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Epithermal gold-copper mineralization associated with Late Neogene-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.

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 with the Circum-Pacific region, pophyry 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 respectively. 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) is overlapping 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 (Fig. 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 as a result of Cenozoic extension (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 magmatic belt active stratovolcanoes

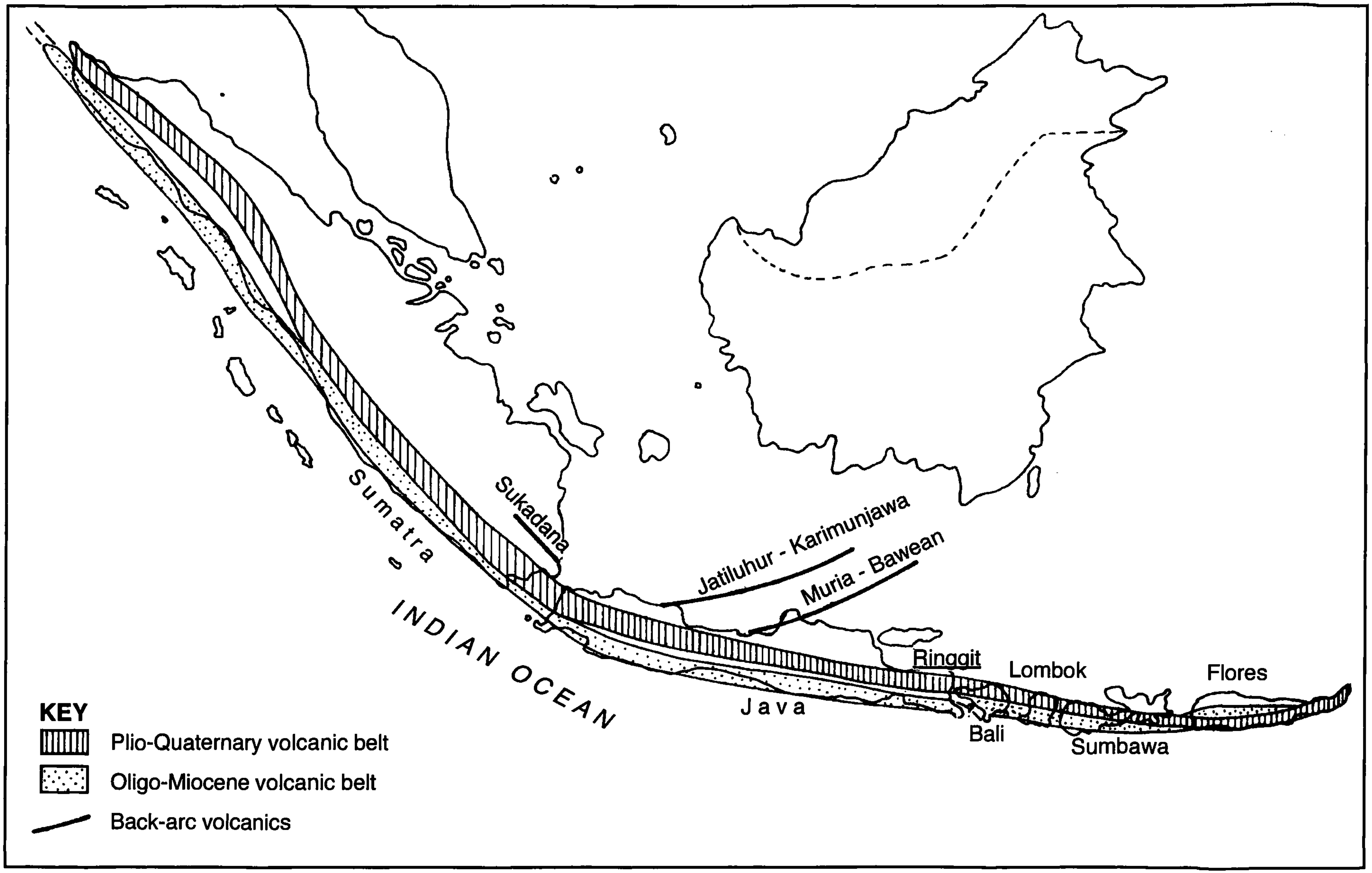

Figure 1. The Oligo-Miocene and Plio-Quaternary volcanic belts in the Sunda-Banda arc (Sumatra-Flores).

