KALIMANTAN MINERAL RESOURCES: AN UPDATE ON EXPLORATION AND MINING TRENDS, SYNTHESIS ON MAGMATISM HISTORY AND PROPOSED MODELS FOR METALLIC MINERALIZATION

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ABSTRACT

Kalimantan, the Indonesian part of Borneo island, contains significant amount of known metallic mineral deposits and potential for future discoveries in Indonesia. However, a synthesis on its geological history, magmatism and metallic mineralization is still lacking. This paper explains results of an initial effort to compile all relevant data regarding the magmatic history and metallic mineralization in this island. Additionally, update on current mining industry in Kalimantan and future potential developments are included. There is a major change in mining industry activities in Kalimantan following the new reform in Mining Law. Current activities are done by small to medium-scale players working on various commodities, including iron, base metals and quartz sands. Real exploration programs are limited as activities concentrate on evaluation of known prospects and efforts to bring productions from existing prospects or re-open old mines.

A long geodynamic history produced different events of magmatism since the Late Paleozoic. More evident magmatic arcs are found for the Cretaceous and younger events. Subduction zone magmatism might come to end after Late Cretaceous in many parts of the island, from which syn- and post-collision magmatism became more prominent. Metallic mineralization can be divided into two major periods. First is the Cretaceous or older events, in which mineralization is dominated by granitoid-related skarn iron and base metals mineralization, geographically located within the Schwaner and Meratus Mountains. Second is the Middle to Late Miocene gold and base metals mineralization associated with Sintang Intrusions. Miocene gold-bearing intrusions are not products of ordinary subduction-zone magmatism, but they are derived from basalts source during major tectonic events following subduction. Gold exploration programs should include study on petrogenesis of intrusive rocks. Suture zones of Late Cretaceous-early Tertiary age should be tested for their potential of orogenic gold mineralization.

INTRODUCTION

On 29-30th March 2010, Indonesian Association of Geologists (IAGI) and Indonesian Society of Economic Geologists (MGEI) conducted a seminar entitled Kalimantan Coal and Mineral Resources (KCMR) at Balikpapan city, East Kalimantan. We refer Kalimantan here as the Indonesian parts of the island of Borneo. During this two-day seminar, various projects on coal and mineral resources in Kalimantan were presented and discussed. Presented papers cover almost all geographical regions and various mineral commodities, deposit styles and sizes, such as porphyry, epithermal (LS-HS), skarn, iron ores, and bauxites. Several new ideas and technologies were presented and discussed, such as exploration on deeper targets, older terrane (Mesozoic host rocks), and application of spectral geology.

The seminar also noted that despite Kalimantan can be considered as a relatively mature
exploration island, in fact no comprehensive data inventory on mineral resources and integrated geologic model of the whole Kalimantan has been done. Therefore, as an important result derived from the above seminar, MGEI considers the need to produce an update of mineral resources inventory and geological model for the whole Kalimantan. It is done through integrating the data delivered during the seminar with other existing publications and conducting several follow-up discussions by inviting prominent researchers and mineral explorers working in Kalimantan.

This paper is part of the first result of compilation efforts, with special attention on metallic mineral deposits. Discussion will start with the update of current status of mineral industry in this island, as results of the new political and mining reform following the 1998’s economic crisis and reform in Indonesia. Following part will evaluate the magmatic history and metallic mineralization, as results of current compilation works. Other aspects are covered within the other two papers concerning the basin development and diamond origin in Kalimantan, which are presented together with this paper in a special session on the Kalimantan geology during the 39th IAGI Annual Convention and Exhibition in Lombok island, Indonesia.

**SOURCE OF DATA COMPILATION**

Geoscience datasets compiled in this study comprise geology, mineral occurrences, radiometric ages and petrochemical data on igneous rocks. Basic information on Kalimantan mineral deposits was derived from exceptional compilation work by Van Leeuwen (1994), which is then enriched by newer materials including papers, internet and KCMR seminar results. Data on geology of Kalimantan are mainly derived from many published geological map sheets by Geological Survey Indonesia at scale 250,000, and prospect maps from many papers. Petrochemical and radiometric data are mainly compiled from Geological Survey Indonesia from their projects in West-Central Kalimantan (e.g. De Keyser and Rustandi, 1993) and Meratus (e.g. Hartono et al., 2000; Heryanto and Panggabean, 2010), and data from certain area such as Kelian (Van Leeuwen et al., 1990; Davies et al., 2008), Mt. Muro (Simmons and Browne, 1990) and Masupa Ria (Thompson et al., 1994). Data from Malaysian parts of Serawak and Sabah are mainly compiled from Hutchison (2005).

