

# Epithermal gold-copper mineralization, late Neogene calc-alkaline to potassic calc-alkaline magmatism and crustal extension in the Sunda-Banda arc

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**Abstract:** The majority of gold-copper mineralization along the Sunda-Banda arc belongs to low-sulfidation epithermal type. Studies by previous authors suggest that mineralization environment changes from low-sulfidation epithermal in the western segment of the arc, minor porphyry and high-sulfidation epithermal to submarine stratiform deposit in the eastern region. It seems that the nature of geologic setting and magmatic evolution exert a profound influence on the mineralization environment. Most epithermal mineralization are hosted by stratovolcanoes and are associated with old caldera complexes controlled by strike-slip faults and graben subsidence. The present available K-Ar ages of mineralization suggest that the process is related to primarily Late Neogene volcanic eruption of fine silicic pyroclastics of calc-alkaline to potassic calc-alkaline affinity.

**Abstrak:** Majoriti pemineralan emas-tembaga di sepanjang lengkung Sunda-Banda adalah pemineralan jenis epiterma pensulfidasi-rendah. Kajian penulis-penulis terdahulu mencadangkan sekitaran pemineralan bertukar daripada epiterma pensulfidasi-rendah di bahagian segmen barat lengkung kepada epiterma porfiri minor dan pensulfidasi-tinggi hingga longgokan stratiform bawah laut di bahagian timur. Kelihatan bahawa tabii kedudukan geologi dan evolusi magma memberi pengaruh kuat terhadap sekitaran pemineralan. Kebanyakan pemineralan epiterma terdapat pada stratovulkano dan berkaitan dengan kompleks kaldera tua yang dikawal oleh sesar-sesar gelinciran-jurus dan amblesan graben. Usia K-Ar pemineralan yang diperolehi mencadangkan proses pemineralan adalah berkaitan dengan letusan vulkano Neogen Lewat yang bersifat piroklas halus bersilika dengan afiniti kalka-alkali hingga kalka-alkali kalium.

## INTRODUCTION

This paper is based on previous gold-copper exploration activities chiefly from Java, Lombok, Sumbawa and Flores. Many radiometric ages obtained from volcanic rocks and ores along the Sunda-Banda arc reveal close relationship between late Pliocene calc-alkaline and potassic calc-alkaline volcanism and gold mineralization. Similar to the Circum-Pacific region, porphyry and epithermal mineralization tend to be associated with oxidized magmas.

## CALC-ALKALINE AND POTASSIC CALC-ALKALINE MAGMATISM

Previous work by Soeria-Atmadja *et al.* (1990,1994) and Sutanto (1997) revealed the presence of two parallel magmatic belts i.e. Early Tertiary and Late Tertiary-Quaternary which constitute the Sunda-Banda arc. The former is made up of volcanic rocks known as van Bemmelen's Old Andesite Formation which extends from the northern tip of north Sumatra along the west coast to the southern coastal region of Java as far as Flores except Bali. The Late Tertiary magmatic belt (Pliocene-Quaternary) overlaps with the former along its southern margin from

Sumatra as far as Flores (Soeria-Atmadja *et al.*, 1998; Sutanto, 1997; Hendaryono, 1998) where the stratovolcanoes are distributed (Figure 1). The onset of magmatism along this arc is different. The westernmost segment of the arc where Sumatra is located shows a very long magmatic history since Permian time (Katili, 1970; Hutchison, 1975; McCourt *et al.*, 1996). The western segment of the arc, from Sumatra to central Java, has been interpreted as an arc resting on a continental type crust unlike the eastern segment being underlain by oceanic type crust (Soeria-Atmadja *et al.*, 1998). The oldest K-Ar dated volcanics of Sumatra are represented by Triassic granitic rocks of Sibolga and Padang which are overlain by younger volcanics (Sutanto, 1997); the latter display island arc chemical signatures consisting of saturated and oversaturated volcanics of chiefly calc-alkaline and potassic calc-alkaline affinities with subordinate shoshonitic rock series; the latter include the Eocene and Miocene volcanics (K-Ar age 50 Ma-18 Ma) of Natal, Painan and Lampung. Volcanic rocks of potassic calc-alkaline affinity are more frequently erupted during Late Pliocene-Quaternary volcanism (3 Ma - 0.5 Ma); they have been documented from the regions of Toba, Sipirok, Sorik Merapi, Padang, Bengkulu and Lampung. In certain parts of the Sumatran