erupted silicic ignimbrites and tuffs from ring fracture zones thereby resulting into caldera formation such as in the regions of 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. Their distribution are controlled by young faults oblique to the magmatic belt (Soeria-Atmadja *et al.*, 1988). 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 (inclusive of the potassic calc-alkaline, alkali-potassic and shoshonitic rock series) 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 along both sides of the Pacific ocean. Many epithermal gold deposits in the western Pacific island arcs exhibit intimate relationship with remnants of strato-type volcanic centers. The location of porphyry gold deposits is controlled by the presence of calc-alkaline rock series, erosion level and exhumation rate, water content, and volatile evolution during magma ascent (Sillitoe, 1980). 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 varying between 40 Ma–10 Ma whereas those of the of the western Pacific exhibit shorter age range between 10 Ma–0.5 Ma. The latter has been attributed to rapid uplift and erosion rates that characterize most western Pacific island arcs during Neogene and Quaternary time. The large known gold-rich porphyry and epithermal deposits are not related to the nature of underlying crust; some are related to rifting while others are formed in regional compression of the upper crust. In certain parts of 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 ± 5 Ma. They are thought to have been emplaced at very shallow depths and that the obtained young ages of mineralization are perhaps suggestive of relatively high rates of uplift and erosion. 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. Other gold-copper mineralizations exhibit characteristics of low sulfidation epithermal type, and they are associated with silicic pyroclastics presumably related to caldera formation. 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. Crystallization in the underlying subvolcanic intrusion took place after volcanism terminated when the overlying edifice was at fumarolic stage. At this stage the volatile content of underlying magma reservoir decreased and thus volatile accumulation in the high-level stock is prevented. Central to proximal volcanic center is more conducive for epithermal mineralization in which the passage of fluid flow is structurally controlled. 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 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. During caldera collapse ash-flow deposits and pyroclastic eruptions continued often followed by resurgent doming, ring fracture volcanism and intrusions. Epithermal mineralization occurs following resurgent doming and re-opening of existing fractures. It appears that structures in the individual volcanic centers are the most important control on emplacement of the heat source and sites of fluid discharge. The underlying intrusive bodies are attended by conditions more conducive to metal concentration of porphyry style in contrast to ignimbrite eruption and caldera collapse which are suitable for dispersion of metals (Sillitoe, 1980).

Eruption of ignimbrites and acidic tuffs provide source materials to contribute to the Late Neogene-Quaternary stratigraphy such as known in the regions of Toba, Ranau and Lampung along the Sumatran arc. In western Java they are known from the regions of Bayah Dome, Jampang High and Pongkor Dome (Fig. 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. In some parts they are associated with discharges of thermal waters and solfatara to which sulphidic mineralizations may be related.

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 late oceanic arcs the potassic magmatic products are the youngest and were erupted after tholeiitic and/or calc-alkaline volcanics. The increasing interest in the generation of potassic volcanic rock suites is due to their association with copper-gold mineralization and the role in reconstruction of tectonic setting. 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) pointed out the importance of contrasting permeability or rheology in playing the role of ponding hydrothermal fluids and modification of their physico-chemical nature. He further stated that unusual arc setting (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 with higher chlorine and sulphur contents, both are favorable condition for hydrothermal base metal and gold transport. 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 chambers and thus preclude the development of major hydrothermal system at shallow depths.

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 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 was related to this Early-Middle Miocene potassic calc-alkaline magmatism. In this setting exposures of intrusive stocks are scarce and porphyry mineralization is lacking.