**KALIMANTAN MINERAL INDUSTRY BEFORE 21st CENTURY**

Kalimantan, with its massive land mass and complex geological history, is endowed with huge potential of economic mineral deposits (e.g. gold, copper, diamond and bauxite) and other important geological resources such as coal and hydrocarbon. The mining industry in Kalimantan has started more than 1,000 years ago. Gold had been worked from alluvial deposits since 4th century and especially during the 18th century the Western Kalimantan (Sambas area) was the site of gold rush (Van Leeuwen, 1994; Gunter, 2010a). Alluvial diamonds have been known since the 7th century. There are also records on mining and processing of iron ore between 5th and 10th century. The foundation for modern-day mineral industry was laid by the Dutch, who undertook exploration and development since the 19th century (Van Leeuwen, 1994). Early investigation programs for metallic deposits in Kalimantan included investigation on tin in Ketapang region in 1820s (De Keyser and Rustandi, 1993) and gold deposits in Sambas region in 1880s (Gunter, 2010a).

Since the Indonesian independence and the introduction of the foreign investments through the Contract of Work (COW) scheme, regulated by the Mining Law No. 11/1967, Kalimantan attracted many major exploration projects. Initial projects under early generation of COW were dominated by bauxite project in the West and Southwestern Kalimantan by ALCOA since 1969 (Van Leeuwen, 1994). The result was the discovery of 10 bauxite deposits in West Kalimantan, totaling 1,300 Mt ore with an average grade of 30% Al₂O₃, with the Tayan (270 Mt) as the biggest one.

Uranium exploration in West Kalimantan during period 1974 and 1988 resulted in the discovery of Kalan deposit, in the form of fault breccia bodies within metasediments nearby Mesozoic granitic intrusives, with a total resource of 11,000 tonnes of U₃O₈ (Sarbini and Wirakusumah, 1988 in Van Leeuwen, 1994).
Intensive porphyry copper search during the early 1970s that swept the majority of Indonesian archipelago did not actually reach Kalimantan, probably due to the lack of recognition of Tertiary magmatic arcs in this island.

Exploration for primary gold in Kalimantan was started by RTZ/CRA in 1975 that lead to the discovery of Kelian deposit. The real massive exploration activities in Kalimantan occurred during the “Revised Third Generation of COW” (Van Leeuwen, 1994) that attracted interests for discovery and development of smaller-size deposits. During the epithermal gold boom in 1980s, the majority of COWs signed in Indonesia during the period 1985 and 1992 were dominantly located in Kalimantan. Van Leeuwen (1994) recorded following alluvial gold prospects had been drill tested during this period: Monterado, Sungai Raya, and Kapuas in West Kalimantan, and Ellahula, Cempaga Buang, and Tewah in Central Kalimantan. Meanwhile, the primary gold deposits were drilled at Kelian and Muyup (East Kalimantan), Mt. Muro, Masupa Ria, Mirah, and Gunung Mas (Central Kalimantan), Buduk (West Kalimantan), Sungai Keruh and Timburu (South Kalimantan).

Among these deposits, two alluvial gold deposits (Monterado and Cempaga Buang/Ampalit) came into production but only for a short period. The biggest success story was the discovery of the Kelian gold deposit that entered into mining stage in early 1992 with a total resource of 92.1 Mt of ore grading 2.61 g/t Au (Davies et al., 2008). Kelian was the biggest gold-only mine in Indonesia until its mining closure in 2005. Along with Kelian, several smaller gold deposits were also discovered within an apparently NE-SW trending Oligo-Miocene magmatic belt in central Kalimantan, such as Mt. Muro (Simmons and Browne, 1990; Moyle et al., 1995), Masupa Ria (Thompson et al., 1994), Mirah and Muyup. Among these, Mt. Muro became the second primary gold mine in Kalimantan, operated by Aurora Gold. The discovery of the Central Kalimantan Gold Belt was major achievement as this belt was not recognized during the Dutch period. Carlile and Mitchell (1994) then proposed the occurrence of the Neogene Central Kalimantan Arc that spans from Sabah in NE through the Gold Belt in the South and bends to the West to reach Singkawang.

