PETROGENESIS OF THE SINTANG INTRUSIVES AND ITS IMPLICATIONS FOR MINERALIZATION IN NORTHWEST KALIMANTAN

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ABSTRACT

Arc magmatism is a direct response to tectonic and chemical processes operating in subduction zones. The Sintang Intrusives consist of microdiorite, microgranodiorite, granite/ microgranite, quartz diorite, dacite, andesite, and minor rhyolite and rhyodacite (dacite predominant). Depletion of Nb relative to K and La concentrations are characteristics of the rocks, implying the magma was generated in a subduction zone environment. However, different from magma of other "normal" arcs that were derived from mantle wedges, the magma of the Sintang Intrusives was generated from subducted oceanic crust melting. The result of a careful study of trace element data show that the rocks are of adakite type, characterized by high Sr/Y and Zr/Sm ratios, moderate to strong fractionation of heavy rare earth elements (HREE) and absence of Eu anomalies suggesting melt extraction from garnet-amphibolite sources. By considering the tectonic development in the South China Sea and northwest Kalimantan, it is believed that the magma was probably originated from the melting of previously subducted South China sea oceanic crust (dead slab or fossil subduction) beneath Kalimantan continent in the Late Oligocene - Early Miocene. A compressive tectonic regime in Middle Oligocene, and possibly until Late Oligocene, led to crustal shortening and thickening that facilitated entrapment of arc magma in the Kalimantan crust. The fluid released caused by amphibole breakdown and may have been expelled from older amphibole-bearing plutons during compressional tectonics would be significantly important for mineralization.

Keywords : Kalimantan, Sintang Intrusives, oceanic crustal melting, mineralization

SARI

Magmatism busur dipengaruhi langsung oleh proses tektonik dan kimia yang bekerja di daerah penunjaman. Batuan Intrusi Sintang terdiri atas mikrodiorit, mikrogranodiorit, granit/mikrogranit, diorit kuarsa, dasit, andesit, dan sedikit riolit dan riodasit (sebagian besar dasit). Pemiskinan kandungan Nb nisbi terhadap K dan La sebagai ciri kimia batuannya, menandai bahwa magmanya terbentuk di daerah penunjaman. Namun demikian tidak seperti umumnya magma di daerah busur "normal" yang berasal dari mantel, magma Intrusi Sintang berasal dari peleburan kerak samudera yang menunjam. Hasil kajian secara seksama terhadap geokimia unsur jejak menunjukkan bahwa batuannya termasuk tipe adakit, dengan rasio Sr/Y dan Zr/Sm tinggi, unsur langka berat (*HREE*) terfraksinasi sedang sampai kuat, serta tidak ada anomali unsur Eu yang menggambarkan sumber magma garnet-amfibolit. Dengan mempertimbangkan perkembangan tektonik di Laut Cina Selatan dan daerah barat laut Kalimantan, magma ini sangat boleh jadi berasal dari peleburan kerak sisa Laut Cina Selatan (*slab* yang telah mati atau fosil penunjaman) di bawah daratan Kalimantan pada akhir Oligosen awal Miosen. Tektonik kompresif pada pertengahan Oligosen, dan barangkali sampai akhir Oligosen, menghasilkan pemendekan dan penebalan kerak, yang mengakibatkan terjebaknya magma di dalam kerak Kalimantan. Air yang dihasilkan oleh terurainya amfibol, dan mungkin juga keluar dari pluton beramfibol yang lebih tua, selama tektonik kompresi mempunyai arti penting di dalam mineralisasi.

Kata kunci : Kalimantan, Intrusi Sintang, peleburan kerak oseanik, mineralisasi

INTRODUCTION

Debates on the origin of arc magmas in subduction zone systems are still continuing among petrologists and geochemists. The debates arise mainly because various types of rocks erupted in volcanic arc suites. The rocks suites in subduction zone systems vary from low-K tholeiitic through calc-alkaline basalt-andesite-dacite to leucitite and related ultrapotassic mafic volcanics. Geochemical, isotopic, and petrologic data imply that most arc magmas are generated by partial melting of the mantle wedge, induced by infiltration of water and incompatible elements derived from a subducting slab (*e.g.* Foden and Green, 1992; McCulloh and Gamble, 1991), and then followed by crystal fractionation with or without assimilation. The parental magma would result in calc-alkaline basalt-andesite-dacite suites. Others (*e.g.* Defant and Drummond, 1990;

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Drummond and Defant, 1990; Peacock *et al.*, 1994; Prouteau *et al*., 1996; Reich *et al*., 2003) believed that subducted oceanic lithosphere is the source of arc magmas. Experimental studies (*e.g*., Defant and Drummond, 1990; Peacock *et al*., 1994; Cosky *et al*., 2005) show the role of slab melting in the generation of arc magmas were found in several subduction zone, in which a young, hot, oceanic crust was being subducted. However, in the area in which young oceanic crusts are not being subducted, melting of underplated mafic lower crust or previously subducted oceanic crust may also be suggested (Peacock *et al*., 1994).

