MINERALIZATION AND ALTERATION SYSTEMS IN PEGUNUNGAN SERIBU, GUNUNG KIDUL AND WONOGIRI: Its Implication in Developing Exploration Models

Sukmandaru Prihatmoko¹, Agus Hendratno², and Agung Harijoko²

¹Austindo Resources Corp. NL
²Department of Geology, University of Gadjah Mada

ABSTRACT

Pegunungan Seribu (Thousand Mountains) in Gunung Kidul and Wonogiri is a famous karst region, which currently attract attentions. This karst area is formed by limestone of Wonosari and Punung Formations, Middle Miocene – Pliocene in age, comprising limestone, marly-tuffaceous limestone, conglomeratic limestone, tuffaceous sandstone, and siltstone (Surono et al 1992). Older volcanic windows commonly exposed in this karst region, which is the basement of the Wonosari and Punung Formations.

Apart from its beauty as a karst region, at least two mineralization and alteration systems were identified around Pegunungan Seribu, i.e. Selogiri and Wediombo. Both mineralization and alteration systems are hosted by older volcanics and intrusives.

In Selogiri, in the northern part of Pegunungan Seribu, biotite–chlorite and quartz–sericite–pyrite alteration zones occurred in dioritic host rocks. Quartz stockworks were observed within both alteration assemblages, and in places containing pyrite, chalcopyrite, bornite, and covellite, as well as galena and sphalerite. Gold and copper are elevated in this system. The above characteristics are indicative of a porphyry copper system.

In Wediombo, in the southern coast, an alteration zone typified by vuggy silica that is enveloped by kaolinite-alunite-illite zone can be observed in dacitic volcanics. This alteration zone is associated partly with polymictic breccias, possibly diatreme. Rock geochemistry shows that the alteration zone particularly the vuggy silica is elevated in arsenic. These indicate that Wediombo alteration zone is a product of high-sulfidation epithermal system.

Although un-economically yet, both Selogiri and Wediombo mineralization/alteration systems indicate that the volcanic and intrusive host rocks underneath Pegunungan Seribu are favorable targets for porphyry copper (+gold) deposits and associated epithermal systems (high- and possibly low-sulfidation systems). The fact that a high sulfidation epithermal system (Wediombo) exposed approximately 40 km to the south of a porphyry system (Selogiri) indicates that the northern part of Pegunungan Seribu has been uplifted higher than its southern part. A block faulting system, which is probably related to the development of Quaternary magmatic arc to the north of Pegunungan Seribu is one of the possible scenarios to build an exploration model.

The roles of Wonosari and Punung Formations as mineralization host rocks require further investigation. However, at this stage they should be considered as rock covers that need special techniques in exploring them, e.g. comprehensive structural study and geophysical techniques.
INTRODUCTION

Pegunungan Seribu (Thousand Mountains), located in Gunung Kidul, the Autonomous Region of Yogyakarta, and Wonogiri, Central Java provinces is a karst region that is part of the Southern Mountain of Java. This mountain range that occupy the southern part of Java has been known representing the Oligo-Miocene Magmatic Arc in Java (Soeria-Atmadja et al, 1991; Prihatmoko, 1998).

The Southern Mountain particularly in Banten and West Java provinces has historically been a subject of mineral exploration. However, in contrast, exploration had not been so intensive in Central and East Java, except for the Pacitan district that has been explored and mined for several base metal commodities during the Dutch era.

During the modern mineral exploration boom days (1970’s to 1990’s), the Southern Mountain of Central and East Java had also been a target. However, due to the Contract of Work moratorium emplaced in Java, there were no many systematic exploration works conducted in the part of this favorable ground.

The above situation had also occurred in Pegunungan Seribu where there was only very limited researches and exploration works carried out emphasizing on the mineral potential. The karst topography of Mio-Pliocene limestones that occupy this area even becomes a serious handicap to assess the mineral potential underneath them.

This paper presents some preliminary thoughts on the assessment of mineral potential in Pegunungan Seribu, particularly the favorable underneath host rocks, on the basis of brief researches on the mineralization and alteration systems of Selogiri and Wediombo areas. An exploration model is also developed based on the current knowledge in Selogiri and Wediombo alteration-mineralization systems. Fig. 1 shows the studied area with respect to Java island.