Although numerous lead-zinc occurrences were identified since the Dutch period in Kalimantan, minor systematic exploration effort for lead and zinc has actually been undertaken. Van Leeuwen (1994) noted two lead-zinc deposits being drilled, i.e. Riam Kusik in West Kalimantan and Long Lai in East Kalimantan. Riam Kusik consists of narrow veins of massive sulfides along Cretaceous limestone-dyke contact, while Long Lai consists of irregular skarn deposits by Cretaceous-Eocene sandstone-siltstone intruded by Oligocene granite. Another base metal skarn deposit is discovered in Ruawai, Central Kalimantan, associated with contact metamorphism between Paleozoic sedimentary rocks and Cretaceous granite (Setijadji et al., 2010).

With exception cases of Kelian and Mt. Muro, the majority of other projects suffered severely from the low commodity prices in the late 1990s, the Bre-X Minerals scandal on the Busang gold deposit in 1997 and global economic crisis in 1998. Many COW projects were terminated and almost no exploration activities were done during 1998 to early 2000s.

**KALIMANTAN MINERAL INDUSTRY TODAY**

Despite the current high commodity prices for almost all metals that started around 2003, Indonesia including Kalimantan do not benefit from significant increasing global exploration spends during the last several years. Many parties claim that the current Mining Law and overall regulations related with mining industry are not welcomed by foreign companies.

Such situation started since the wave of reformation following the 1998’s economic-political crisis gradually has brought to the fundamental changes to decentralize the mining system. Among all geological resources, only oil and gas are now still regulated by the central government; other commodities including minerals are transferred to the district governments. The reformation culminated by the release of Mineral and Coal Mining Law No. 4/2009. This Law groups mineral resources as
radioactive, metal, non-metal, and coal, peat, and oil shale. Among other restrictions, the law aims to shorten the period of mining contracts. As results, actually there are very limited funds being spent for exploration and no new deposits have been discovered since the mid 1990s. Since the closure of Kelian gold mine in 2005, Kalimantan has now lost its position as a primary gold producer in Indonesia.

Existing gold projects are now mainly evaluation and further exploration programs on known prospects discovered during the 1980-1990s exploration period, such as Buduk (Gunter, 2010a), Jelai (Gunter, 2010b), Seruyung (Rura et al., 2010), and Mansur-Beruang district (Geiger et al., 2010). There are also small-scale gold operations in East, Central and West Kalimantan. Among them, the Mt. Muro gold mine in Central Kalimantan is the biggest one, operated by Straits Resources Ltd. that took 100% ownership of Mt. Muro since 2004. In its 2008 annual report, Straits Resources reported ore reserves at Mt Muro of 1,800kt with gold content of 433,000oz Au and annual production 80,000oz Au (http://www.mining-technology.com/projects/mt-muro/). Other gold operations have smaller scale, such as the case of Buduk mine in Singkawang district, West Kalimantan (Gunter, 2010a).

In better sight, the current mineral industry has encouraged the births of many national mining enterprises, mostly funded by Chinese and Indian investors. Commodities of interest have grown dramatically into various minerals, such as iron, base metals, bauxites, zircon, and quartz sand. Revival of interest on bauxite has drawn P.T. Antam to continue its Tayan project and even expand its exploration areas into Mempawah and Landak districts in West Kalimantan that resulted in delineation of larger bauxite district in West Kalimantan (Surata et al., 2010). Iron deposits are now being explored and exploited in Schwaner Mountains region in West-Central Kalimantan, such as Kendawangan (Subandrio and Kuswanto, 2010), Ketapang (Aribowo, 2010) and Lamandau districts (Setijadji et al., 2010) and in the Meratus Mountains and surroundings in Southern Kalimantan. Lateritic iron ore is reported to be mined near Buntok, NW Meratus, and further exploration programs on known prospects discovered during the 1980s-1990s exploration period, such as Buduk (Gunter, 2010a), Jelai (Gunter, 2010b), Seruyung (Rura et al., 2010), and Mansur-Beruang district (Geiger et al., 2010). These small-scale gold operations in East, Central and West Kalimantan. Among them, the Mt. Muro gold mine in Central Kalimantan is the biggest one, operated by Straits Resources Ltd. that took 100% ownership of Mt. Muro since 2004. In its 2008 annual report, Straits Resources reported ore reserves at Mt Muro of 1,800kt with gold content of 433,000oz Au and annual production 80,000oz Au (http://www.mining-technology.com/projects/mt-muro/). Other gold operations have smaller scale, such as the case of Buduk mine in Singkawang district, West Kalimantan (Gunter, 2010a).