In the Bayah dome area (Fig. 2) of western Java two important structural trends of the gold-bearing quartz veins have been recognized respectively the Jampang trend (NW-SE) and south

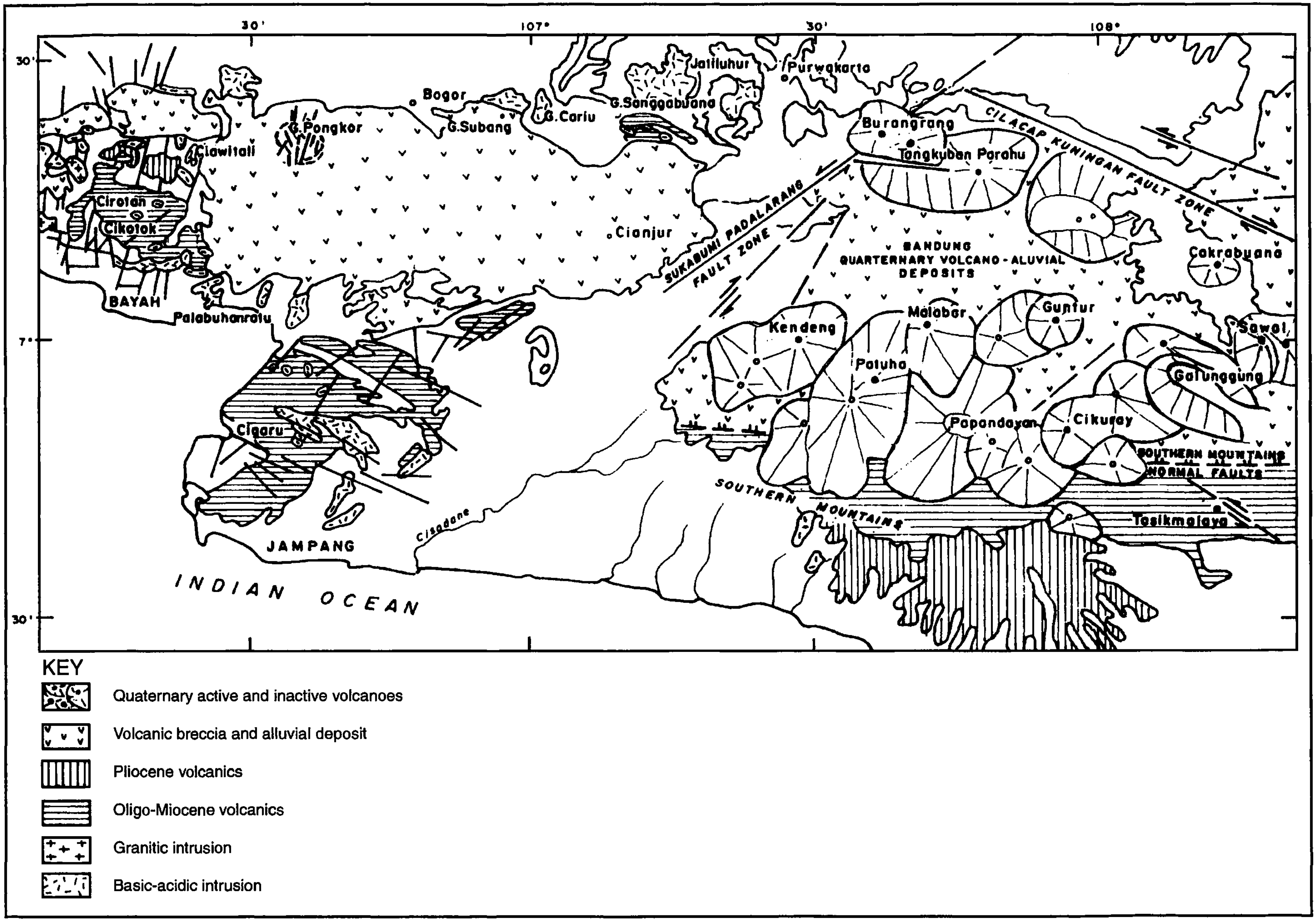

Figure 2. Regional geology of west Java showing the mineralized zones of (1) Jampang-Bayah-Pongkor and (2) G. Subang-Jatiluhur stratovolcano complex, whereas a large part of the area between the above zones are occupied by products of the Quaternary volcanoes.

