CHARACTERISTICS OF THE ARAI GRANITE ASSOCIATED WITH THE IRON ORE AND Zn-Cu-Pb DEPOSITS IN MUSI RAWAS REGENCY, SOUTH SUMATERA

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Abstract

The Arai Granite exposed in the Jangkat District, Musi Rawas Regency, South Sumatra. This rock which is in the form of a stock, is assigned to be Cretaceous in age. Petrographical identification shows that this rock is dominated by quartz, feldspar (plagioclase and orthoclase), biotite with minor hornblende, pyroxene and secondary muscovite of holocrystalline- equigranular textures. On the basis of A/CNK ratio (<1.1), the Arai granite belongs to metaluminous type of calc-alkali composition (K_2O/Na_2O = 0.9-1.06). The Plot of trace elements indicates that this rock belongs to I-type and falls within VAG/SYNCOLG. This granite is intimately associated with subduction of Indian Ocean and Eurasian Plates. It is characterized by strong depletion of Nb, P and Ti significantly. The Arai granite intrudes the Rawas and Peneta Formations of older ages so that lithology of both formations experienced contact metamorphism (marble and hornfels) and mineralization. The presence of iron ore, Zn-Cu-Pb and gold deposits is closely associated with limestone replacement within those formations. Therefore, these deposits are classified into skarn style.

Keywords: Arai granite, pluton, Rawas Formation, Peneta Formation, mineralisation, skarn

Sari

Granit Arai tersingkap di Kecamatan Jangkat, Kabupaten Musi Rawas, Sumatra Selatan. Batuan yang berumur Kapur ini muncul sebagai stok. Secara petrografis, batuan ini didominasi oleh kuarsa, felspar (plagioklas dan ortoklas), biotit dan sedikit horenblenda, piroksen dan muskovit sekunder dengan tekstur holokristalin-ekuigranular. Berdasarkan perbandingan A/CNK (<1.1), batuan granit Arai ini termasuk jenis metaluminus yang berkomposisi kalk-alkali (K_2O/Na_2O = 0.9-1.06). Plot unsur jejak termasuk granit tipe-I dan berasal dari granit busur vulkanik (VAG) dan granit tumbukan/orogenik (SYNCOLG/ORG). Granit Arai diduga berhubungan erat dengan subduksi Lempeng Samudra Hindia terhadap Lempeng Asia. Hal ini ditandai oleh penurunan unsur Nb, P and Ti secara mencolok. Batuan granit ini menerobos Formasi Rawas dan Peneta yang berumur lebih tua, sehingga litologi formasi ini sebagian mengalami malihan kontak (marmer dan batutanduk) dan mineralisasi. Adanya mineralisasi berupa cebakan bijih besi, Zn-Cu-Pb dan emas di daerah ini diduga berkaitan erat dengan "replacement" batugamping yang terdapat dalam formasi tersebut. Dengan demikian, cebakan tersebut digolongkan ke dalam jenis "skarn".

Kata kunci: granit arai, pluton, Formasi Rawas, Formasi Peneta, mineralisasi, skarn

Introduction

The Arai granite is one of the granite body occupying the Jangkat District, Musi Rawas Regency, South Sumatra (Figure 1 and 2). The body is exposed as a window within the older sediment sequence of Peneta and Rawas Formations. The presence of the Arai Granite is important because it could be as a heat source for ore deposit in the area. Several ore deposits such as iron ore, Zn-Cu-Pb and gold are present in the area.

Consequently, many investigators visit the area in order to evaluate the occurrence of those deposits (Van Bemmelen, 1949; Hamilton, 1979; Hartono, 2002; Kusnama *et al*.,1994). Suwarna *et al*. (1993) has carried out a geological mapping in the area. British Geological Survey (BGS) in cooperation with Directorate of Mineral Resources (DMR) as well as the Geological Research and Development Centre has collected stream and pan concentrate samples in order to compile a geochemical map of south Sumatra (Machali *et al*., 1997).

During 1980s, DMR (Indonesia) joint cooperation with JICA (Japan) (JICA, 1987) carried out a detailed investigation on geology, mineralization and has established some drilling tests in order to evaluate the resource potential in the area. A detailed and systematic drilling to evaluate the deposit is being

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carried out by PT. Galtam, Indonesia (Prayogo, 2009). The main target of the company is to explore base metal deposits, mainly Zinc with minor lead (Pb), copper (Cu) and silver (Ag).

A geology team from the Centre for Geological Survey (CGS) (Harahap *et al*., 2009) undertook field work in the area to collect samples (volcanic and intrusive rocks, mineralized outcrops, and ore minerals) in order to study the geochemical characters of the rocks as well as to evaluate mineral occurrences in the area.

This paper is to study basic petrology and geochemical characters (major, trace elements and REE) of the Arai granite which is intimately associated with ore deposit, mainly iron ore and Zn-Cu-Pb deposits in the area.

Sampling and analytical methods

Sampling and fieldwork have been carried out during a research project under the Centre for Geological Survey (CGS) in 2009. Several samples of granite and other rocks have been collected in the area of study. However, in the office, these samples are again screened in order to delineate both altered and weathered materials. Samples have been selected for thin sections and geochemical analysis. All sample treatments were conducted in the Geo-Lab of the CGS. The chemical analyses including major and trace elements were analyzed using X-Ray Florescence (XRF) while ICP-MS type X-7 Thermo was used to analyze REE. Result of analyses is tabulated in Table 1.