Cretaceous subduction zones occurred in the NW and SE Kalimantan, forming two pairs of trench-magmatic arc belts (e.g. Carlile and Mitchell, 1994). In the SE corner of Kalimantan, the Meratus Mountains was formed by northwestwards subduction (part of the Sumatra-Meratus arc). This subduction produced overlapping Early to Late Cretaceous granitoids typical of Volcanic Arc Granite (VAG) emplaced within the Meratus Mountains and northern part of Pulau Laut (Hartono et al., 2000). The Early Cretaceous granitoids are dominated by intrusive rocks called the Batang Alai (Balawayan) Granites (118-101 Ma).
Ma), while the Late Cretaceous magmatism produced the dominated volcanic rocks named the Haruyan Volcanics.

Meanwhile, from the NW Kalimantan, the southwards subduction zone during the Cretaceous resulted in the Schwaneer Mountains Granitoids. The Early Cretaceous I-type granitoids (124-99 Ma) formed in the Singkawang region and northern part of the Schwaneer Mountains, forming the 500km long ESE trending magmatic arc called the Schwaneer Arc by Carlile and Mitchell (1994). These granitoids are typical of VAG whose magma affinities are dominated by medium-K and high-K granodiorite (Mensibau Granodiorite) and tonalite (Sepauk Tonalite). The Late Cretaceous I-type granitoids (91-66 Ma) were emplaced south of the older ones, forming a separate yet partly overlapping Sunda Shelf Arc (its name was given by Carlile and Mitchell, 1994). The distribution of dated Late Cretaceous granitoids is rather a rectangle area (about 200 x 170 km) than a typical arc. In Ketapang region, such granitoids are named the Sukadana Granite (De Keyser and Rustandi, 1993). The Late Cretaceous granitoids in general are more alkaline than the Early Cretaceous one, but in overall still show VAG characteristics. Hutchison (2005) and the Indonesian-Australian joint team (e.g. Amiruddin and Trail, 1993; Supriatna et al., 1993) preferred post-subduction origin for the Late Cretaceous Sukadana Granites. Indeed, parts of the Sukadana Granite show transitional signatures into syn-collision and within-plate granite, suggesting the termination of subduction and the beginning of collision at the end of Cretaceous. In several locations, such as Lamandau, the Late Cretaceous granites are intruded by diorite to basalt dykes of probably Early Tertiary age. Some Late Cretaceous granitoid rocks were also formed and emplaced along the collision zone north of the Schwaneer Mountains (Menyukung Granite) that also show a transition signature from the VAG to within-plate granite. Syn-collision Late Cretaceous magmatism seems to occur along the collision zone at the northern boundary of the Schwaneer Mountains. The extension of Late Cretaceous silicic volcanics is recently recognized to reach the Kelian district (Davies et al., 2008) on what previously thought to be Late Eocene (Van Leeuwen et al., 1990).

The timing of termination of southwards subduction post Late Cretaceous is still matter of debate. Arc magmatism seems to be terminated post the Late Cretaceous (~65.5 Ma). There was then a period of no magmatic event during the Paleocene, which was followed by Eocene magmatism that started at 51 Ma (Soeria-Atmadja et al., 1999). Through the Tertiary, magmatism-volcanism formed a long arc starting from the Singkawang district at the western end to the Tawau or Dent Peninsula (Malaysia) at the northeastern end; this arc is referred to be the Tertiary Central Kalimantan Arc (Carlile and Mitchell, 1994). Tertiary magmatism also occurred in the Meratus Mountains (Eocene-Miocene) that produced scattered and overlapping basaltic to dacitic volcanic and subvolcanic rocks (Hartono et al., 2000). This Tertiary magmatic belt in Meratus Mountains is previously not known (e.g. Carlile and Mitchell, 1994).