Banten trend (NE-SW). In the area north of it (Ciawitali area) the volcanic rock assemblage consists of rhyolites, rhyolite tuffs and fine to coarse pyroclastic breccias of intermediate composition. They are cut by intrusions of andesitic and basaltic compositions and sulphidic quartz vein network, and the main direction of the quartz veins are northeast-southwest and north-south. These volcanics are overlain by younger tuffs and ash fall deposit and themselves cut by dykes and sills; to these Pliocene volcanics belong 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). Four main fault systems may be recognized from aerial photographs (N20°E, N110°E, N135°E and N220°E) of which the latter two correspond to the directions of respective veins and major faults. Manganese as one of the typical elements of gold mineralization in west Java commonly occurs as rhodochrosite or its altered forms. 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 *et al.*, 1996). 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. The range in salinity values point to significant influx of dilute meteoric water into the hydrothermal system.

Rock outcrops of the Jampang Formation in the Jampang area (Fig. 2) are relatively very rare due to the fairly thick soil blanket. Results of joint exploration activities by BRGM and DMR (1991) in the area indicate that gold is the only metal found with large dispersion accompanied by narrow dispersion of base metals. However, the quartz veins and stockwork systems are trending east-west to northnorthwest-southsoutheast, 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 respectively 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 crosscut the meta-volcanics resulting into porphyry style mineralization. No K-Ar ages and chemical data on the volcanics are available from this eastern segment of Sunda-Banda arc. Gold mineralization in the westernmost part of southwestern Lombok (Fig. 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; the obtained K-Ar ages are 4.21 ± 1.43 Ma and 1.71 ± 2.16 Ma (Early Pliocene to Early Pleistocene) representing the age of hydrothermal processes. Sunarya (personal communication) reported the occurrence of three mineralized segments in Lombok as well as Sumbawa each of which are separated by northnortheast-southsouthwest strike-slip faults. The geological setting of southwestern Lombok appears to be very similar to that of southwestern