Magma generation in arc settings is greatly influenced by both chemical and tectonic processes. It means that by studying geochemistry of rock produced and tectonic development of an area where the rocks deriving magma occurred, it is possible to understand the origin of arc magmas. Precious metal-bearing epithermal and porphyry-Cu deposits are produced by the interplay of several magmatic, tectonic, and hydrothermal processes at subduction zone environments. They are genetically associated with broad range compositions of arc magmas from low-K- through high-K-calc-alkaline to alkaline (Sillitoe, 2000; Tosdal and Richards, 2001). Recently, a preferential association of Au-bearing porphyry-Cu (Reich *et a*l., 2003) and epithermal deposits with adakite has been suggested (Oyarzun *et al*., 2001; Sajona and Maury, 1998; Thiéblemont *et al.*, 1997).

This paper discusses magma generation of the Sintang Intrusives, that have been proposed as adakite (Hartono and Suyono, 2006), and the last portion of this paper, figure out the role of magma generation in mineral deposit formation. Previous authors (Williams and Harahap, 1987) proposed that the Sintang Intrusives were originated from magma derived from high-alumina basaltic rocks melting in a lower crust. By a careful study of available geochemical data published by previous authors (Heryanto *et al*., 1993; Harahap, 1987), especially trace and rare earth elements, this study presents an argument of the magmatic source. The results of the geochemical study combined with geodynamic evidences of northwest Kalimantan are presented to explain the magmas generation. The close spatial and temporal relationships between mineral deposit found in northwest Kalimantan and the Sintang Intrusives imply that magma generation has a role in mineral deposit formations.

GEOLOGICAL SETTING

Following the Late Cretaceous - Early Tertiary southward subduction, two fore arc basins (the Melawi and Ketungau basins) were formed in northwest Kalimantan (Williams *et al*., 1988). This subduction produced a magmatic belt along the northern margin of the Sundaland (Kalimantan) that can be followed from northwest Kalimantan (Sintang area) through Kelian to the Upper Tarakan (Soeria-Atmadja *et al*., 1999). Soeria-Atmadja (*op. cit.*) further implied that this subduction ceased in the middle Oligocene following the collision and docking of the Luconia continental block with the northern margin of the Sundaland. Oligocene - Miocene magmatic activities superimposed on the Early Tertiary magmatic belt, which could be traced from Sintang through Masuparia, Mount Muro, Kelian, Muyup, Busang, Muara Wahau, Mangkaliat, and Sesayap (Soeria-Atmadja *et al*., 1999). The magmatic belt, which is called Central Kalimantan arc by Carlile and Mitchell (1994), is occupied by intermediate to acid volcanics (andesite, trachyandesite and dacite) and their intrusive equivalents.

The Sintang Intrusives (Heryanto *et al*., 1993) that consist of mostly granodiorite and few diorites or subvolcanic andesites discussed in this paper are part of the rocks of this belt exposed in northwest Kalimantan. The intrusives, which are Oligocene-Miocene in age, were exposed in the Melawi Basin to the south and in the Ketungau and Mandai Basins to the north (Figure 1). Since there was no indication of subduction younger than Eocene (Williams and Harahap, 1987, Soeria Atmadja *et al*., 1999), the origin of the Oligocene-Miocene Sintang Intrusives is interesting to discuss.

Most of primary gold prospects in Kalimantan are associated with the above belt. Kelian deposit, the largest Indonesia's gold mining, represents transition between epithermal and mesothermal systems. The other deposits are epithermal systems, both low sulphidation (*e.g.* Mount Muro and Muyup) and high sulphidation (*e.g*. Masuparia) (Hedenquist, 1987 in : Carlile and Mitchell, 1994). Although only minor primary quartz vein gold deposits are reported (Anon., 1988), alluvial gold and some base metals are found widely in this area (Anon., 1988; Heryanto *et al*., 1993).