Geology

Regional Tectonics

Sumatra forms a complex tectonic setting (Katili, 1969; 1973; Hamilton,1979; Curray *et al*.,1979; Daly *et al*., 1991; Taponier *et al*., 1982; Kusnama *et al*., 1994; Barber *et al*., 2005). A subduction process between the Indian Ocean Plate from the west and the Sundaland basement in the east, took place from Mesozoic to Caenozoic times. Consequently, a mixing rock originated from oceanic and continental areas within both volcano and magmatic zones were emplaced (Aspden *et al*., 1982).

Tectonically, the studied area falls within the West Sumatra (Cathaysian) Complex (Figure 3)

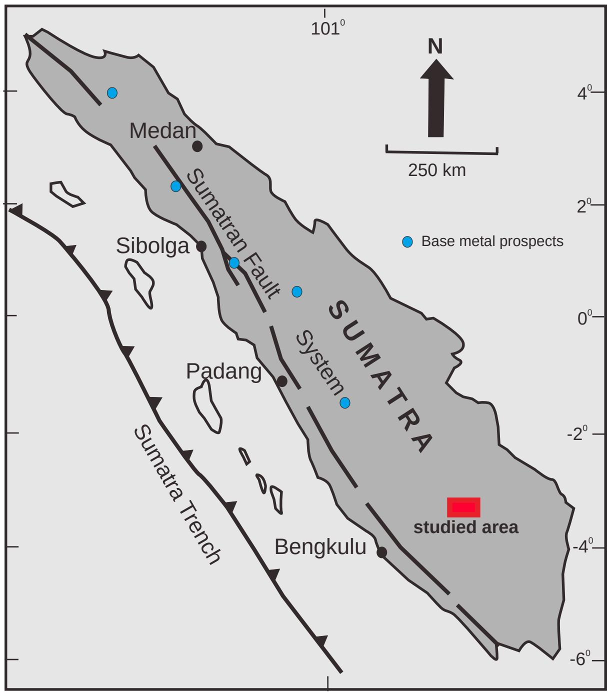

Figure 1. Map showing the location of the studied area.

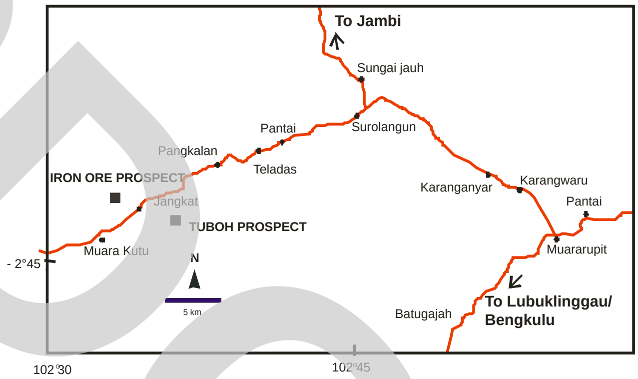

Figure 2. Access road to the Iron ore and Tuboh Prospects.

(Hutchison, 1994). It is superimposed with the magmatic arc of the Bukit Barisan Range of the Southern Sumatra within the Sumatran Fault Zone where Indian Oceanic Plate is currently being obliquely subducted beneath the Sundaland continental plate (Hamilton, 1979). This oblique subduction has resulted in the formation of dextral transcurrent fault zones of Sumatran Fault System (SFS) or Semangko Zone, parallel to the plate margin (Katili, 1969). It links to a series of transform faults associated with spreading on the Andaman Sea (Curray *et al*., 1979). The SFZ can be traced over a distance of approximately 1650 km from the Semangko Bay in South Sumatra to Aceh Valley in the north (Bemmelen, 1949). Dextral displacements of approximately 130 km along the SFZ have taken place since the Tertiary and have continued up to present. This movement has led to development of complexly superposed volcanic and magmatic arcs (granite/ andesite) as well as mineralization. The subsequent dextral fault zone is of more importance in localizing mineralization in the area.

Regional Geology

The studied area that forms flat to undulated hilly country is occupied by several formations (Figure 4). The oldest rock cropped out in the area is Peneta Formation. The age of this formation is assigned to be Cretaceous –Jurassic (Suwarna *et al*., 1993). It is comprised of slate, shale, siltstone and sandstone and limestone intercalation. In general, these rocks have been metamorphosed, collectively termed as “meta” (meta sandstone and meta siltstone, marble and hornfels). This formation is interfingering with the Rawas Formation consisting of turbidite, pebbly wake, sandstone, siltstone, limestone, grewake, argillite, diabas and basalt. Both formations are well distributed in the studied area and become as a host rock for mineralization.

The Peneta and Rawas Formations were intruded by Cretaceous Arai Granite consisting of granite and aplite. The granite is exposed in the Iron Ore prospect while the aplite formed as a dyke and cut the volcanic rocks. The older rocks are unconformably overlain by the Air Benakat and Muara Enim Formations.

Prospect geology

In the prospect area, a detailed geology has been mapped by JICA (1987) (Figure 5a). The oldest sequence found in the area is meta-sediments and limestone. The meta sediments consist of sandstone, siltstone and andesite lava, slate, and phyllite (Figure 5b, c). Sandstone is light grey, meta, fine grained, well-bedded and folded. Limestone is light grey, meta, luticeous, thin bedded and strongly folded. Due to contact aureole metamorphism, some limestones have been changed into marble (Figure 5d) while siltstone changed into hornfels (Figure 5e). These rocks are exposed both in the iron ore deposit and in the Tuboh prospects.