Within the Central Kalimantan Magmatic Arc, dated Eocene igneous rocks are found as thin arc (width approximately 50km) found in all sections (Singkawang to Dent Peninsula) and are dominated by acid volcanics. They consist of the Piyabung, Nyaan, Serantak and Muller Volcanics, and whose affinities are low-K (tholeiitic) to medium-K (calc-alkaline). Soeria-Atmadja et al. (1999) and Priadi (2010) concluded them as products of (new) southward subduction in the NW of Kalimantan. It means that there was newly initiated subduction zone in the Eocene along the NW Kalimantan (boundary between Indonesia and Malaysia) that was different from the Cretaceous one. The Late Oligocene to Miocene magmatism forms a wider arc, probably 75-150 km wide that might be consisted by double volcanic chains in several parts. Magma affinity is dominated by calc-alkaline whose compositions range from andesite, dacite and rhyolite with few basalts (Soeria-Atmadja et al., 1999). Volcanic edifice groups include the Kelian, Mount Muro, Masuparia and Sintang Intrusions. The Sintang Intrusions occur as hundreds of stocks, sills and dykes that cut the sedimentary sequence of the Ketungau and Melawi Tertiary basins (Hutchinson, 2005). They often form high inselbergs, which may reach a height of 1000 m rising from the surrounding area. In many cases no associated lava flows and volcanics have been found; some
researchers suggest that the volcanic parts have been completely eroded.

The origin of Late Oligocene to Miocene magmas is still controversial and probably different among different locations. In western Sarawak, two kinds of intrusions can be distinguished (Prouteau et al., 2001 in Hutchison, 2005). The Early Miocene (22.3-23.7 Ma) intrusions in the northern part are dominated by high-K to medium-K calc-alkaline diorites and microdiorites that show all the usual characteristics of subduction-related magmas. On the other hand, the younger Middle to Upper Miocene (14.6-6.4 Ma) intrusions to the South (Bau area) are dominated by microtonalites and dacites that share some of the subduction-related characteristics, but in addition they display the typical adakitic magma. Adakites are interpreted to have resulted from melting of basalt, which is different from the typical source of subduction zone, i.e. peridotite. The separation between the above two episodes of intrusions was at least 8 Ma.

Adakites versus typical subduction-zone magmas are also identified in Kalimantan, and they occur within almost all geological epochs (Fig. 3). This phenomenon can be interpreted that within the majority of subduction-related magmas in Kalimantan, there was always other source (basalt) that produced the melts. The most striking feature is on the Sintang intrusion suite within the Central Kalimantan Arc that strongly shows adakitic characters. We conclude that non-subduction zone magmas became more frequently present after the Middle Miocene.

In the Sabah area in NE Borneo, separate magmatic evolution may be present especially during the Neogene. Earlier suggestion was that from the Paleogene until the Early Miocene, there was southward-directed subduction of the proto-China Sea that produced the Middle to Late Miocene (12.9–9Ma, Rangin et al., 1990) ages for Neogene magmatism in the Semporna and Dent Peninsulas. The southward subduction preceded the collision at Late Miocene that resulted in the emplacement of Mount Kinabalu granites (13.7-6.4 Ma, Rangin, et al., 1990; Hutchison, 2005). The questionable whole-rock dating results by Rangin et al (1990) and the lack of tomographic evidence for a dipping slab, has challenged Hall (2002) to use the geological configuration of Sabah to propose that the Neogene subduction in the Dent and Semporna Peninsula was actually directed towards the northwest, as the southern end of the Sulu Arc.

The youngest phase of magmatism in Kalimantan is presented by widespread basaltic lava flows of Plio-Pleistocene age. This unit includes the Niut Volcanics in western Kalimantan (4.9 Ma, Supriatna et al., 1993), Metulang Volcanics in central Kalimantan (2.41-0.97 Ma, Pieters et al., 1993; Abidin, 1996 in Daview et al., 2008), and Kunak basalts in Dent and Semporna Peninsula (<2.95 Ma, Hutchison, 2005). Origin of this basalt is considered to be within-plate magmatism with tholeiitic composition (Soeria-Atmadja et al., 1999; Priadi, 2010; Macpherson et al., 2010). Nevertheless, several Metulang volcanics from central Kalimantan show certain adakitic signature.