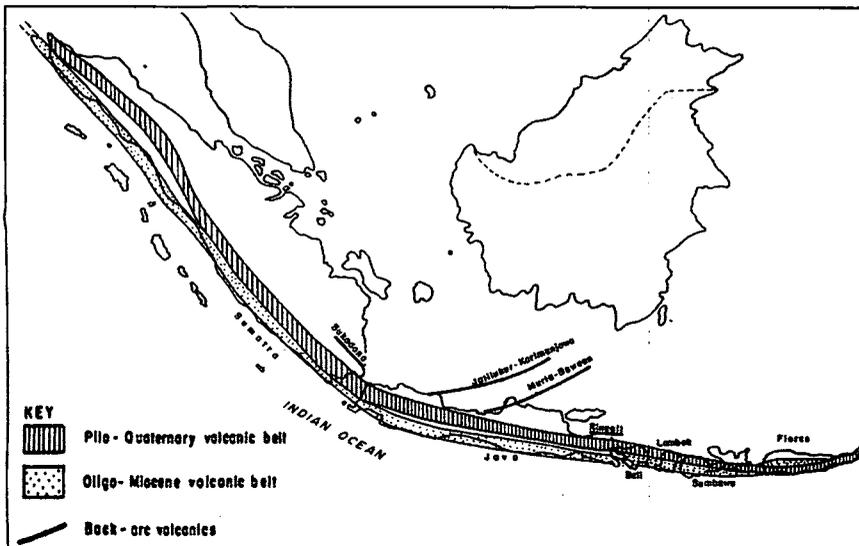


Figure 1. The Oligocene - Miocene and Pliocene - Quaternary volcanic belts in the Sunda - Banda arc (Sumatra - Flores)

magmatic belt, active stratovolcanoes erupted silicic ignimbrites and tuffs from ring fracture zones, forming calderas such as Toba, Maninjau, Painan and Lampung.

The majority of Tertiary volcanics in Java exhibit calc-alkaline affinity whereas the distribution of potassic calc-alkaline and shoshonitic rock series are limited in space and time; these potassic volcanics were commonly erupted in Pliocene time (Cianjur-Jatiluhur and Malabar-Papandayan regions of west Java; Soeria-Atmadja *et al.*, 1994). The relative increase in  $K_2O$  contents of the Quaternary magmas are also witnessed by the occurrence of alkali-potassic to ultrapotassic rock series in the back-arc regions. In Bali, only the Neogene volcanics are exposed. They include intercalated undersaturated alkali-basalt in Early Neogene sediments in the southern coastal region and Late Neogene potassic calc-alkaline andesite in the north (Soeria-Atmadja *et al.*, 1998). In Lombok, Sumbawa and Flores the oldest exposed volcanic rocks are of Paleogene age (Suratno, 1994; Hendaryono, 1998). The emplacement of Quaternary potassic volcanic rocks in Sumbawa is thought to be related to extrusion along transcurrent faults. Hendaryono (1998) documented Mio-Plio-Quaternary calc-alkaline andesites and dacites in the southern coastal areas of Flores and Middle-Late Miocene calc-alkaline andesite-dacite-rhyolite in the central part of the island.

## EPITHERMAL AND PORPHYRY MINERALIZATIONS

Sillitoe (1997) gave a review on the distribution of the largest porphyry and epithermal gold deposits around the Pacific rim located in the magmatic arcs. The stocks that host the large gold-rich porphyry deposits are of I-type magnetite series magmas indicating contributions from the oxidized subcrustal melts (Ishihara, 1981). This is also reflected in the high magnetite contents (Sillitoe, 1997). Some gold deposits of east Pacific have K-Ar ages vary between 40 Ma - 10 Ma whereas those of the western

Pacific exhibit shorter age range between 10 Ma-0.5 Ma. The large known gold-rich porphyry and epithermal deposits are not related to the nature of the underlying crust. In certain parts of the extensional arcs the magmatic rocks associated with many gold deposits are rhyolitic to rhyodacitic with bimodal compositions. Elsewhere, the majority of gold deposits are associated with predominantly andesitic to dacitic composition.