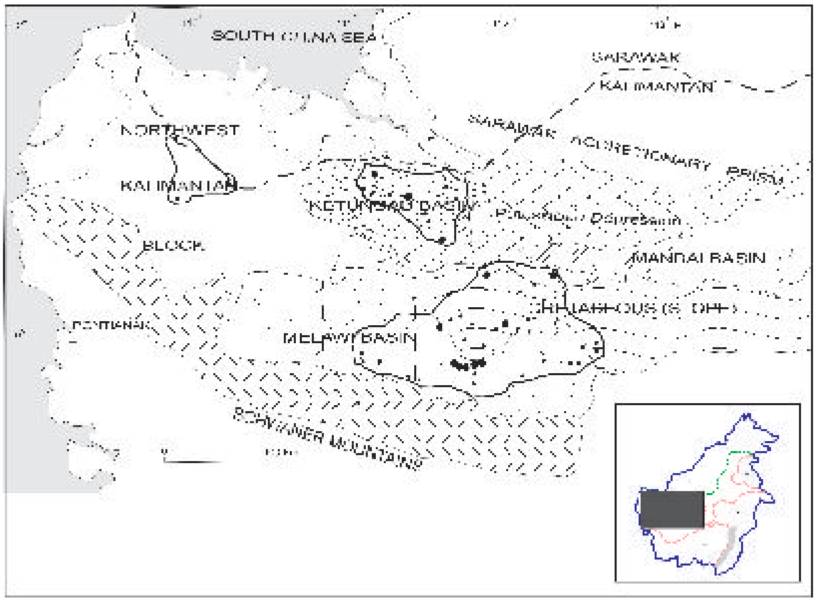

Figure 1. The regional geology of West Kalimantan showing the distribution of the Sintang Intrusives discussed in this paper (Modified from Williams and Harahap, 1987, Figure 2).

PETROGENESIS

Based on the geochemical data, Hartono and Suyono (2006) stated that the Sintang Intrusives are adakite, different from rocks of "normal" arc environments. Here the petrogenesis of the magma will be discussed further based on mineralogy and geochemical composition of the Sintang Intrusives. By using the trace elements Y and Sr, Hartono and Suyono (2006) show the differences between the Sintang Intrusives adakite and andesite-dasite-rhyolite from other "normal" arcs. Here, the Sintang Intrusives is plotted again in the same way with the additional comparison of the Mount Muro (Simmons and Browne, 1990) and Masuparia (Thompson *et al*., 1994) intrusives and volcanics (Figure 2). The Mount Muro and Masuparia rocks are used for comparison as it is generally known that gold mineralization extensively develop in these two areas and geochemical data are available. Figure 2 shows there is a different distribution between the Sintang Intrusives and the Mount Muro and Masuparia intrusives and volcanics. The Sintang Intrusives occur in an adakite field, while the Mount Muro and Masuparia rocks occupy the andesite-dasite-rhyolite area. The difference probably has a significant meaning in mineralization processes, and it will be discussed later.

Williams and Harahap (1987) proposed that the rocks of the Sintang Intrusives were generated from differentiated magma derived from primary magma produced by crustal melting. Using additional geochemical data from a neighbouring country, Sarawak, they further postulated that the primary magma is possibly high alumina tholeiite as a result of lower crust melting following crustal thickening over a wide area. Based on the field data and a detailed study on geochemical characteristics, the differentiation model is argued as follow.

The geochemical characteristics, especially low Y (< 20 ppm) and high Sr (> 200 ppm) and Al_2O_3 (> 15%) concentrations, of the Sintang Intrusives from northwest Kalimantan could not be explained by fractional crystallization modellings, because of two reasons. First, there is no basaltic rocks, which can act as parent magma exposed in the Sintang inrusives, although Williams and Harahap (1987) used the basaltic rocks from Sarawak as the parent magma. The major element Harker diagrams comparing the Kalimantan and Sarawak rocks (Figure 3 : Figure 6 of Williams and Harahap, 1987) show that the Kalimantan Sintang Intrusives are not sitting on the same straight-line with the Sarawak rocks. The Kalimantan Sintang Intrusives are also high in MgO and Al_2O_3, and lower in FeO concentrations than the Sarawak rocks, which means that the Sintang Intrusives magma could not be derived from basaltic

