas deposit has been subdivided into 5 discrete domains, namely: the Ongan, Mapacing, Lematik, Tanjung, and Rante domains.

Current mineral resources for Awak Mas total approximately 2.13 million ounces of gold. In terms of resource potential, the Salu Bulo and Tarra prospects have a combined potential resource of approximately 400,000 ounces gold based on current limited drilling.

The Tarra and Salu Bulo prospects confirm the regional prospectivity of the Latimojong Formation for low-grade, structurally controlled, mesothermal deposits. Anomalous gold geochemistry has been identified within a 5 by 13 km zone extending from north to south of the Awak Mas deposit. With a systematic exploration, it is possible for additional mineral resources to be identified.

**ACKNOWLEDGEMENTS**

The article has been presented in the Seminar of the Sulawesi Mineral Resources, Manado, 2011, and compiled in the proceedings of the seminar. The authors acknowledge the Committee. By improving the content, the article is published in the Majalah Geologi Indonesia - IAGI. Therefore, the authors thank to IAGI.

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