REGIONAL GEOLOGY

The karst topography of Pegunungan Seribu area is formed by limestone of the Wonosari and Punung Formations, Middle Miocene – Pliocene in age, comprising limestone, marly- tuffaceous limestone, conglomeratic limestone, tuffaceous sandstone, and siltstone (Suroso et al 1992). Older volcanic windows commonly exposed in this karst region, which is the basement of the Wonosari and Punung Formations.

Fig. 2 exhibits the regional geology of Pegunungan Seribu area, summarized from Suroso et al (1992) for which the geology description in this chapter is quoted.

The oldest rocks exposed in the area are metamorphic rocks (Bayat’s Metamorphic Complex) considered to be Cretaceous – Early Paleocene in age. These include schist, marble, metavolcanics, metasediments, and slate, and unconformably overlain by sandstone, sandy marl, claystone, and lens of limestone of Gamping – Wungkal Formation, Middle – Late Eocene in age.

Kebobutak Formation consisting of volcaniclastic sandstone, siltstone, shale, tuff, and agglomerate in the lower part, and interbedded sandstone and claystone with tuff intercalation in the upper part, Oligo-Miocene in age, unconformably overlie the Bayat Metamorphic Complex. In the eastern part of the area, this formation is correlatable to Mandalika Formation that comprises lava flows and pyroclastics, andesitic to dacitic in composition.

Semilir Formation in the western part and Jaten Formation in the eastern part, locally unconformably overlie the Kebobutak and Mandalika Formations respectively. Both Semilir and Jaten Formations are composed of dacitic tuff, tuffaceous sandstone, shale, siltstone, claystone, marl, and marly limestone.

Above Semilir and Jaten Formations, Nglanggran and Wuni Formations lie conformably, consisting of basaltic andesite to dacitic volcanic breccias and lavas, agglomerate, and tuff, with some intercalation of tuffaceous sandstone.

Sambipitu and Nampol Formations are reported unconformably overlying the Nglanggran and Wuni Formations. They consist of sandstone, siltstone, claystone, conglomerate, tuff, and agglomerate. In the western part, the Sambipitu Formation is conformably overlain by Oyo
Formation composed of andesitic tuff, tuffaceous marl, and conglomeratic limestone. The Semilir, Jaten, Nglanggran, Wuni, Sambipitu, Nampol, and Oyo Formations are reported to be Middle to Late Miocene in ages. These dates were determined mainly based on paleontologic data.

The limestones of Wonosari Formation in the western part and Punung Formation in the eastern part are interfingered with Oyo and Nampol Formations. These formations consist of limestone, marly limestone, conglomeratic limestone, siltstone, and tuffaceous sandstone. Paleontologic dating determined that these formations are Mio-Pliocene in ages. It is also reported, that the Wonosari Formation in the western part is interfingered with Kepek Formation, which is composed of marl and bedded limestone.

Intrusive rock in the studied area is recognized in Bayat Complex. It is a diorite body that was dated 3.9 Ma + 3.9 (Pliocene) by K-Ar dating method (Mahfi, 1984 vide Surono et al, 1992). Another intrusive outcrop was reported in Selogiri area, which is also diorite in composition (Prihatmoko, 2002).

The northern parts of the area, particularly in the low-lying areas are occupied by Quaternary volcanic rocks, produced by recent volcanoes of G. Merapi in western part and G. Lawu in the eastern part. Near the Gajahmungkur dam and along the S. Bengawan Solo alluvial unit could be mapped well, in where some of them called as Baturetno Formation, postulated as the lacustrine sediments.

The rock units in this area are folded in NE-SW trend in the western part and NW-SE in the eastern part. The fold flanks were reported to be gently dipping 3° to 15°, and involving the Semilir, Oyo, Wonosari, and Kepek Formations.

Faults are also reported cross cutting the area. It is reported that the northern and western part of Pegunungan Seribu (in the Gunung Kidul area) are fault bounded by major E-W and NNE-SSW structures, presumably block faulting.