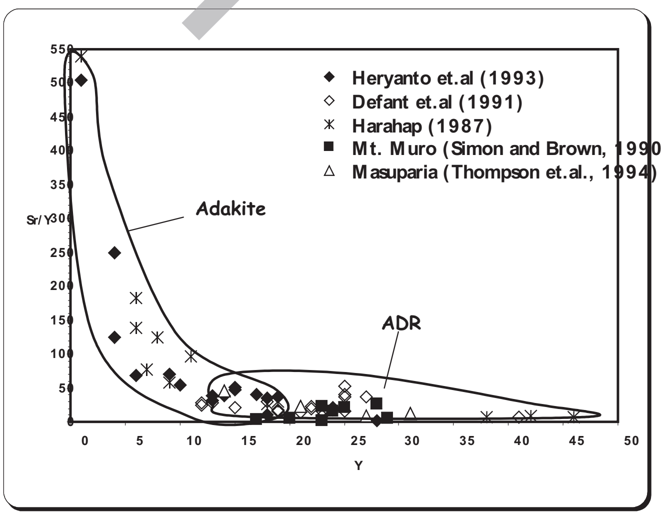

Figure 2. Sr/Y vs Y plot of the Sintang Intrusives. Show for comparison are the data of andesite-dacite-rhyolite (ADR) from Mt. Muro (Simmons and Browne, 1990), Masuparia (Thompson *et al.*, 1994), Southern Luzon, Pilippines (Defant *et al.*, 1991).

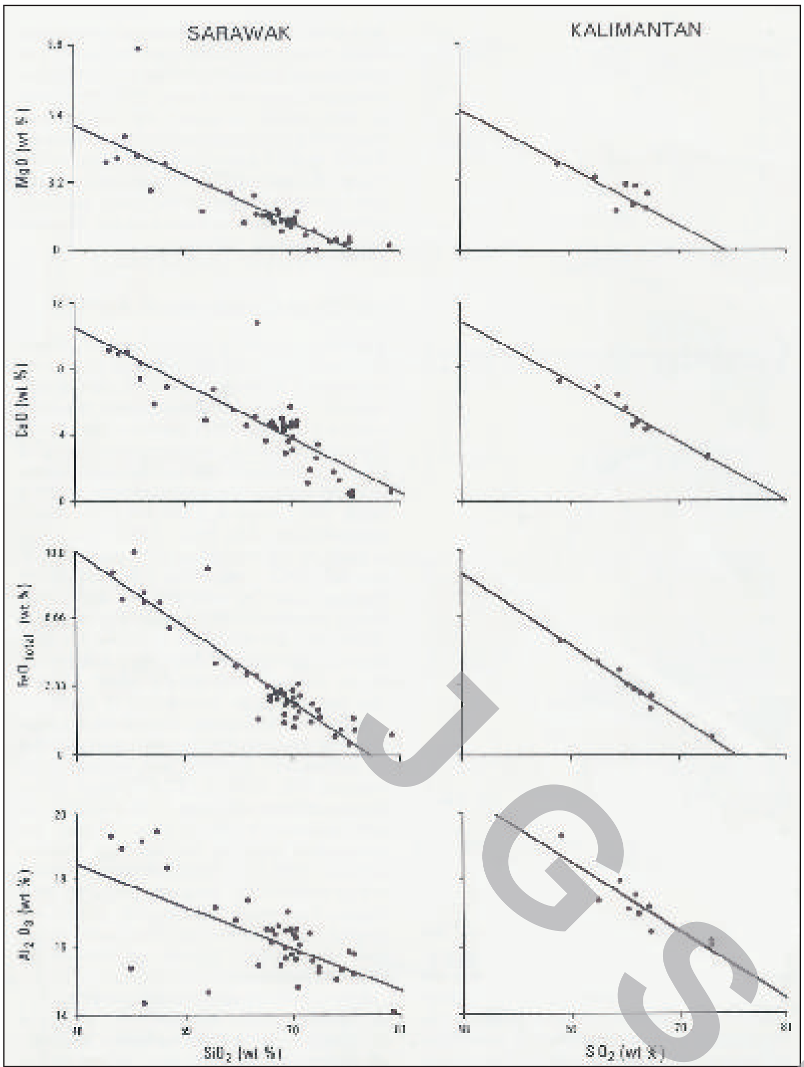

Figure 3. Harker variation diagram from Sarawak and Kalimantan (the Sintang Intrusives) taken from Williams and Harahap (1987) figure 6.