Table 1. Result of Analytical Data of the Arai Granit, Jangkat Area

	09HOZ50Pk	09HOZ51Pk	09HOZ52Pk	09HOZ53Pk	09HOZ54Pk
SiO_2	70,43	70,16	70,73	71,10	70,14
TiO_2	0,29	0,29	0,28	0,31	0,29
Al_2O_3	14,93	15,11	15,04	14,62	14,85
Fe_2O_3	3,65	3,62	3,15	3,39	3,52
MnO	0,05	0,06	0,06	0,05	0,07
CaO	2,22	1,69	2,01	2,10	2,21
MgO	0,56	0,52	0,51	0,49	0,50
Na_2O	4,05	3,98	4,02	4,12	4,28
K_2O	3,63	4,19	4,27	3,89	4,13
P_2O_5	0,07	0,08	0,10	0,09	0,10
LOI	0,65	0,58	0,37	0,50	0,30
Total	100,53	100,29	100,55	100,65	100,39
in wt.%					
A/CNK	1,04	1,08	1,03	1,01	0,97
	09HOZ50Pk	09HOZ51Pk	09HOZ52Pk	09HOZ53Pk	09HOZ54Pk
Ba	237,27	266,6	253,67	244,73	234,47
Rb	99,23	107,46	101,23	101,46	105,77
Th	17,49	15,32	18,47	24,62	25,55
K	2,50	2,88	2,94	2,68	2,84
Nb	5,63	5,93	4,43	4,47	5,92
La	26,37	23,75	21,31	25,33	22,36
Ce	52,99	47,55	44,08	50,2	46,18
Sr	99	87,43	87,5	88,93	87,21
Nd	23,01	21,21	18,49	21,39	20,33
P	0,06	0,07	0,09	0,08	0,10
Sm	4,44	4,33	3,75	4,32	4,31
Zr	239,63	184,25	268,46	444,58	220,83
Ti	0,03	0,03	0,03	0,04	0,03
Y	22,43	23,33	19,98	22,27	22,48
Yb	3,52	3,62	3,11	3,89	3,57
in ppm					

This meta sediment/limestone sequence is unconformably overlain by interbedded sandstone, shale, slate, basalt and pyroclastics. As a whole, the oldest formations were unconformably overlain by younger sediments.

The lithology of older meta sediment sequences are very similar to those of Kluet and Kuantan Formations of Carboniferous age in the north Sumatra (Aspden *et al*., 1982). Kuantan and Kluet formations have been proved to contain base metal deposit (Cu-Pb-Zn). Within the Kluet Formation, the well known Sedex deposit has been discovered while within the Kuantan Formation, the skarn Latong deposit which is similar to the Tuboh deposit has been identified (Noya *et al*., 2002).

The metasediments were intruded by granite, aplite and andesite. Granite is in the form of blocks or small outcrops, exposed in the Jangkat and the Tuboh prospect. Granite is light grey, medium grained, hard and compact (Figure 5f). It is mixed within the iron ore deposit. The granite body could be a heat source for the formation of ore deposit that hosted within the metasediments. Aplite and andesite are in the form of dykes cutting the metasediment.