Known copper-gold mineralizations along the Sunda-Banda arc, as well as in other island arcs of Indonesia (Neogene arc of Kalimantan and North Sulawesi) show K-Ar ages less than  $\pm 5$  Ma. They are mostly related to stratovolcanoes, flows domes and maar-diatreme systems. The distribution of porphyry type mineralization in this arc appears to be very limited to certain regions such as in north Sumatra (van Leeuwen *et al.*, 1987), and southwestern Sumbawa (Meldrum *et al.*, 1994). According to Taylor and van Leeuwen (1980) copper-gold porphyries in Southeast Asia are associated with oceanic environments whereas copper-molybdenum and molybdenum mineralization are associated with more continental rock suites. Carlile and Mitchell (1994) noted a marked change in mineralization environment along the Sunda-Banda arc. Low-sulfidation epithermal mineralization characterize the western regions whereas porphyry style and high-sulfidation mineralization are more common in the eastern region of the arc. Further eastwards from Flores mineralization style changes to stratiform gold-silver-barite-base metal association in shallow submarine environment.

The scarcity of significant porphyry-style mineralization in calc-alkaline arc volcanics in the western Sunda-Banda arc may be only apparent; in this respect Sillitoe (1980) proposed the mechanism of cauldron subsidence as an alternative explanation. While andesitic flows and pyroclastic rocks are dominant in regions of calc-alkaline volcanics and porphyry stocks, the abundance of acid ignimbrites and tuffs characterize environment of epithermal mineralization. Eruption of silicic ignimbrites typically associated with caldera collapse brings about

expulsion of volatiles from the roof zone of the magma chambers giving rise to metal dispersal and thus preclude porphyry style mineralization. At fumarolic stage the volatile content of underlying magma reservoir decreased and thus volatile accumulation in the high-level stock is prevented. According to Mitchell and Garson (1981) porphyry deposits have much less preservation potential because they are liable to erosion after their formation as the result of synsubduction uplift.

Cauldron subsidence appears to be a common phenomena in some parts of the calc-alkaline Sunda-Banda arc during certain volcanic episodes. It is commonly preceded by regional updoming resulting to the generation of ring- and radial-fractures, graben subsidence accompanied with major ash-flow eruptions. Epithermal mineralization occurs following resurgent doming and re-opening of existing fractures.

Eruption of ignimbrites and acidic tuffs provide source materials to contribute to the Late Neogene-Quaternary stratigraphy (Toba, Ranau and Lampung along Sumatra). In western Java they are known from the regions of Bayah Dome, Jampang High and Pongkor Dome (Figure 2). Caldera structures are indicated by the presence of circular depressions bounded by arcuate fracture systems with evidence of subsidence; the Neogene acidic tuffs of eastern Java may also be generated this way. Arcuate fracture patterns and volcanic depressions are also widely distributed in Flores, mostly in the southern coastal region where volcanic exposures comprise Mio-Plio-Quaternary calc-alkaline andesites and dacites.

Potassic magmatism has been documented in several distinct tectonic settings. Muller and Groves (1997) distinguished five tectonic settings: continental arcs, post-collisional arcs, initial as well as late oceanic arcs and within-plate settings. In the western Pacific region some gold deposits exhibit alkaline association related to various types and degrees of extension characterizing some island arcs. Sillitoe (1997) stated that unusual arc settings (back-arcs, post-subduction arcs, rifted arcs and arc junctions) and magma chemistry (alkaline, shoshonitic and bimodal compositions) are criteria favorable for the generation of porphyry and epithermal gold deposits from highly oxidized magmas. However, according to White and Hedenquist (1990) several subaerial volcanic settings (Muller and Groves, 1997) are not prospective for epithermal mineralization because of deep and/or small magma.

## NEOGENE MINERALIZATION

### Mineralized Zones in the Early Tertiary Magmatic Belt

The Lebong Tandai gold deposit of Bengkulu in northern Sumatra is located in the Early Tertiary magmatic belt. Mineralized breccias here are hosted by Neogene volcanics and volcanoclastic sediments. Like the majority of gold mineralization in the Sunda-Banda arc the gold deposit of Bengkulu exhibits characteristics of low-sulfidation epithermal environment (Jobson *et al.*, 1994). Sutanto (1997) mentioned a few K-Ar ages of potassic