REGIONAL MINERAL POTENTIAL

In the Indonesia region, a summary of postulated magmatic arcs was provided by Carlile and Mitchell (1994). 15 magmatic arcs are defined, and developed during magmatic events from Cretaceous to Pliocene. Two of them are extending through Java, i.e. (1) Sumatra-Meratus arc, which extends from Sumatra-Java-SE Kalimantan; and (2) Sunda-Banda arc extending from Sumatra- Java- Nusa Tenggara. Known mineralisation in the Sumatra-Meratus arc includes base metal skarn, epithermal, and porphyry deposits, while in the Sunda-Banda arc, mineralisation is dominated by porphyry, e.g. Batu Hijau, Beutong, and Tangse, and epithermal deposits, e.g. Gunung Pongkor, Cikotok District, Lebong Tandai District, Way Linggo, Rawas, and Miwah (Prihatmoko, 1998).

The characteristics of the magmatic arc that extends through Pegunungan Seribu (Oligo-Miocene arc) are considered to be prospective for porphyry Cu-Au and epithermal Au deposits, including skarn and sediment hosted Au deposits.

Some technical knowledges in the Circum Pacific that fit with the geology of the Pegunungan Seribu are summarized below.

- Porphyry and epithermal systems are known to form in calc-alkaline to alkaline volcanic arcs, particularly where the arc is associated with oceanic-oceanic subduction (Sillitoe, 1992; White et al, 1995).
- Most of the known porphyry, epithermal, and skarn deposits are of Tertiary age, specifically Miocene, although some epithermal deposits are known to have younger ages, Pliocene to Holocene (Sillitoe and Gappe, 1984; Hedenquist et al, 1996).
- Intrusions-related porphyry deposits vary from diorite, quartz diorite, and tonalite to monzonite and granodiorite (Sillitoe and Gappe, 1984; Corbett and Leach, 1998). These intrusions commonly are vertically extensive stocks (1 to 2 km) or grossly cylindrical forms, although mushroom-style shapes are also known (Sillitoe, 1992). In contrast, epithermal systems are not necessarily related to intrusive rocks. Host rocks of epithermal deposits are mostly sub-
aerial volcanics ranging from andesite, dacite, to rhyolite in composition, and contemporaneous volcanogenic sedimentary rocks, and sometimes the basement units (Hedenquist et al, 1996).

- In some areas, calcareous sediments are known to be favorable hosts of significant sediment-hosted (Carlin) deposits such as Mesel, North Sulawesi and Bau, Serawak, and skarn deposits such as the Ertzberg District, Irian Jaya.

- Mineralisation and intense hydrothermal alteration in porphyry systems generally occur on top and periphery of stocks, and may extend both vertically and laterally up to a thousand meters (Lowell and Guilbert, 1970). In the Philippines, many porphyry stocks occur on the margins, and very rarely inside of older medium- to coarse-grained batholiths. In contrast, epithermal systems are usually emplaced several kilometers above related intrusions (Titley and Beane, 1981).

- Both porphyry and epithermal systems are considered to be correlatable with respect to the intrusive activities and emplacement setting. Several authors believe that hydrothermal fluids in the high-sulphidation epithermal system are similar to those that form porphyry deposits (i.e. magmatic). Classical examples are the high sulphidation deposit of Lepanto and related porphyry system at Far South East (Concepcion and Cinco, 1989); Wafi and Nena in PNG (Corbett and Leach, 1998); and the Motomboto high-sulphidation system and Sungai Mak porphyry (Perello, 1994). The juxtaposition of both systems may be resulted by a tectonic/structural process (faulting or thrusting) such as in Tombulilato District, Sulawesi (Perello, 1994) or by a telescoping process such as in Marte, Chile (Sillitoe, 1994).

- In the Pacific rim, major structures associated with plate convergence have controlled the emplacement of both porphyry and epithermal systems. The popular examples are the West Fissures and their subsidiaries in Andes, which controlled the emplacement of giant porphyry deposits, e.g. Escondida and Chuquicamata (Ortiz et al, 1986), and the Philippines Fault and their subsidiaries, which controlled the emplacement of most porphyry deposits in the Philippines (Sillitoe and Gappe, 1984).