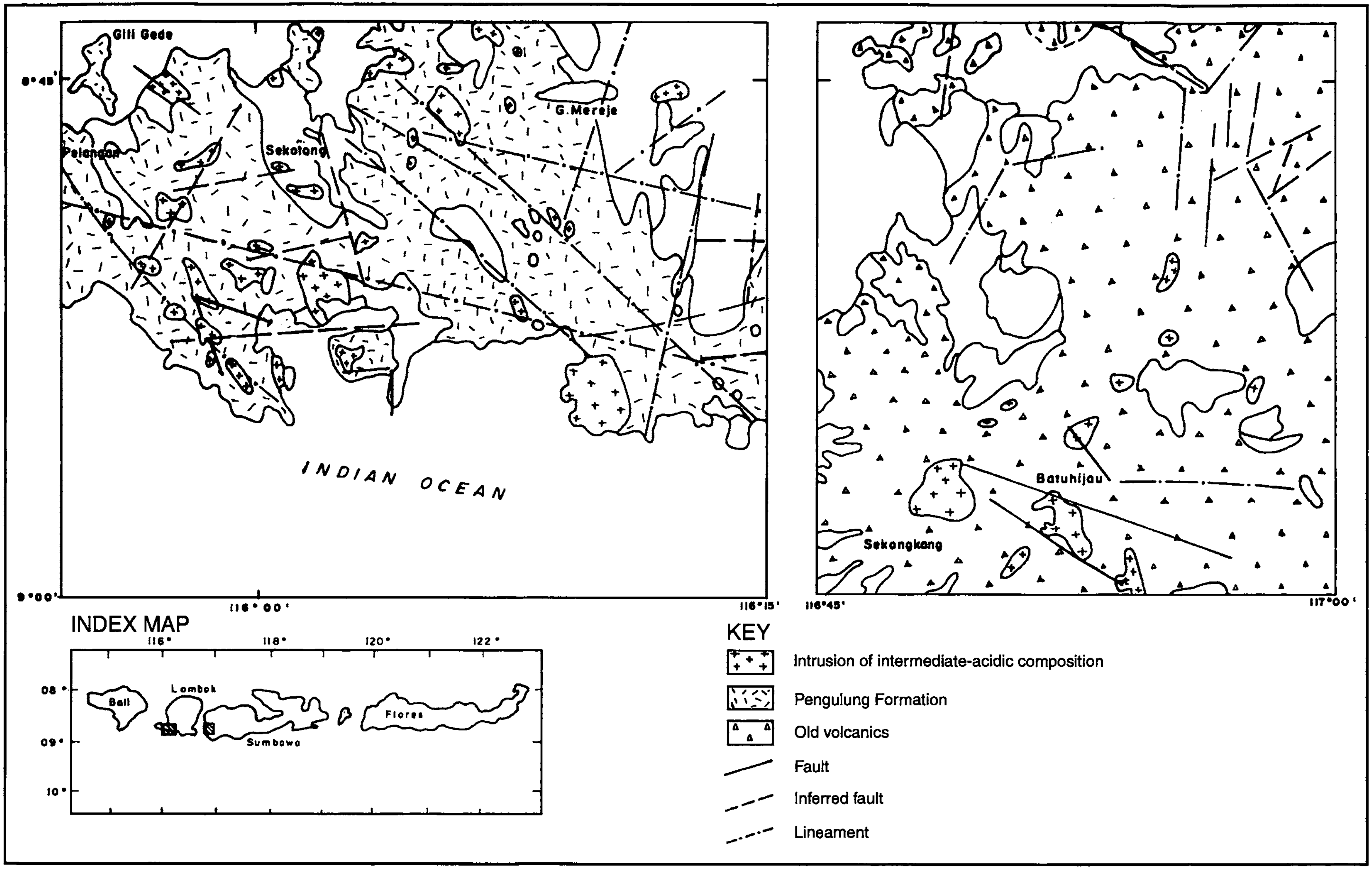

Figure 3. Geological sketch map of southwestern Lombok (Fig. 3a) and Sumbawa (Fig. 3b), eastern Indonesia.

Sumbawa (Fig. 3b) in that Neogene calc-alkaline magmatic intrusions crosscut 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

Unlike the mineralization in the Early Tertiary magmatic belt ore deposition in the Late Tertiary magmatic belt is hosted by mainly neogene volcanics such as in the volcanic complexes of Jatiluhur, Sanggabuana, Gunung Subang (Cariu) and areas north of Cikotok-Cirotan (Fig. 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. Thus, enrichment in K_2O and other incompatible elements took place toward the end of Late Tertiary magmatism; the same phenomena were also observed elsewhere in the Sunda-Banda arc.

In the Jatiluhur andesitic vent complex (Fig. 2) the rock chemistry indicates relatively K-rich volcanics (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) along mineralized almost east-west trending quartz veins and north-south trending shear zones in propylitized andesite host rock.

Volcanic setting of Sanggabuana (Fig. 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). Therefore at least part of the Sanggabuana volcanic complex represents a volcanic facies of the Subang Formation, and that volcanic activity may have continued until Quaternary time. Products of the earlier episodes are interfingering with sediments of the Subang Formation; subsequent volcanics overlie the latter. The volcanic rock association in the Jatiluhur-Cianjur region is characterized by chiefly potassic calc-alkaline and shoshonitic affinities consisting of 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 (Fig. 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 (± 8 km in diameter) corresponding to a caldera collapse (Marcoux *et al.*, 1996). Result of $^{40}Ar/^{39}Ar$ dating on adularia gave an age of 2.05 ± 0.05 Ma (Milesi *et al.*, 1999). The mineralized volcanic host consists of a Lower Unit of subaequous andesites, brecciated flows and andesitic lavas which is overlain by a Middle Unit composed of explosive volcanics including lapilli tuffs, ignimbrites and fine volcaniclastics sediments of subaequous environment. The Upper Unit is made up chiefly of andesitic flows. The main lodes occur along northnorthwest-trending structures. 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_2 content of the fluids. Recent work by Milesi at 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 volcaniclastic sediments are cut by subvolcanic intrusions of basic to intermediate composition (basalt, andesite and dacite) which resulted into quite extensive silicification and argillic alteration halos. Fluid inclusion studies on quartz yield homogenization temperatures varying between 150°C–290°C. Mineral assemblage of the quartz vein outcrops indicates adularia-sericite epithermal type (Sunarya, personal communication).