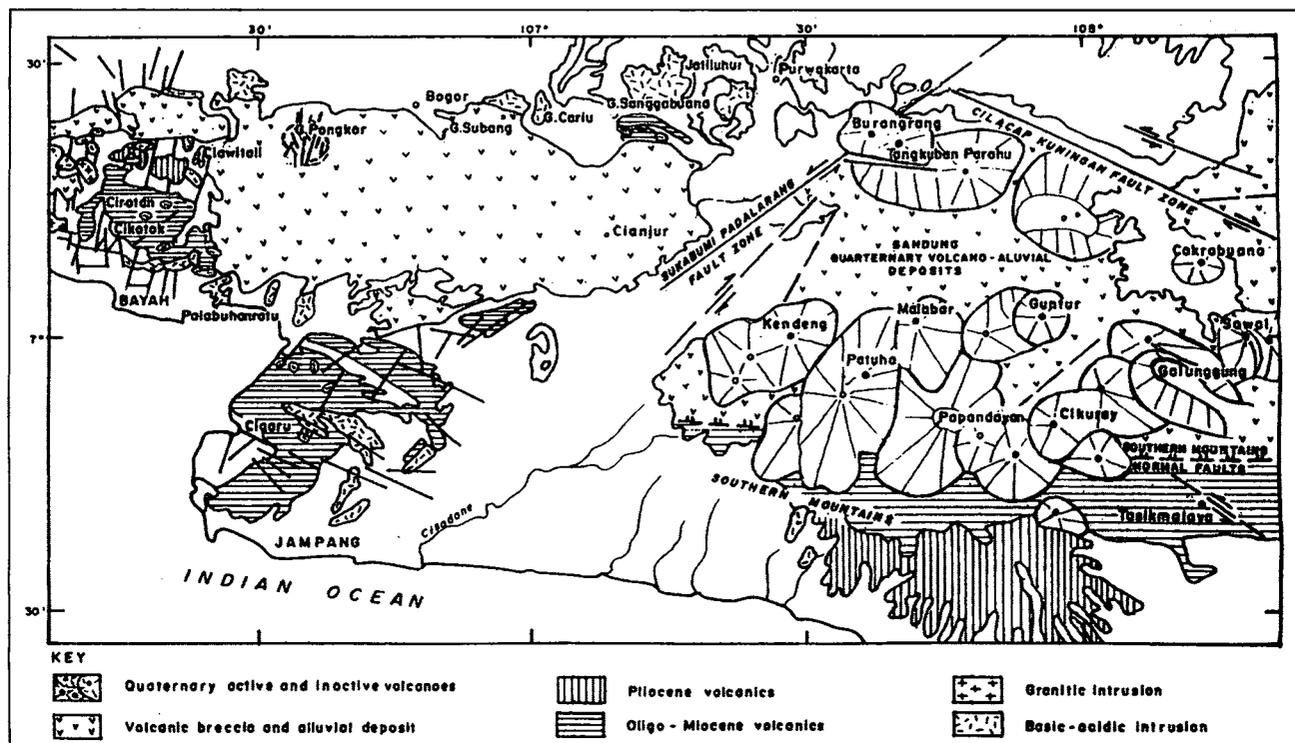


Figure 2. Regional geology of west Java showing the mineralized zones of Jampang-Bayah-Pongkor (west) and G. Subang-Jatiluhur stratovolcano complex (centre-north). Large part of the area between the above zones are occupied by products of the Quaternary volcanoes.

calc-alkaline andesite and basaltic andesite dykes (16.5 Ma - 12.8 Ma) including a rhyolite tuff in the region. Possibly epithermal mineralization in Bengkulu is related to this Early-Middle Miocene potassic calc-alkaline magmatism.

In the Bayah dome area (Figure 2) of western Java two important structural trends of the gold-bearing quartz veins have been recognized i.e. the Jampang trend (NW-SE) and south Banten trend (NE-SW). In the area north of it (Ciawitali area) rhyolites, rhyolite tuffs and fine to coarse pyroclastic breccias of intermediate composition are cut by intrusions of andesitic and basaltic compositions and sulphidic quartz vein network. These volcanics are overlain by younger tuffs and ash fall deposit and themselves cut by dykes and sills; these Pliocene volcanics belong to the ignimbrite type pyroclastic rocks of Citorek and tuffs of Malingping.