magmas similar to the Sarawak magma. The dolerite rocks exposed in the Sintang area are much older than the Sintang Intrusives, *i.e.* 97.8 my (Cretaceous) and 209 my (Triassic) (Heryanto *et al.*, 1993), so they may not came from the same magma with the Sintang Intrusives. Furthermore, high abundance of Al_2O_3 may have significant meaning, that will be discussed in the second argument. Secondly, petrographic characteristics (Heryanto *et al.*, 1993) show that plagioclase and hornblende are the dominant mineral phases in the Sintang Intrusives, while pyroxene are rare. These characteristics are inconsistent with the geochemical data when the fractional crystallization is applied. Plagioclase fractionation would drive magmatic liquids toward high Y, low Sr, and low Al_2O_3 based on the partition coefficient between minerals and melt.

Pyroxene and amphibole are the only mineral phases that can push magma toward low Y and high Sr and Al_2O_3. However, as long as plagioclase fractionates during the fractionation of amphibole and pyroxene, magma with low Y, high Sr, and high Al_2O_3 will not be produced.

Defant and Drummond (1990) postulated that extensive fractionation of amphibole (60%) could result in adakite geochemical characteristics, but 60% fractionation is unrealistic, because it would be in disagreement with the amount of amphibole normally found in adakites. Although there were no detailed petrographic description available that showed the amount of hornblende, concentration of hornblende up to 60% in rocks of the Sintang intusives is unlikely. Pyroxene is absent in most of the Sintang Intrusives (except in samples from the Ketungau Basins which probably belong to the Triassic Betung volcanics). Therefore, it is difficult to explain the role of this mineral fractionation to produce most of the Sintang intrusive rocks.

If the Sintang Intrusives were not derived from magma produced by fractionation (with or without assimilation) of basaltic magmas, the rocks might be originated from magma resulted from melting of the crust, either underplated lower crust or a subducted oceanic lithosphere. The content of Al_2O_3 was used by Drummond and Defant (1990) to classified the leucocratic subducted related rocks (trondhjemite-tonalite-dacite/ TTD), and they put the value of 15 wt % as the demarcation line between high Al and low Al TTD (Baker *et al.*, 1976). The subdivision of high Al and low Al may suggest the presence or absence of significant amount of amphibole in the TTD's petrogenesis. Removal of subaluminous hornblende, either by process of fractionation or as refractory source component, would result in the daughter liquid (in fractionation) or the melting produced to evolve to relatively high Al_2O_3 concentrations. Experimental studies show that amphibole plays an important role in the generation of andesite and/or dacite from basaltic magmas (*e.g.* Allen and Boettcher, 1978, 1983; Cawthorn and O'Hara, 1976). In a low pressure experiment, about 1 to 3 kbar, melting greenstone and amphibolite resulted in low Al TTD melts in equilibrium with restite of 40 - 60% plagioclase, orthopyroxene, clinopyroxene, and Fe-Ti oxide assemblage, and absence of refractory hornblende (Beard and Lofgren, 1989).

The low Al type is probably produced by low pressure fractionation or partial melting where plagioclase and pyroxene play the role, and garnet and hornblende were not involved in the petrogenesis (Drummond and Defant, 1990). The argument is based on the geochemical characteristics, that the low Al type has low concentration of Sr (< 200 ppm), a negative anomaly Eu, slightly enriched LREE, and flat HREE pattern (Barker and Arth, 1976). The extraction of plagioclase and pyroxene phases would not efficiently remove HREE, such as Y and Yb causing the flat pattern of rare earth element pattern in chondrite normalized diagram.

In contrast, the high Al type has high Sr content (> 300 ppm ranging up to > 2000 ppm), low Rb/Sr ratios (<0.5), enriched LREEs, depleted HREEs, no Eu anomaly, low Y (<15 ppm), and low to moderate K/Rb ratios. The LREE enrichment and HREE-depletion indicate the involvement of high pressure garnet and/or hornblende extraction. An experimental study shows that high Al TTD resulted from melting MORB source with Yb_N = 10-12 leaves the refractory garnet amphibolite to eclogite (Drummond and Defant, 1990).