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; gold, silver and some base-metals occur in quartz veins in propylitized andesites of Neogene age (Fig. 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. The Quaternary volcanic cones in the eastern part of west Java is bounded by northeast-southwest trending Sukabumi-Padalarang fault in the west, northwest-southeast Cilacap-Kuningan fault in the east and an east-west trending fault in the south (Katili and Sudradjat, 1984). Numerous evidence of epithermal gold and lead-zinc vein mineralization have been documented from areas south of G. Sawal volcanic cone. 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 where interaction processes between rock/fluid are intense due to steep thermal gradients, 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. In contrast, regional compression in the crust during generation of porphyry mineralization inhibits penetration of fluids to deeper levels, and consequently the magmatic fluids retain CO_2 , sulphur and metal contents during the evolution of magmatic fluids (Carlile and Mitchell, 1994). 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 association of calderas and graben structures with significant silicic volcanic products appears to be common phenomena in epithermal environment.

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. Although major structural lineaments have a regional control on the localization of ore deposits, mineralization is situated commonly on subsidiary structure. 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 & 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 distribution of these rocks is more or less confined to the western and northern regions of the Bayah dome. The relative abundance of neogene acidic tuff and the continuity of chemical trends from mostly andesites (subordinate basalts) to dacites and rhyolites strongly suggests fractional crystallization of more basic parent as the source of the tuffs and rhyolites. The circular structural features measure around 5 km in diameter and the mineralized zones tend to cluster around them and also at intersections of linear structures. These subvolcanic intrusions as well as the associated mineralization are related to processes succeeding cauldron subsidence, and that the latter only served to prepare the host structurally for subsequent mineralization.

In the Jampang region Suparka *et al.* (1987) distinguished three structural domains: (1) northern domain, the Jampang High, being characterized by circular structures associated with dioritic intrusion, dykes and quartz veins, (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 Bandung (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) which host dominantly northwest system of gold-bearing quartz veins. 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 which include dacitic tuffs, tuff breccias and green tuffs. These features appear to be characteristic of epithermal gold mineralization; it differs from the Pongkor and Bayah epithermal mineralization on account of the occurence of As-Sb minerals and lack of adularia in the gangue mineral assemblage; mineralization took place in the Middle-Late Miocene.

The relatively wide distribution of the Neogene acidic tuffs in eastern Java is possibly related to either caldera collapse or graben subsidence and are possibly the source materials for the young tuffaceous rock formations. 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. A large part of the investigated area consists of basaltic, andesitic and dacitic volcanics of Besole Formation with crosscutting shallow-depth intrusions. The Besole Formation is made up of Late Oligocene sedimentary member and Early Miocene mostly rhyolitic and dacitic volcanics. It appears that the Early Tertiary magmatic activities were more basaltic in composition and became progressively acidic starting Early-Middle Miocene time. 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 resulting into: (1) Copper-bearing zinc deposit (sphalerite, chalcopyrite, pyrite, hematite and minor galena), (2) fracture filling copper and iron deposits in skarn (chalcopyrite, minor pyrite and pyrhotite), (3) mineralization along the contacts of limestone, tuffaceous calcareous rocks and dacitic stock (massive hematite, specularite and minor magnetite).

Caldera structures are also widely distributed in Flores, (Koesoemadinata *et al.*, 1994; Suwarna *et al.*, 1990); they are exposed mostly in the Plio-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 being exposed in the central region along the length of the island. Results of previous exploration activities by ANEKA TAMBANG (1999) covering the period of 1995–1997 reported the occurence of submarine massive sulphide intercalations in the acidic volcanic sediments of Laka Formation in the northern region of western Flores. Field observation and studies of samples from 19 core drillings representing a total depth of 1,500 m indicate close association of gold-barite with strong silicification which are controlled by north-south trending faults; sulphidic veins appear to be related to weaker silicification.

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