The veins at Bayah are composed of milky quartz with pockets of manganese oxides, massive and banded manganese oxides and rhodochrosite; the younger quartz veinlets are barren. A vertical zonation of mineralization in this epithermal system consists of an upper zone of gold-silver-manganese deposits (Ciawitali) and a deeper zone characterized by the occurrence of manganese, pyrite and minor base metals (Cirotan). The appearance of wolframite-cassiterite assemblage in epithermal deposits is not known except in Cirotan (Milesi *et al.*, 1994). Manganese is one of the typical elements of gold mineralization in west Java. In the Cirotan district the most abundant sulphide mineral assemblage consists of pyrite/marcasite-galena-chalcopyrite-sphalerite; the paragenetic sequence points to epithermal type mineralization suggesting adularia-sericite alteration type. Milesi *et al.* (1994) distinguished two phases of mineralization in the Cirotan district: (1) a contemporaneous deposition of epithermal gold-silver in the upper level and (2) porphyry tin at deeper level followed by tin-tungsten mineralization which overlaps partly with the first phase. The result of K-Ar dating points to major Pliocene magmatic episode (5.7 Ma-2.0 Ma) which were spatially associated with Bayah dome and epithermal mineralization (Marcoux and Miles, 1994). Fluid inclusion studies by Maunder (1988 in Sunarya and Suharto, 1989) gave mean homogenization temperatures ranging between 130°-335°C with low salinity values varying up to 2.4 eq. wt % NaCl and Au/Ag ratios of the ores between 6-97.

Results of joint exploration activities by BRGM and DMR in the Jampang area indicate that gold is the only metal found with large dispersion accompanied by narrow dispersion of base metals, and the ore mineral assemblage is similar to those occurring in the Cirotan-Cikotok district. Soebowo (1988), Soebowo *et al.* (1989) and Soemarto *et al.* (1993) reported that the mineralized quartz veins of the Cimanggu-Cigaru area south of Palabuhanratu are controlled by two main structures i.e. N345°E (Cimanggu pattern) and N325°E (Cigaru pattern). The epithermal system is closely related to diorite and andesite intrusions of which the latter are cut by nearly vertical gold-bearing quartz veins in deeper zones and covered by a siliceous cap in the

upper zones.

High sulfidation epithermal mineralization has been documented in northern Sumatra (van Leeuwen, 1994) and southwestern Lombok (van Leeuwen, 1994; Carlile and Mitchell, 1994; Meldrum *et al.*, 1994). The low sulfidation veins in Sumbawa are peripheral to the porphyry stocks suggesting genetic relationship and that they are integral part of the metallogenic setting (Meldrum *et al.*, 1994). Gold-copper mineralization is hosted by older volcanic rocks (ash, lapilli and breccia tuffs), referred to as meta-volcanics (Meldrum *et al.*, 1994), underlying the Pengulung Formation; the latter is not exposed in Sumbawa. Thus we are here dealing with calc-alkaline intrusions (diorite, quartz-diorite, andesite porphyry and tonalite) that cross-cut the meta-volcanics resulting into porphyry style mineralization. Gold mineralization in the western-most part of southwestern Lombok (Figure 3a) represents shallow-depth mineralization hosted by strongly altered volcanics (van Leeuwen, 1994) known as Pengulung Formation (Suratno, 1994). The latter is made up of Paleogene volcanics transected by Middle Miocene andesite-dacite intrusions which bring about alterations and high sulfidation epithermal gold mineralization (van Leeuwen, 1994).

Setiagraha *et al.* (1987) reported the results of K-Ar dating on separated hornblende from the diorite intrusions of southwestern Lombok. They obtained K-Ar ages are  $4.21 \pm 1.43$  Ma and  $1.71 \pm 2.16$  Ma (Early Pliocene to Early Pleistocene) representing the age of hydrothermal processes. The geological setting of southwestern Lombok appears to be very similar to that of southwestern Sumbawa (Figure 3b) where Neogene calc-alkaline magmatic intrusions cross-cut the Pengulung Formation as well as the underlying meta-volcanics (Suratno, 1994). Porphyry style mineralization of Sumbawa is related to multiple intrusions of diorites, dacites and younger diatreme breccias. The present authors believe that the shallow-depth high sulfidation epithermal gold mineralization on Lombok may change to environments more conducive to porphyry style mineralization at greater depths where the meta-volcanics of Sumbawa may occur.