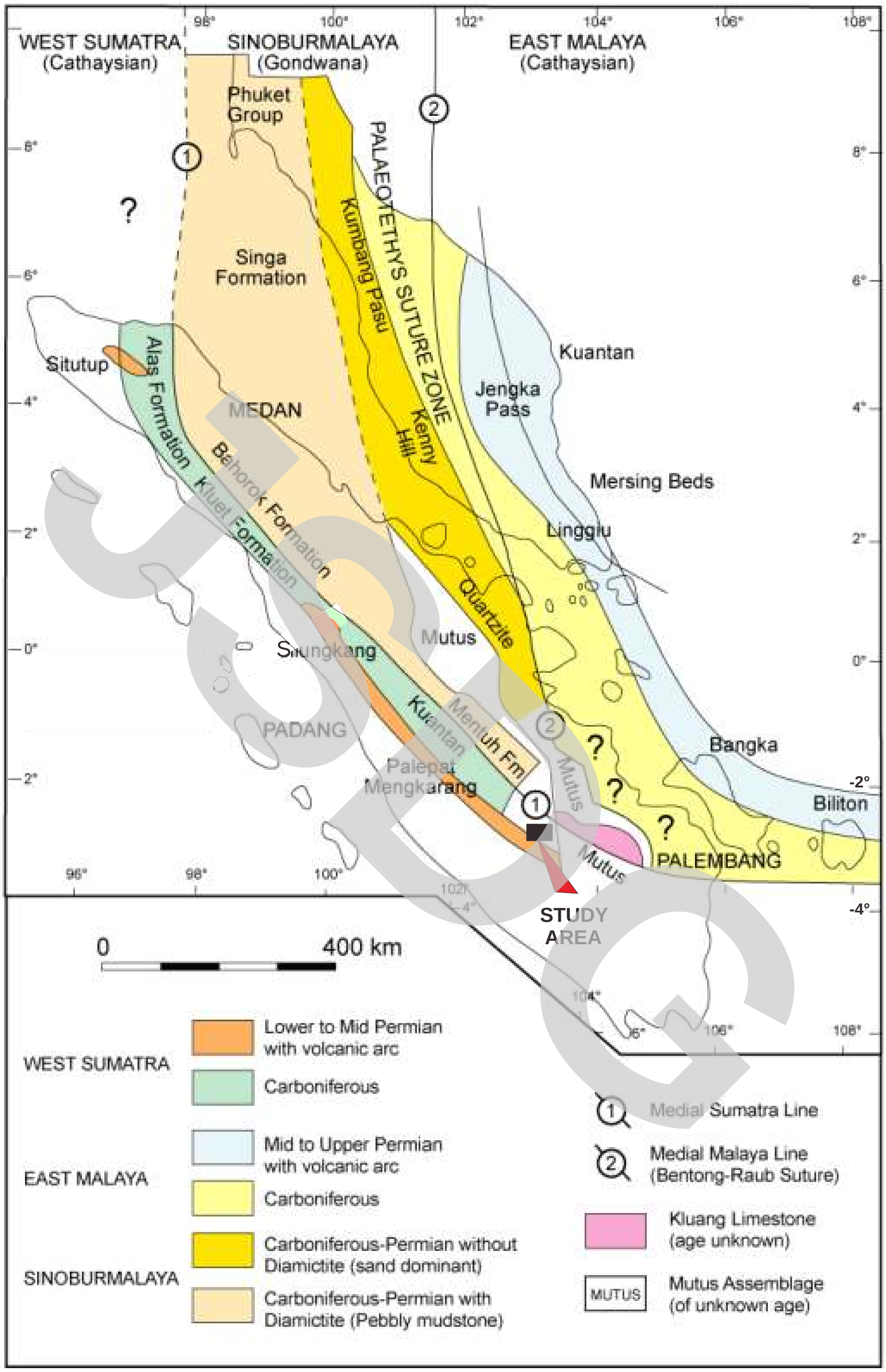

Figure 3. Tectonic map of Sumatra (Hutchison, 1994).

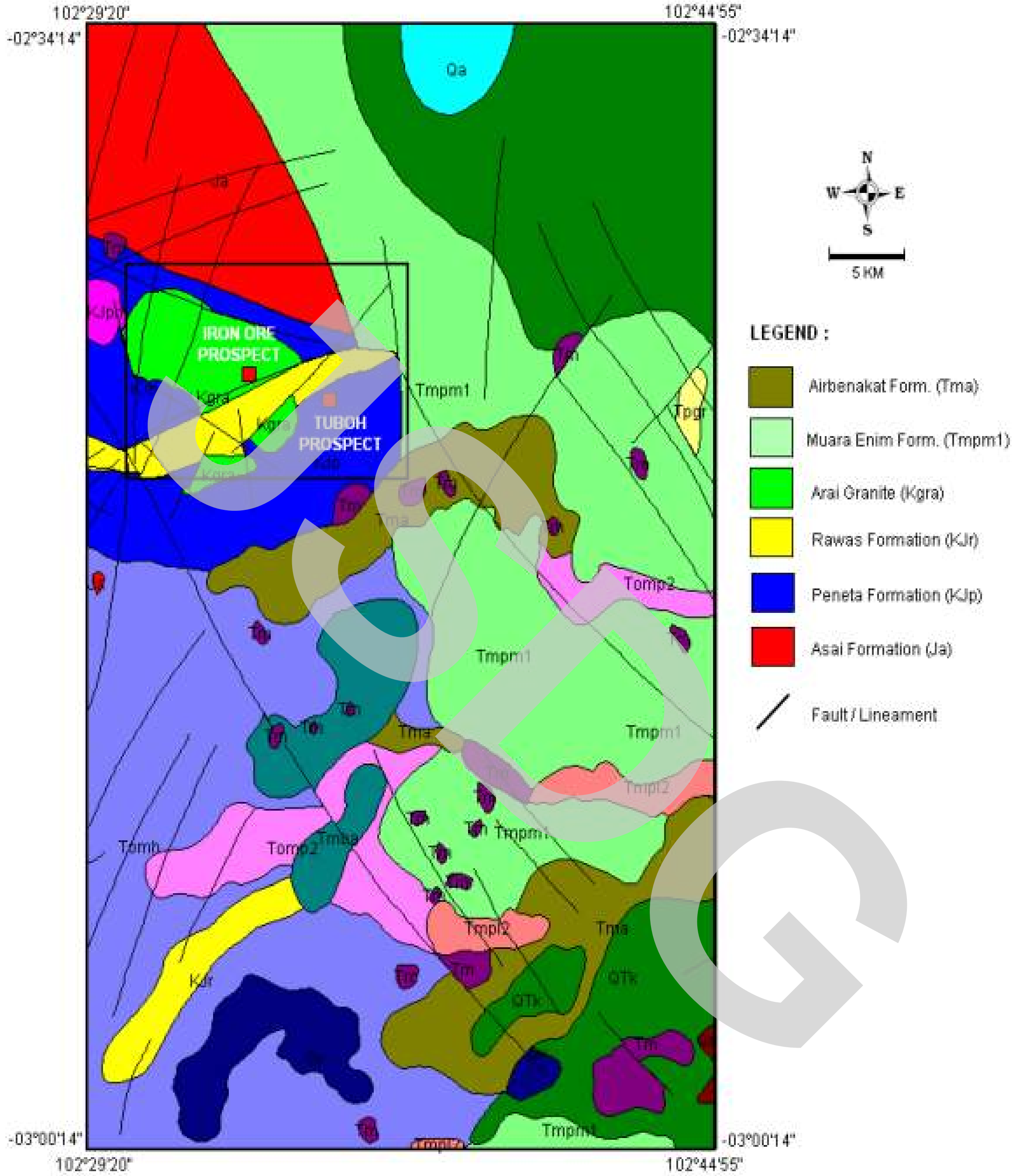

Figure 4. Regional geological map of the studied area (Suwarna *et al*., 1993).