METALLIC MINERALIZATION

Metallic mineral deposits are discussed based on their geological ages and domains. We start with Paleozoic-Mesozoic geologic domain and finish it with Neogene events. Due to the lack of reliable age data on mineralization, discussion on spatial association between certain mineral occurrences and geologic domain is not necessarily implying that mineralization events occurred at the same period with the host geological domain.

Late Paleozoic-Mesozoic

In Kalimantan, the Late Paleozoic-Mesozoic domain is known to be present in two geologic domains, i.e. the Meratus in SE Kalimantan and the Schwaner Mountains in W-SW Kalimantan (Fig. 4). These units may represent magmatism produced during the collision and amalgamation events of Gondwanaland fragments during the Late Paleozoic and Mesozoic era. There is actually another Paleo-Mesozoic magmatic system in the Dent-Semporna Peninsula, but it is not discussed here due to its location that is in Malaysia.

Pre-Cretaceous granitoids are sparsely found and their association with metallic mineralization is poorly understood. The Lumo granite in NW Meratus Mountains (260-319 Ma, Carboniferous-
Early Permian) is the oldest magmatic rock, characterized by S-type granite supposed to form within plate (Harmoko et al., 2000; Heryanto and Panggabean, 2010). Although theoretically such granite may carry tin, so far no information about the presence of tin placer is reported in this area. In the Sanggau area, West Kalimantan, the Early Permian to Early Jurassic Embuoi Complex (Supriatna et al., 1993) is spatially associated with several occurrences of placer gold, placer diamond as well as primary gold, base metals, uranium and mercury, but their genetic link is not clear. Triassic and Jurassic granitoids are probably of subduction origin and are present at limited exposure in Meratus and Singkawang areas. Their genetic association with mineralization is still poorly known, although at Singkawang they are spatially related with many mineral occurrences.

The Cretaceous granitoids become the backbone of the Schwaner Mountains in the west and southwest Kalimantan, and can be divided into two separate areas. First is the Singkawang cluster that consists of the Early Cretaceous, medium-K calc-alkaline I-type granitic rocks. Here we find a high concentration of various metallic mineralization of Au, Cu, Mo, Pb, Zn, Bi, Mn and Hg spatially associated with various Mesozoic and Tertiary intrusive rocks (Suwarna and Langford, 1993). It is not clear which intrusive stage was actually responsible for certain mineralization style. However, as many occurrences show features of deeper level of emplacement (e.g. abundance of base metals) that are significantly different from typical epithermal mineralization associated with Middle Tertiary Sintang intrusions, we believe that many are genetically linked to Mesozoic granitoids.

Within the Schwaner Mountains, there is strong indication of metallic mineralization, including precious metals, associated with Early Cretaceous I-type granitoids (e.g. Sepauk Tonalite and associated volcanics), located at the northern part of the Schwaner Mountains. In the Nangapinoh sheet area, Amiruddin and Trail (1993) described the occurrence of Kalan uranium deposit within this sheet, hosted by the Paleozoic-Triassic Pinoh Metamorphics associated with both Early and Late Cretaceous granitoids. Operations on placer gold as well primary gold-lode mines were also reported to be done from intensely kaoliniteised Sepauk Tonalite. Amiruddin and Trail (1993) therefore suggested that the Sepauk Tonalite apparently contain gold over a wide area. Primary gold mineralization is also reported to occur within Pinoh Metamorphics. On the other hand, no such direct evidence was found for primary gold in the Sintang intrusions in that region, although some alluvial deposits are likely to derive from these rocks. Several occurrences of iron and base metal mineralization were reported to be hosted by Pinoh Metamorphics, with traces of gold and silver.

Within the Late Cretaceous Sukadana Granite, occurrences of iron, base metals and some gold were reported. Iron occurrences were already known since the Dutch era, but it was just recently that iron becomes exploration target by several Indonesian companies. In southern Schwaner Mountains (Ketapang and Lamandau districts), there are clusters of probably skarn-type Fe deposits found as small pockets of magnetite bodies spatially associated with Late Cretaceous Sukadana Granites (Aribowo, 2010; Setijadji et al., 2010). Some deposits show banding features that may resemble features of a Banded Iron Formation (Subandrio and Kuswanto, 2010), but the others support the iron skarn mineralization model. All iron deposits are spatially associated with Cretaceous I-type granitoids that intruded host rocks of sedimentary and/or metamorphic rocks.