### Mineralized Zones in the Late Tertiary Magmatic Belt

The Late Tertiary magmatic belt is hosted mainly by Neogene volcanics such as in the volcanic complexes of Jatiluhur, Sanggabuana, Gunung Subang (Cariu) and areas north of Cikotok-Cirotan (Figure 2). The volcanic products are dominantly calc-alkaline and potassic calc-alkaline andesites with dacites/rhyolites and minor basalts. The Late Tertiary magmatism began with outpouring of arc tholeiitic pillow lavas succeeded by calc-alkaline rock series; (Soeria-Atmadja *et al.*, 1994); high-K calc-alkaline and shoshonitic rock series seem to be more characteristic of the younger magmatic activities, presumably during the period of 5 Ma to 2 Ma.

In the Jatiluhur andesitic vent complex (Figure 2) the rock chemistry indicates relatively K-rich volcanics

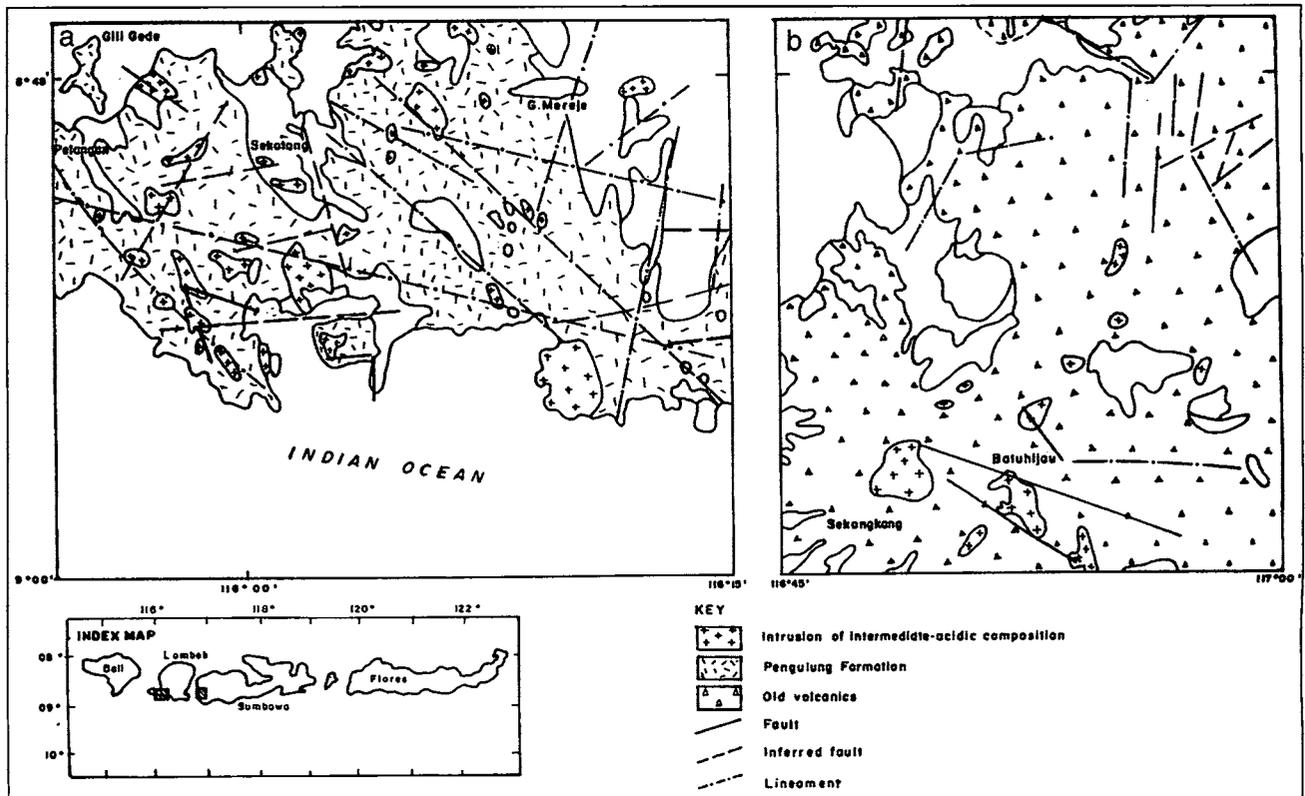


Figure 3. Geological sketch map of southwestern Lombok (a) and Sumbawa (b), eastern Indonesia.