SELOGIRI

The prospect is located in the north of Pegunungan Seribu (Fig. 2) and administratively included in the Kabupaten Wonogiri, Central Java province. The area is on the undulating hills of G. Randu Kuning, G. Tumbu, and Kalipuru. Elevations range from 150m in the hill foots up to 222m on top of G. Tumbu. Fig. 3 illustrates the factual geology of Selogiri.

Regionally, this prospect lies on the Mandalika Formation, Oligo-Miocene in age (Surono et al, 1992) that is composed of andesitic to dacitic lava and tuff, and diorite intrusives. It seems that a major WNW-ENE normal faults (which is a part of the Southern Mountain block faulting) occurred just south of the prospect. It puts the prospect in the northern edge of the Southern Mountain.

Potassic alteration zone (chlorite-biotite) with quartz-calcite stockworking, overprinted by phyllic (quartz-sericite-pyrite) was identified in the localities of G. Tumbu and G. Randu Kuning. The host rock is diorite. Disseminated pyrite-chalcopyrite-bornite-covellite commonly occurred 2 to 3%. Galena and sphalerite are also noted in places associated with the stockworks. The individual veinlet in the stockwork is 1 – 3 mm wide, coarse-grained, crystalline, and composed of quartz and calcite. Malachite is commonly found smearing the potassic zones. Two rock samples, collected from the stockwork in the phyllic zones in G. Tumbu and G. Randu Kuning yielded 0.34 and 7.34 g/t Au respectively with low Cu but elevated Pb and Zn. While in the potassic zone of G. Randu Kuning, a sample was returned at 1.49 g/t Au and 0.96% Cu (Fig. 3).

Sheeted quartz veins crosscutting the potassic zone were also identified in the south of G. Randu Kuning, characterized by crystalline textures, hematitic and limonitic. A sample taken from the sheeted vein was returned at 20.9 g/t Au, 0.31% Cu, and hundreds ppm Pb and Zn (Fig. 3).

In Kalipuru, about 1 km south of G. Tumbu and G. Randu Kuning, the locals mined out gold from the quartz stockwork within the phyllic altered diorite. In this vicinity, the sulfides are mainly...
pyrites, which are commonly coarse-grained, cubic crystalline, even up to 3 cm in diameter. A sample taken from this area yielded 0.92 g/t Au with low base metals (Fig. 3).

The mineralization and alteration characteristics suggest that Selogiri prospect is a porphyry Cu-Au system, which is also convinced by the assay results. The sheeted quartz veins crosscutting the potassic zone which could be regarded as the quartz sulfide vein related to the porphyry system (Corbett, 2005) even support this concept. Fig. 4 exhibits the interpretative alteration zonation of Selogiri with respect to a porphyry system.

**WEDIOMBO**

Wediombo prospect is located in the Kabupaten Gunung Kidul, the Autonomous Region of Yogyakarta, and is in the southern edge (at the coast) of Pegunungan Seribu (Figs. 2 and 5).

This area is a volcanic window of the Wuni Formation, Middle Miocene in age that is surrounded by limestones of the Wonosari Formation (Surono et al, 1992). The volcanic rocks are composed of dacitic lavas and breccias. Fig. 5 shows the factual geology of Wediombo prospect, while Fig. 6 exhibits the interpretation of alteration zonation.

Hydrothermal alterations are well developed in the dacitic volcanics, and could be recognized in the parking area of the tourism place of Wediombo beach. The alterations include vuggy silica zones that are surrounded by kaolinite-illite-alunite zones with disseminated pyrite 2-3%. Another vuggy silica outcrop (sub-crop?) can also be observed in the coast NW of the parking area. Some rock samples yielded low gold and base metal grades but elevated in arsenic (see Fig. 5).

In the coastal cliff approximately 800 m NW of the parking area, an outcrop of diatreme can be recognized. The breccias are polymictic with rounded to subrounded rock fragments set in rock flour matrix. The rock fragments are composed of altered dacite and andesite. Two samples collected from the breccia matrix and clast respectively yielded low gold grade, however the one from the matrix had hundreds g/t Cu.