The REE characteristics of the Sintang Intrusives are shown in the spidergram (Figure 4). The figure shows moderate to deep slope REE patterns with moderate to strong enrichment in LREE and depleted in HREE. This indicates the role of garnet and/or amphibole in the petrogenesis of the Sintang Intrusives in a high pressure condition. Although amphibole fractionation could cause depletion in HREE, it has been argued that low prsessure fractionation involving amphibole for the Sintang Intrusives is unlikely. Other significant characteristic of the Sintang rocks is the positive Eu anomaly, including PP001A samples. This supports the argument that the Sintang Intrusives could not be a result of low pressure fractionation involving plagioclase, because plagioclase fractionation would cause a negative anomaly in the REE pattern. In addition, the high Zr/Sm ratios of the Sintang Intrusives (Figure 5) are also indicative of garnet amphibolite sources, because of high partition of Zr in amphibole and garnet and low partition of Sm in those two minerals. In contrast, the andesite-dacite-rhyolite from the Southern Luzon arc (Defant *et al.*, 1991) show different pattern with low Zr/Sm ratios. Hence, it is convinced here that the Sintang Intrusives are adakite type rocks as a result of crustal melting.

Experimental works (Defant and Drummond, 1990; Drummond and Defant, 1990; Peacock *et al.*, 1994; Kay, 1978) show that adakites were produced by partial melting of subducted oceanic lithosphere. However, other types of petrogenesis are possible, for example melting of the lower crust, because

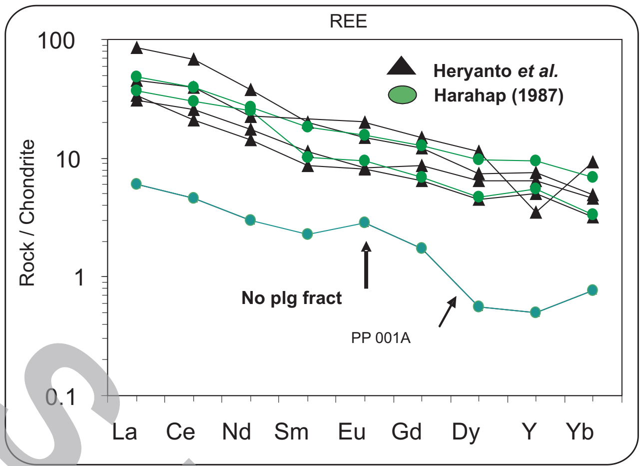

Figure 4. Rare earth element spidergram for the Sintang Intrusives showing moderate to high slope patterns indicating the role of garnet and/or amphibole in the petrogenesis of the Sintang rocks in a high pressure condition (see the text for discussion). The absence of Eu negative anomaly and some samples show positive anomaly suggesting no plagioclase fractionation.

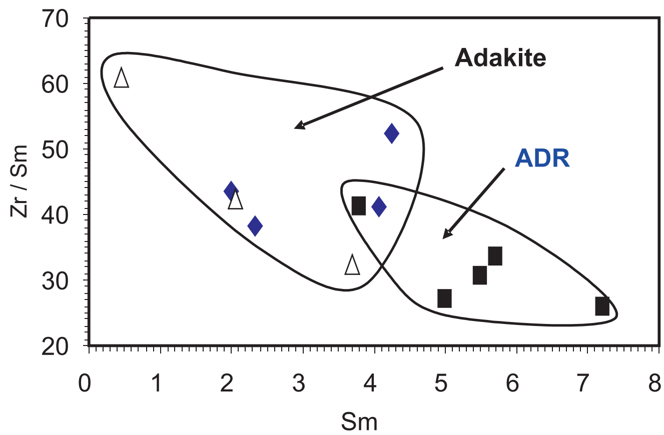

Figure 5. Zr/Sm vs Sm plot of the Sintang Intrusives compared to that of andesite-dacite-rhyolite from the Southern Luzon arc (ADR) (Defant *et al.*, 1991). The high Zr/Sm for adakite indicates a garnet amphibolite sources.

geochemical signatures of adakites suggest basaltic sources. In addition, field evidences also indicate that in some arcs (*e.g*. Baja and New Guinea) adakite is also present, although oceanic crust is not currently being subducted (Peacock *et al*., 1994). The writers implied that the adakite may have resulted from either partial melting of the lower crust or previously subducted oceanic lithosphere. The positive Eu anomalies of the adakite of the Sintang Intrusives (Figure 4) could not be explained as a lower crust melting, because the magma produced will have negative Eu anomalies, as this basaltic magma will not reach the amphibolite-eclogite transition under most arcs (Defant and Drummond, 1990).