(potassic calc-alkaline and shoshonitic rock series). They occur as acidic lava domes and andesitic volcanic necks one of which shows a K-Ar age of 2.0 Ma. The Neogene sediments exposed in this region are transected by abundant volcanic necks and dykes of mostly calc-alkaline to potassic calc-alkaline basalt-andesite with minor dacite and rhyolite. Later work by Sunarya (1994) in the Jatiluhur area, southwest of Purwakarta and north of Plered reported the occurrences of cinnabar, native gold, tetrahedrite, chalcopyrite, sphalerite, galena, stibnite and rhodochrosite in the Neogene volcanics. Similar mineral assemblage is also known from the Gunung Subang volcanic complex (Cariu).

Volcanic setting of Sanggabuana (Figure 2) area shows central to proximal character which is made up of alternating lava flows, pyroclastic- and laharic-breccias with several volcanic plugs of andesitic composition. Result of K-Ar dating on one sample from an andesite lava outcrop at the southwestern margin of Sanggabuana yields an age of 5.35 Ma (Soeria-Atmadja *et al.*, 1990). The volcanic rock association in the Jatiluhur-Cianjur region characterized by chiefly potassic calc-alkaline and shoshonitic affinities, mostly andesitic to dacitic composition. Their K-Ar ages range between 18.1 Ma - 4.39 Ma (Sutanto, 1993). The eruptive centers of Jatiluhur area consist of mostly potassic calc-alkaline and shoshonitic volcanic products which according to Sutanto (1997) may represent the southwestern prolongation of Karimunjawa back-arc zone.

The Gunung Subang area, east of Bogor, is made up of folded sediments of Middle Late Miocene sediments of

alternating clays, shales and sandstones supposedly equivalent to Cidadap Formation (van Bemmelen, 1949). They are overlain by Quaternary laharic breccias. They may well be part of the Sanggabuana and Jatiluhur volcanics related to young Neogene magmatic activity. They are cut by closely spaced subvolcanic intrusions (dykes and plugs) composed of strongly porphyritic calc-alkaline andesites (Soeria-Atmadja *et al.*, 1994). Hydrothermal alteration of these volcanics show evidence of gold and base-metal mineralizations. In general the epithermal ore deposits are of disseminated type.

In the area westsouthwest of Bogor (Figure 2), Gunung Pongkor, which is the western extension of the mineralized belt of Jatiluhur - Sanggabuana - G. Subang (Jatiluhur-Cianjur region) several northwest-southeast trending quartz veins have been mapped within an extensive zone of hydrothermally affected Neogene sediments. The low sulfidation epithermal deposit of Pongkor is part of Miocene volcanic sediments within the Pliocene-Quaternary volcanics at the northeastern flank of the Bayah dome (Milesi *et al.*, 1994). The deposit is located at the northwestern rim of the circular fracture system ( $\pm 8$  km in diameter) corresponding to a caldera collapse (Marcoux *et al.*, 1996). Result of  $^{40}\text{Ar}/^{39}\text{Ar}$  dating on adularia gave an age of  $2.05 \pm 0.05$  Ma (Milesi *et al.*, 1999). The mineralized volcanic host consists of a Lower Unit of subaequous volcanics overlain by a Middle Unit (subaequous explosive volcanics). The Upper Unit is made up chiefly of andesitic flows. Marcoux *et al.* (1996) mentioned that homogenization temperatures of fluid inclusions for the Pongkor Lode are

quite low ranging between 165-205°C with very low CO<sub>2</sub> content of the fluids. Recent work by Milesi *et al.* (1999) on fluid inclusion based on four successive stages of deposition in vein fill exhibit homogenization temperatures ranging between 150°C-382°C indicating boiling of hydrothermal fluid with initial temperature around 205°C; salinities are generally less than 1 wt.% eq. NaCl. According to Sumanagara and Sinambela (1991) these volcanoclastic sediments are cut by subvolcanic intrusions of basic to intermediate composition. Fluid inclusion studies on quartz yield homogenization temperatures varying between 150°C-290°C.

Other occurrences of vein type gold-silver mineralization were reported by Sunarya (1994) from the regions south of Bandung, south of Cianjur and the eastern districts of Bandung (Figure 2). Their distribution are possibly related to heat sources of epithermal system at depth in the Neogene basement of Quaternary stratovolcanoes. They are clustered mainly in the southern part of west Java. Such relationship was noted earlier by Koolhoven (1933) who mentioned the possibility of precious metal deposition by hot springs. Epithermal mineralization in the regions of Bayah-Jampang-Pongkor, the mineralized belts of Jatiluhur-Cianjur as well as the southernmost volcanic cone complex of western Java belong to andesitic-dacitic volcanic system. The latter is an active geothermal system, and they are good guidance in locating possible epithermal mineral deposits often formed at shallow depths.