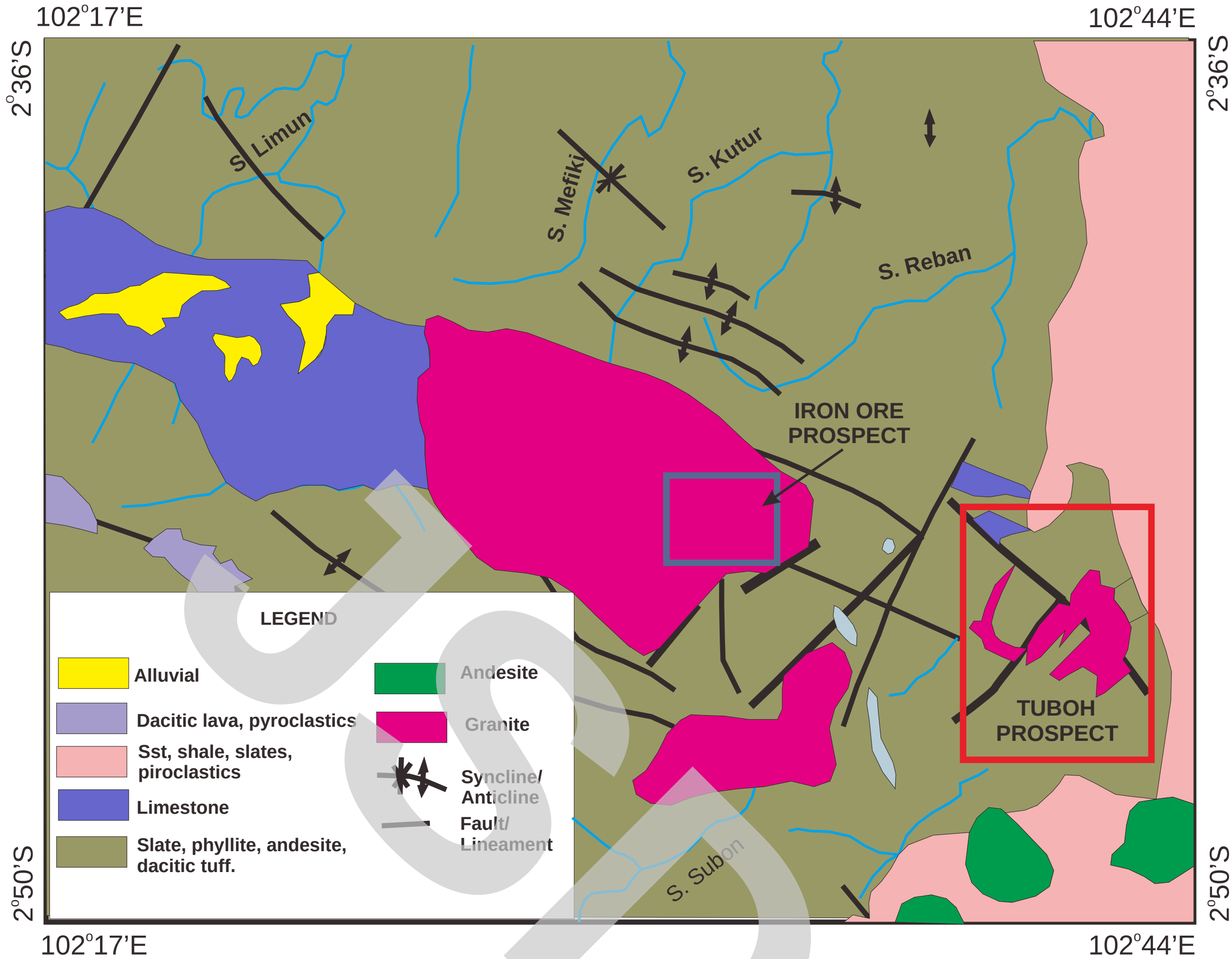

Figure 5a. Prospect geology of the studied area (JICA, 1987).

Figure 5b. Meta sandstone in the studied area.

Figure 5c. Folded metalimestone in the studied area

Figure 5d. Marble in the Tuboh prospect.

Figure 5e. Hornfels outcrop in the Tuboh prospect.

Figure 5f. Granite expore in the Iron ore deposit.

Mineralization

As mentioned earlier that the studied area is attractive for the mining company due to the presence of several ore deposits (iron ore, Zn-Cu-Pb and placer gold). The iron ore prospect owned by PT MAJU, is located about 1 km northwest of Jangkat Village. Iron ores as hematite and magnetite have been exploited (Figure 6a). However, it is now terminated due to the drop of all metal prices including the iron ore. Zn-Cu-Pb prospect refers to as the Tuboh Prospect (Figure 6b) which is located in the eastern part of the iron prospect. The Tuboh deposit is polymetallic minerals (Zn, Cu, Pb, Py, and Ag). Besides this, it is also found oxidized hematite/magnetite, goethite and oxidized copper ore as malachite and azurite) within the Tuboh deposit. These ores are associated with NE-SW trending structures. The placer gold is mined by the local people using mechanic technology and gold panning during the dry season in the Rawas River (Figure 6c).

Petrography

A total of five fresh granite samples has been petrographically identified. In general, granites are light grey, medium to coarse grained, and show holocrystalline/granular textures (Figure 7a). The primary minerals are quartz, plagioclase, orthoclase, biotite with minor hornblende, pyroxene and secondary muscovite (Figure 7b). Quartz is subhedral to euhedral and represents as free from alteration. Plagioclase is colourless, subhedral, bladed and represents the most abundant phenocrysts phase. It is generally displays simple oscillatory zoning and twining (Figure 7a). Apatite inclusions are common found within plagioclase. In contrast, orthoclase forms as megaphenocryst, fractured, and show microperthitic textures (Figure 7b). Biotite is typical bladed crystal and showing strong pleochroic colour. Hornblende is found as bladed crystal while pyroxene forms as small discrete crystals. Both hornblende and pyroxene are minor constituents. Secondary muscovite due alteration is found within feldspar.