Setijadji et al. (2010) observed from the Ruwai deposit in Lamandau district, Central Kalimantan, the typical mineralization associated with epizonal I-type granitoids. At contact zone between this type of intrusion and carbonate-bearing sedimentary rocks, a zoning skarn mineralization within a lateral distance of about 3 km is observed. Skarn deposits are strongly controlled by structure and favorable stratigraphy. At proximal zone directly at contact with intrusive rock, Fe skarn deposits are formed enveloping the intrusion with magnetite as the main ore mineral. Meanwhile approximately 3 km away, still within the same structural trend, several distal Zn-Pb-Ag skarn deposits are found.

Several iron ores are found within the Meratus Mountains, such as nearby the Batu Licin region, are probably associated with Cretaceous
granitoids. Lateritic iron is reported to be mined at Sebuku island; the nearest Cretaceous granitoid is found at the nearby Laut island. Carlile and Mitchell (1994) concluded several gold-bearing quartz and quartz-carbonate veins at Timburu and Sungai Keruh as part of the Cretaceous events. Sungai Keruh is hosted by a potassic altered monzonite porphyry intruded into volcanics and sediments resembling mixed features of both epithermal and porphyry-style mineralization (Van Leeuwen, 1994). Meanwhile, the Timburu is hosted by silicified and brecciated ultramafic rocks around phyllically altered quartz-diorite porphyry intrusions: quartz texture suggests a mesothermal condition (Van Leeuwen, 1994). As recently Tertiary igneous rocks are also identified to be present in this region (Harmoko et al., 2000), there is also possibility that actually the hydrothermal events occurred during the Tertiary rather than Cretaceous.

**Tertiary**

Gold mineralization is so far the most promising metal to reach industrial scale mining operations in Kalimantan. The biggest known gold deposits so far are dominated by low-sulfidation gold-carbonate-base metals system (Kelian, Mt. Muro) but other gold deposits types are also present, such as low-sulfidation Au-Ag (Jelai), high-sulfidation Au (Seruyung), sediment-hosted Au (Bau in Serawak), porphyry Cu-Au (Beraung, Mansur and Mamut) and skarn Au (Buduk). The most striking similar features among these deposits are their spatial association with narrow, shallow level, and acidic intrusive rocks called collectively as the Sintang Intrusions. Sintang Intrusions are typically present as hundreds of stocks, sills and dykes that cut the older rocks, and they often form high inselbergs that can reach a height of 1000 m rising from the surrounding area. As in many cases we do not find the syn-intrusion volcanics nearby, there probably unique petrogenesis of this rock suite. As discussed in earlier section, Sintang Intrusions have a distinctive adakite signature that differs from typical characteristics of subduction-related magmas. Rather, adakites are interpreted to have resulted from melting of basaltic source such as oceanic crust derived from older subduction and/or basalt underplate.

The ages of several gold and copper deposits have been constrained relatively well, and the majority falls into the Middle to Late Miocene. The Kelian gold deposit was long time considered to be formed around 20 Ma (Van Leeuwen et al., 1990) which is now confirmed by state-of-the-art zircon U-Pb dating on ore-bearing quartz-phryic rhyolite (19.8 ± 0.1 Ma) and quartz-feldspar-phryic rhyolite (19.5 ± 0.1 Ma) (Davies, 2002 in Davies et al., 2008). The Bau gold deposit was emplaced from series of ore-bearing microtonalites and dacites that were firstly emplaced around 14.6 Ma (Proteau et al., 2001 in Hutchison, 2005). The average age of Mamut porphyry copper deposit in Kinabalu was dated to be 9 Ma (Hutchison, 2005).