## CONCLUDING REMARKS

The knowledge of gold-copper mineralization (van Leeuwen *et al.*, 1987, 1994; Carlile and Mitchell, 1994) along most parts of the western Sunda-Banda arc confirms the occurrence of major low sulfidation epithermal mineralization. They are related to crustal extension following early andesitic magmatism in areas where intrusive bodies are rarely exposed and porphyry mineralization is absent. Geological interpretation of aerial photographs from many parts of the Sunda-Banda arc shows numerous clearly defined circular structures suggesting caldera formation. Our knowledge of the Tertiary volcanic stratigraphy points to the widespread occurrences of more silicic volcanics toward Late Neogene time.

The possibility of cauldron subsidence in the Bayah dome was first indicated by Suparka *et al.* (1987) based on geological interpretation of enhanced landsat MSS data of the region. A number of arcuate fracture zones and caldera depressions within Bayah dome are abundant and other structural lineaments show the following main directions : NW-SE, E-W to NNE-SSW and N-S; the area is dominated by volcanic-related structures. The distribution of subvolcanic intrusions and lava flows along the outer rim of Bayah dome may be related to post-caldera resurgence. They crosscut the Tertiary sediments and are perhaps related to the formation of dacitic and rhyolitic plugs, lava domes and acidic tuffs. A careful study on the young Neogene

stratigraphy indicates a remarkable increase in dacitic to rhyolitic tuff intercalations within the Late Miocene-Pliocene sediments. The circular structural features measure around 5 km in diameter and the mineralized zones tend to cluster around them and also at intersection of linear structures.

In the Jampang region Suparka *et al.* (1987) distinguished three structural domains : (1) northern domain (the Jampang High), (2) central domain with nearly east-west trending lineaments and (3) southern domain with buried arcuate structures. According to Soemarto *et al.* (1993) the mineralized quartz veins of Cimanggu-Cigaru area in the Jampang region, south of Palabuhanratu are related to an old caldera structure. The result of joint exploration activities in western Java conducted by Japan International Cooperation Agency (JICA) - Metal Mining Agency of Japan (MMAJ) - Directorate of Mineral Resources (DMR) in the southern part of Tasikmalaya, south of G. Sawal volcano revealed an area of epithermal mineralization with gold showings (JICA-MMAJ-DMR, 1995, 1996). The area is largely occupied by Quaternary volcanic cones resting on volcanics of the Jampang Formation (andesitic, dacitic volcanics and pyroclastic rocks). A number of complex circular structures suggesting caldera collapse occur in the area possibly related to the emplacement of the upper member volcanics of Jampang Formation. They are represented by andesitic/acidic pyroclastics, and they appear to be characteristic of epithermal gold mineralization. It differs from the Pongkor and Bayah epithermal mineralization on account of the occurrence of As-Sb minerals and lack of adularia in the gangue mineral assemblage.

The relatively wide distribution of the Neogene acidic tuffs in eastern Java is possibly related to either caldera collapse or graben subsidence. A three-phase mineral exploration in the Pacitan-Ponorogo area in eastern Java has been conducted jointly by the Korean Mining Promotion Corporation (KMPC) and the Directorate of Mineral Resources (DMR) during the period of 1991-1993 (KMPC-DMR, 1991, 1992, 1993). A large part of the investigated area consists of basaltic, andesitic and dacitic volcanics of Besole Formation with crosscutting shallow-depth intrusions. Shallow-depth intrusions and lava domes in the Pacitan Region yielded K-Ar age range of 19 Ma - 9 Ma (Soeria-Atmadja *et al.*, 1994) and probably even younger. Hydrothermal alteration and mineralization are very likely more related to acidic magmatism.

Caldera structures are also widely distributed in Flores, (Koesoemadinata *et al.*, 1994; Suwarna *et al.*, 1990); they are exposed mostly in the Pliocene-Quaternary calc-alkaline volcanics of intermediate to acid composition in the southern coastal regions. Older caldera structure is also present in the Tertiary volcanics of Kiro Formation. Results of previous exploration activities by Aneka Tambang (1999) covering the period of 1995-1997 reported the occurrence of submarine massive sulphide intercalations in the acidic volcanic sediments of Laka Formation in the northern region of western Flores.

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