Geochemistry

Major Element

The result of major oxide analysis is shown in Tabel 1. The content of SiO_2 is quite constant, ranging from 70-71 wt.%. This is also followed by low content of CaO (1.6-2.22 wt.%), Fe_2O_3 (3.15-3.65 wt.%), MgO (0.49-0.56 wt.%) while K_2O is slightly higher (3.63-4.27 wt.%). In order to plot the oxide mineral within diagrams, it is firstly calculated to 100% total without LOI while Fe_2O_3 is calculated for FeO total using division of 1.111. Plot of the Alkali Index versus SiO_2 (Figure 8a) indicates that this granite composition falls within calc-alkaline. It is consistent with the ACF diagram (Wright, 1969; Miller, 1985) (Figure 8b), where they fall within "mataluminous granite"

Figure 6a. Iron ore mining by PT. Maju, Jangkat.

Figure 6b. Local mining in Tuboh prospect.

Figure 6c. Local gold panning in Rawas River.

Trace elements

In order to obtain the trace element contents, five selected samples have also been analyzed (Table 1). This rock indicates a slightly depletion of Nb and strong depletion of P and Ti in the spider diagram (Figure 9a). However, mobile elements such as K and Sr, Rb, Th significantly increase. This means that

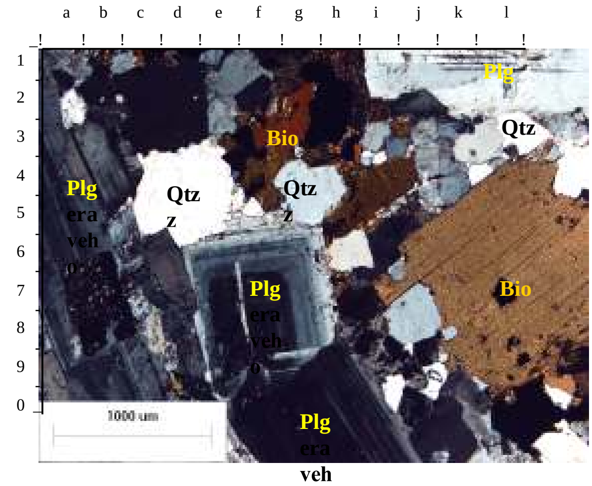

Figure 7a. Microphotograph of granite (09HZ53PK) showing primary minerals of plagioclase (Plg), quartz (Qtz) and biotite (Bio). Plagioclase show zoning textures.

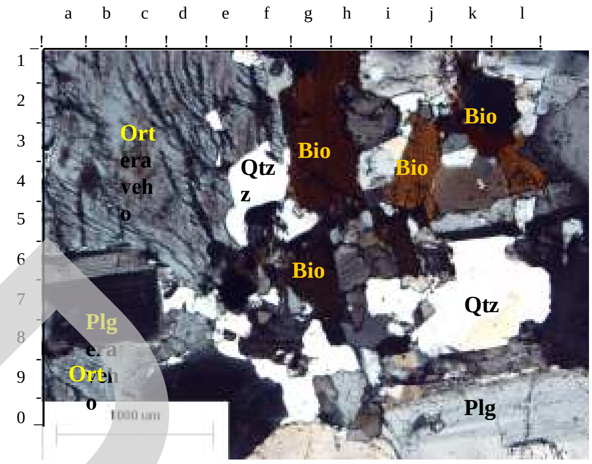

Figure 7b. Microphotograph of granite (09HZ53PK) showing primary minerals of plagioclase (Plg), orthoclase (Ort), quartz (Qtz) and biotite (Bio). Orthoclase shows microperthitic texture.

the rock is possibly related to subduction process. Moreover, plot of Rb- (Y+Nb) (Pearce *et al*., 1984) (Figure 9b), belongs to volcanic arc granite (VAG) while plot of Y-Nb (Fig 9c), falls within VAG-SYNCOLG. This is also respectively confirmed by SiO_2-Rb and SiO_2-Y plots (Figure 9d, 9e).

Rare Earth Elements

The result of analysis of samples for Rare Earth Elements (REE) is shown in Table 1. Chondritic normalized plot of rare earth element data is shown in Figure 10. The figure shows a flat pattern with a slightly enriched in LREE, drop of Eu and decrease in HREE. The drop of Eu suggested due to plagioclase fractionation or the presence of garnet within the rock.

Discussion

The Arai granite in the studied area belongs to calc-alkaline (Figure 8a) and falls into I-type (metaluminous) (Figure 8b). Mole ratios of Al_2O_3/ Na_2O + K_2O + CaO (A/CNK) indicate the value of <1.1 which also confirms that the Arai Granite belongs to I-type granite (Chappell and White, 1974; Hanson, 1978; Takahasi *et al*., 1980; Chappel *et al*. (1987). The presence of biotite and hornblende within this rock also supports the characteristic features of I-type granite for the Arai granite.

Major and trace element characteristics (Figure9) indicate the rocks arc originated from magma in an orogenic environment. This is confirmed by the regional geology that the genetic origin of the Arai granite in the area is intimately related to tectonic development of Sumatra due to the oblique collision (Taponier *et al*., 1982) of Australian Plate and Eurasian Plate with respect to the Indian Ocean Plate. Amiruddin (1998) suggests that the granite was formed during collisions.