Proteau *et al*. (1996) proposed that the Miocene magmatism in northwest Kalimantan (and Sarawak) might be attributed to the subduction zone of a narrow Proto South China Sea. However, their model does not take into account the Oligocene rocks found in northewest Kalimantan. From the above discussion, it is concluded here that the Sintang Intrusives were produced by melting of subducted ocanic crust, and the South China Sea dead slab is a good candidate, because it was subducted beneath Kalimantan continent in the Late Oligocene - Lower Miocene (Soeria-Atmadja *et al*., 1999; Hamilton, 1979). This conclusion is in contrast with the suggestion of Williams and Harahap (1987), who proposed the Sintang Intrusives are differentiated products from the high alumina tholeiitic basaltic magma as a result of underplated lower crust melting. The magma produced would then be intruded into the crust to produce plutons and/or underplated the lower crust while crystallizing plagioclase and amphibole (Figure 6). Remelted weakened amphibole bearing pluton and possibly underplated lower crust caused by shortening and thickening crust when subduction ceased, would result in amphibole break down. The break down of amphibole would release H_2O, which has a significant role in mineralization in northwest Kalimantan.

IMPLICATIONS FOR MINERALIZATION

Alluvial gold deposits have been found in many rivers in Sintang area, mainly in a coarsed-grained or conglomeratic alluvium directly above the bedrocks (Heryanto *et al*., 1993). In the area of Seberuang, Selangkai, and Boyan Rivers gold has been mined by local people for many years. In Kapuas River banks gold occurs in alluvium forming the higher levels of the Kapuas River, possibly remnant of the old alluvium in the present drainage system. In the Kapuas River upstream of Sintang, a few operation is working recent river gravels. Gold deposits in the old alluvium were also reported in Belitang River (van Emmichoven, 1939).

The primary gold occurs in quartz veins and stockworks in the silicified zone, but also disseminated in the oxidized/argillized rocks (Anon., 1988). The disseminated gold occurs in clayey zone, but in sandstone it may form coarse grains filling pores. The coarse grain gold in sandstone was interpreted to be a result of supergene reworking and agglomeration of microscopic gold liberated from gold-bearing pyrite during oxidation. Other minerals that have been mined in small-scale operation are cinnabar and stibnite. Both minerals are associated with gold, but base metals (Zn and Cu) are rare, and it was interpreted as epithermal low-sulphidation (Anon., 1988).

There is no indication of direct link between the shallow Sintang intrusive and the alteration and mineralization. However, the close spatial and temporal association, recognized from the alluvial gold deposits widespread in a wide area as the Sintang intrusive imply that the Sintang Intrusives was the heat source agent for the mineralization (Anon., 1988). The next discussion deals with the role of magma genesis to the mineralization processes, and whether or not the primary gold deposits in West Kalimantan would be economically significant.

In West Kalimantan, the water released resulted by amphibole break down during remelted hornblende-bearing plutons and the lower crust might play a significant role in the formation of gold deposits. As mentioned before, the presence of gold associated with pyrite, stibnite, and cinnabar suggests an epithermal low-sulphidation (Anon., 1988). The minor base metals (Zn and Cu) associated with gold deposits may be interpreted as a result of low-suphidation outflow processes. In this mechanism, a mix between saline hot mineralized fluid and bicarbonate groundwater would cause calcite deposited and decrease the pH solution (Lawless *et al*., 1997). As saline water rich in Ca, the reaction is shown as follow :

$$Ca^{2+} + HCO^{3-} \approx CaCO_3 + H^+$$

Decreasing pH solution is also caused by base metal deposition. Base metals usually occur as complex chloride in saline water, for example Zn, and the reaction is :

$$ZnCl_2 + H_2S \approx ZnS + 2H^+ + 2Cl^-$$

The consume of H_2S and H^+ produced would lower pH solution and cause gold deposition, for example :

$$2Au(HS)_2^- + H_2 + 2H^+ \approx 2Au + H_2S$$

The shallow intrusive dykes, stocks, plugs, and sills of the Sintang Intrusives are good places for accumulated gold deposits. On the other hand, crustal plates are also possibly a good source for the metal, including gold. However, this condition alone is not enough for the deposits to be economically important. Gold deposits would be economically significant when the deposit is accumulated in a long-lived hydrothermal system. Considering the magmatic process of the Sintang Intrusives (Figure 6) a long-lived hydrothermal system might not be maintained. A repeated small intrusion, as a heat source, would not be happened as there was no continous melting of the South Cina Sea oceanic crust (as mentioned before that the crust was only a dead slab). Although the Kelian magmas (represented by Mt. Muro and Masuparia; Figure 2) were emplaced to the crust at the same time as the Sintang Intrusives was, different magmatic origin might result in different mineralization history. The basaltic through andesitic to dacitic rocks of the Mount Muro and Masuparia (Simmons and Browne, 1990; Thompson *et al*., 1994) might have been produced by fractionation of basaltic magma originated from the mantle. This fractionation process combined with magma mixing (Hartono, 2003) could possibly cause a long-lived hydrothermal system in the Kelian mineralization system.