The alteration characteristics (i.e. vuggy silica, kaolinite-illite-alunite) combined with the elevated arsenic suggest that Wediombo is a high-sulfidation epithermal system. The diatreme with elevated Cu contents (hundreds g/t) support very well this idea (refer to Corbett, 2005).

**EXPLORATION MODEL**

The current knowledge in Selogiri and Wediombo suggesting porphyry and high-sulfidation epithermal systems are used to develop an exploration model. Some classical examples on the relationship of porphyry and high sulfidation systems, e.g. Far Southeast and Lepanto (Philippine), Wafi and Nena (PNG), and Motomboto and Sungai Mak (North Sulawesi) are the real model that could be adopted in Pegunungan Seribu, although Selogiri and Wediombo are quite far separated.

Fig. 7A illustrates the interpretative deposit models of Selogiri and Wediombo in the original position. The assumption applied for this model is that the mineralization and alteration processes in Selogiri and Wediombo occurred in a relatively same time (so far there is no exact dating data). Using this model, Selogiri porphyry system is considered to be formed at 1 to 1.5 km deeper than the high-sulfidation system of Wediombo. Quartz sulfide veins are to be formed in association with the porphyry system.

In Wediombo, the hydrothermal fluids producing vuggy silica with envelopes of illite-alunite-kaolinite alteration are considered to be magmatic origin. Steam heated alteration products (kaolinite) are interpreted to overprint the system. The diatreme is also common in the high-sulfidation system such as Lepanto and Motomboto.

The next process is uplifting (in combination with block faulting) and erosion (Fig. 7B). These processes are postulated to be responsible for the uplifting that locate Selogiri and Wediombo at a relatively same level (even Selogiri is slightly higher). It means that the whole area is uplifted, but the northern parts are more intense (roughly 1 to 1.5 km uplift in the northern part and at least 200 m uplift in the southern part). The larger uplifting in the northern parts, occurred since Oligo-Miocene (33.9 – 5.3 Ma), is interpreted to
be triggered by the development of younger magmatic arc to the north (G. Merapi and G. Lawu) that also created block faulting. The locations of block faulting in Fig. 7B are speculative and need further justification.

The limestones of the Wonosari and Punung Formations that produced karst topography most likely unconformably overlie the volcanic host rocks since they are Mio-Pliocene in age (Surono et al, 1992). In this case, the limestones would act as the young covers that hinder the exploration.

**DISCUSSION AND CONCLUSION**

The ages of mineralization and alteration processes in both Selogiri and Wediombo have not been defined (require age dating). It has made a difficulty in interpreting on how long the uplifting process has happened. The only dating data available is 3.9 Ma (diorite in Bayat Complex), which is too far to be considered as the mineralized intrusive events to either Selogiri or Wediombo.

However, although preliminary, an interpretative deposit model could be figured out to direct the exploration strategy. The understanding on the deposit models should be improved with the increasing data, and this may assist explorationists to prioritize the exploration projects.

In Pegunungan Seribu, the presences of Selogiri porphyry system and Wediombo high-sulfidation epithermal system are the important evidences of the prospectiveness of this area.

Until updated data obtained, the Wonosari and Punung limestones, at this stage, should be considered as young rock formations that might cover up the possible economic mineralization systems. Further systematic exploration techniques should be applied to detect the mineralization underneath the cover such as comprehensive structural evaluation combined with airborne geophysical surveys (e.g. magnetic).

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**REFERENCES**


FIGURE 1: Location map of the area of study (Pegunungan Seribu)

FIGURE 2: Regional geology of Pegunungan Seribu (summarized from Surono et al, 1992)
FIGURE 3: Factual geology of Selogiri prospect

FIGURE 4: Interpretative alteration zonations of Selogiri with respect to a porphyry system
FIGURE 5: Factual geology of Wediombo

FIGURE 6: Interpretative alteration zonation of Wediombo with respect to a high-sulfidation epithermal system
FIGURE 7: Exploration model of Wediombo and Selogiri (refer to Corbett, 2005)
A. Idealized model for the original hydrothermal stages
B. Recent position model (not to scale)