Magma source of the Arai granite which mostly belongs to calc-alkaline (Figure 8a) due to an anaxtesis/partial melting of lower crust (*i.e*., amphibole/biotite break down in the presence of quartz and feldspar). It is possibly coincident with initiation of SE–directed subduction of Indian Ocean Plate with respect to the Eurasian plates (Hamilton, 1979; Watanabe and Izawa, 2002). This is also confirmed by the ratio of K_2O/Na_2O (0.9-1.06) suggesting that the rocks are calc-alkaline (Vogt and Flower 1989). The presence biotite and hornblende suggest that the source of materials of the Arai Granite were possibly derived from an original igneous source of basalt (gabbro), andesite (diorite) within the continental crust and belongs to the contact aureole granite (Chappel *et al*., 1974; Takahasi *et al*., 1980).

In Sumatra as a whole, many deposits (Au, base metals, Fe) are formed due to the influence of the granite intrusions (Sukirno, 2006). The presence of Pb-Fe deposit in Lokop District, East Aceh Regency is due to the effect of Lokop Granite (Abidin and Harahap, 2006). The occurrence of gold deposit in Bonjol area, East Pasaman Regency, West Sumatra, is also triggered by the granite intrusions (Abidin and Harahap, 2007). Again, the Latong skarn Pb deposit in Latong River, Madina Regency, North Sumatra was associated with granite intrusions (Noya *et al*., 2002). Also, the presence of Pb-Fe in Abai District (Solok Selatan) and iron ore in Surian area, Alahan Panjang District, Solok Regency, West Sumatra are also related to granite intrusion (Abidin, 2005; 2006; Abidin and Baharuddin, 2008).

Granite, in general, can be divided into two main types *i.e*., I-type (magnetite series) and S-Type (ilmenite series) (Chappel and White, 1974; Chappel *et al*., 1974; Ishihara, 1977; Takahashi *et al*., 1980; Kutsukabe, 1988; Andrew, 2009). The I-type granite which is referred to magnetite series is formed by the melting of igneous rocks while S-type granite is produced by the partial melting of sedimentary rocks. The type of ore deposits associated with granotoids can also be related to these classifications. Molibdenum (Mo) and base metals (Fe, Cu, Pb, Zn), precious metals (Au) and porphyry copper are the product of I-type granite of magnetite series (Takahasi *et al*., 1980). On the other hand, tin deposits (greisen-type) occur characteristically in ilmenite series of S-type granites (Smirnov, 1976). Similarly, the Arai Granite is also I-type of magnetite series in character. Therefore, the Arai granite could also produce such base metals and gold. For example, gold mineralization in the Kerinci Regency, Jambi is associated with I-type granite (Abidin and Suyono, 2004; Abidin and Suwarti, 2005).

As discussed earlier that the area of study belongs to Rawas Cluster" (Machali *et al*., 1987) (Figure 11). In this cluster, geologically it is occupied by Peneta and Rawas Formations which consist of interbedded claystone, sandstone and intercalation of limestone. The emplacement of the Arai granite (Cretaceous in age) has generated a metamorphic contact with limestone and changed lithology of both formations. As a result, most lithology of both formations become "meta" referred as to meta sandstone, meta siltstone *etc*. A strong thermal metamorphic effect of the granite intrusion to both formations has resulted marble and hornfels. At the same time, it is also followed by a metasomatic process. The process transformed the existing minerals into totally/partially new mineral by replacement of their chemical constituent (Lapidus, 1987). In this regard, the limestone has been changed partially/totally by new minerals such Fe, Cu, Pb, Zn, Py, Au *etc*. As a result, iron ore and Zn-Cu-Pb as well as gold were formed in the area of study. The iron ore prospect is found together with the granite body while base metal is present in the eastern part of the other granite body.

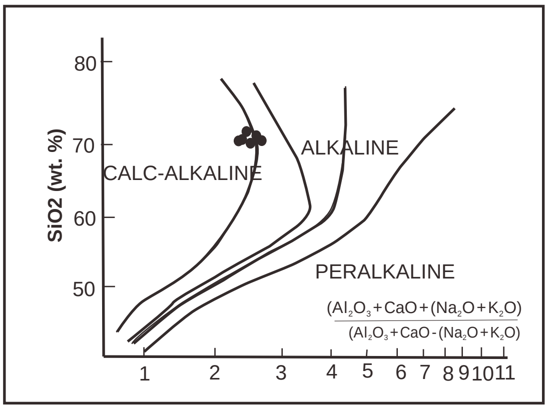

Figure 8a. Alkali index of the Arai granite (Wright, 1969).

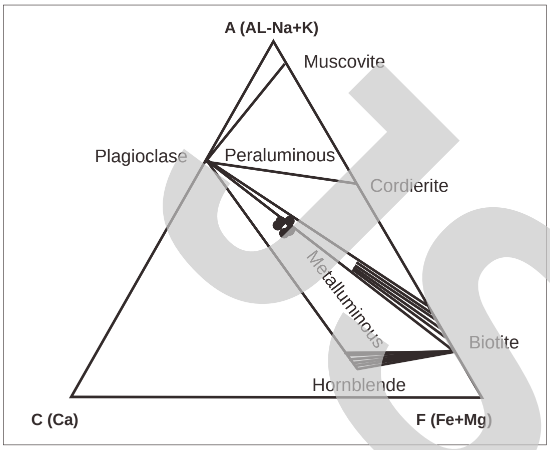

Figure 8b. ACF diagram showing the distribution of the Arai granite (Wright, 1969) .