Therefore, the above discussion indicates further exploration for gold deposits associated with the Sintang Intrusives is not be recommended, not only because the epithermal gold has intensively eroded, but also the deposit may not economically significant for an industrial size. However an alternative model for mineralization, for example porphyry copper deposits, may be possible as an association between adakite and ore deposits that has been documented in many places. For examples at Mount Pinatubo, Luzon (Sillitoe and Gappe, 1984; Malihan, 1987; Imai *et al*., 1993) and East Mindanao (Maury *et al*., 1996; Sajona and Maury, 1998), both in Philippines; in Andes (Thiéblemont *et al*., 1997) and Los Pelambres (Reich *et al*., 2003; Kay and Mpodozis 1999), Chile. As the adakite magma of the Sintang Intrusives was originated from oceanic crust melting, fluid released by amphibole breakdown should be important in mineralization. Further research, such as fluid inclusion, isotopic and mineralogical studies as well as geophysical modeling, are needed to better understand the type of melts and subsurface geological condition around the intrusive bodies.

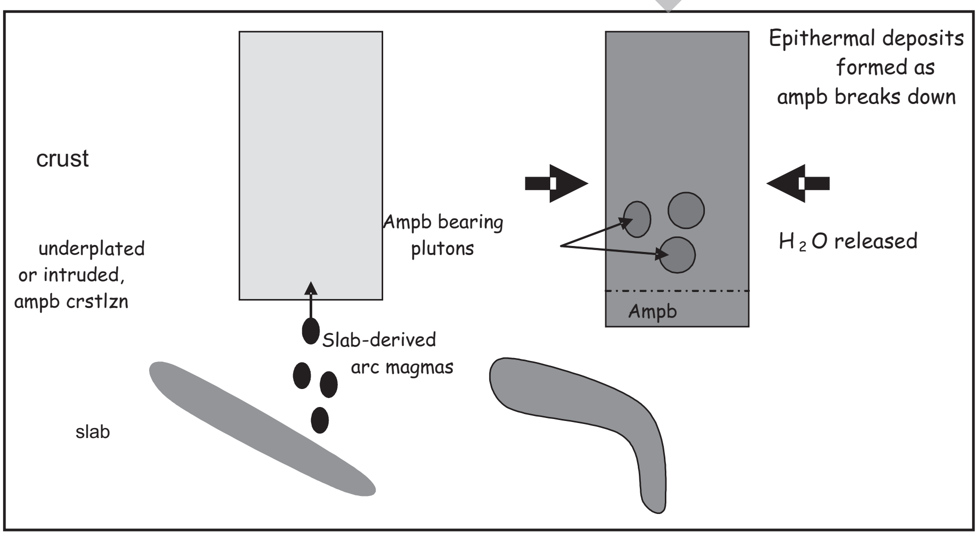

Figure 6. Cartoon of the magmatic origin and the role of mineralization of the Sintang Intrusives.

CONCLUSION

The petrogenesis of the Sintang Intrusives involves the role of plagioclase and amphibole in a high pressure. The rock is adakite, which is derived from magma produced by a dead slab of South China Sea lithospheric melting in the Late Oligocene Early Miocene. The magma produced intruded into the Kalimantan crust and/or accumulated in the lower crust, subsequently crystallized amphibole and plagioclase producing amphibole-bearing pluton and/or amphibole-bearing residual mineralogy. The plutons and possibly underplated lower crust, then underwent remelted caused by shortened and thickened crust when the subduction ceased. A saline hot mineralized water released, as amphibole break down, is considered fundamental for the formation of epithermal gold deposits. The presence of pyrite, stibnite, and cinnabar is a good evidence for epithermal low-sulphidation. Further exploration in primary epithermal gold deposits is not recommended, not only because the deposits have been intensively eroded, but also the mechanism of mineralization indicates the deposit would not economically important for industrial sizes. This mechanism may be important in porphyry-type deposits in northwest Kalimantan. However, further studies are needed.

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