There are some interesting common features that apply in many gold and base metals mineralization in Kalimantan that actually are not common features for other Indonesian islands. First, the melts that produced gold mineralization in Kalimantan are not derived from typical subduction-zone magmatism, i.e., many gold-bearing intrusions have adakite characters. Second, there is strong evidence of spatial and genetic links between gold mineralization and intrusions, including the epithermal and sediment-hosted types. Third, the lack of syn-intrusion volcanic rocks being found at the proximity of gold deposits. In term of geodynamic perspective, the emplacement of major gold and base metals mineralization can be correlated with major tectonic events beyond the ordinary, long-lasting subduction processes. The emplacement of Kelian at approximately 20 Ma was coincident with the initiation of counter-clockwise rotation of Borneo, in which the location of Kelian-Mt.Muro-Masuparia at that time was approximately at the rotation pole (Hall, 1996, 2002). The Bau gold mineralization was generated after new adakitic magma was generated about 15 Ma (during the event of counter-clockwise rotation). Finally, Mamut copper porphyry was emplaced around 9 Ma at the time of termination of the rotation and the collision period.

Talking about collision, it is challenging to test the presence of orogenic gold in the western Kalimantan, i.e. Lupar or Boyan suture zone (Hutchison, 2005; Metcalfe, 2006). This suture zone, located along the boundary between Indonesia and Malaysia, was the site of multi
collision events. Major collision event took place during the Late Cretaceous or Early Tertiary. Active continental margin-type of Cretaceous subduction, the presence of alluvial gold and occurrences of Sb and Hg mineralization are some of critical evidence that indicate the orogenic gold potentials. Such potential may also be present at the Meratus Mountains, however this site lacks the evidence of Au, Sb and Hg occurrences.

Quaternary
Mineral accumulations during the Quaternary are found as alluvial gold, diamond and zircon, lateritic iron and bauxite deposits. Alluvial gold is almost found within all geologic domains, with the main concentration at West Kalimantan (Monterado, Mempawah) and Central Kalimantan (Cembaga Buang, Tewah). Three separate areas are known to hold alluvial diamond, i.e. Martapura in South Kalimantan, Muarateweh area in Central Kalimantan, and Mempawah area in West Kalimantan. Quartz sands are widespread within Central and West Kalimantan, from which zircon is mined in several sites such as at Kota Waringin Barat district, Central Kalimantan. Lateritic iron is reported to be mined at Sebuku island. The main bauxite-prospective region is the Schwaner Mountains in West Kalimantan (Surata et al., 2010). Placer tin is reported to be present at limited area in the Ketapang region.

CONCLUDING REMARKS
The reformation of mining regulation in Indonesia and the China-India factors have resulted in the major change in mining activities in Kalimantan. The players change from major companies, working on gold-related targets into various commodities for small- to medium-scale resources. Real exploration programs are few as activities concentrate on upgrading the known prospects into production or re-open old mines.

Metallic mineralization can be divided into two major periods. First is the Cretaceous or older event, which is dominated by granitoid-related skarn iron and base metals mineralization, especially within the Schwaner and Meratus Mountains. Second is the Middle to Late Miocene gold and base metals mineralization associated with Sintang Intrusions. Such gold-bearing intrusions are not products of ordinary subduction-zone magmatism. Rather, they are derived from basaltic source melted due to major tectonic events such as collision, faulting and regional rotation. As results, the widely accepted model of the presence of Central Kalimantan Gold Belt that extends from Singkawang at the west to Sabah and is synonymous with the distribution of the Central Kalimantan Arc (e.g. Carlile and Mitchell, 1994) should be revised. We propose that the Central Kalimantan Gold extends from Sabah in the north to somewhere around Mirah gold deposit in the south. Gold occurrences are concentrated along the backarc part of magmatic arc (east to southern parts), while copper occurrences at the volcanic front side (west and northwest). This belt is separated from the Bau-Singkawang gold district in western part (Fig. 4). For exploration targeting, studying the melt origin of intrusive rocks is important tool to define their metallic potentials, especially gold. Testing new ideas of different styles of gold mineralization, such as orogenic gold along the suture zones, opens more opportunities for future new discoveries.

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REFERENCES


FIGURE 1: The dated Tertiary igneous rocks in Kalimantan

FIGURE 2: The dated Pre-Tertiary igneous rocks in Kalimantan
**FIGURE 3:** Occurrences of adakite in Kalimantan
FIGURE 4: Compiled database on metallic mineral occurrences in Kalimantan