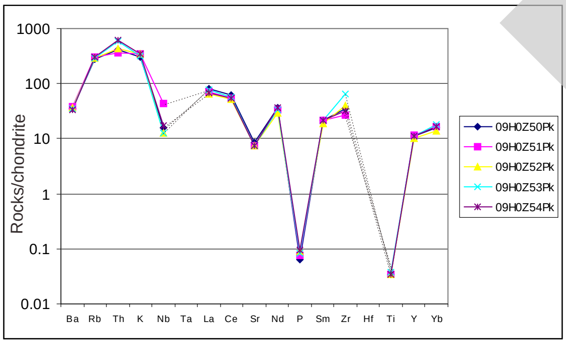

Figure 9a. Spider diagram of the Arai granite.

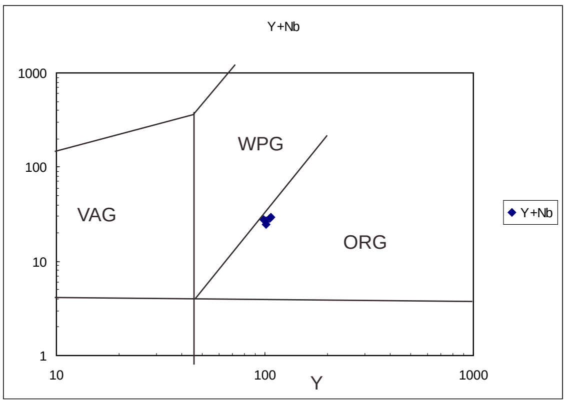

Figure 9b. The Arai granite within Y vs (Y+Nb) (Pearce *et al.*, 1984).

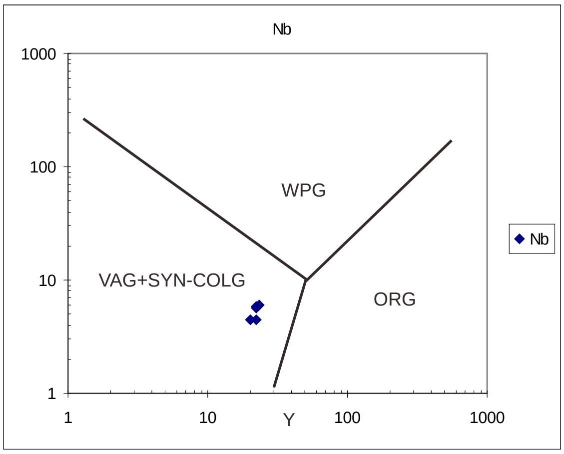

Figure 9c. The Arai granite within Y vs Nb (Pearce *et al.*, 1984).

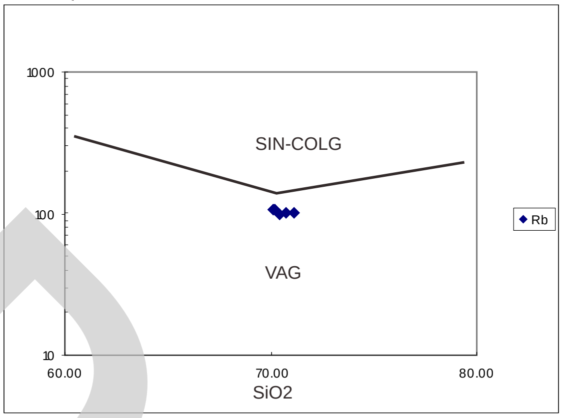

Figure 9d. The Arai granite within Rb vs (Y+Nb) (Pearce *et al.*, 1984).

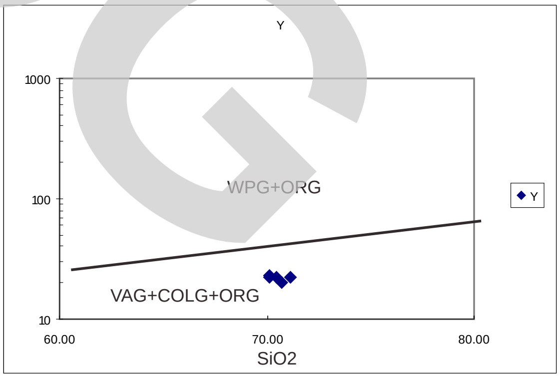

Figure 9e. The Arai granite within Rb vs (Y+Nb) (Pearce *et al.*, 1984).

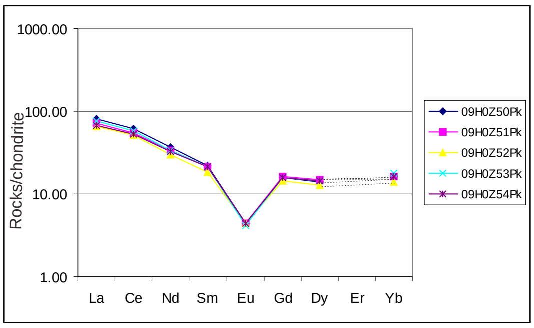

Figure 10. Chondrite REE normalized plot from the Arai granite.

Figure 11. Mineralization zones of South Sumatra (Machali *et al.*, 1987).

The presence of such mineralization (iron ore and base metal) which is associated with the Arai granite could be classified into skarn type. This is confirmed by the marble and hornfels within the deposit. The occurrence of the iron ore together with granite body may be classified into indoskarn while those associated marble and hornfelsic rocks may classified into exoskarn.

Conclusions

On the basis of petrologic and geochemical characteristics, the Arai granite is metaluminous I-type calc-alkaline affinitiy. Tectonically, the Arai granite is Volcanic Arc Granite (VAG) or SYNCOLG/ORG, which is intimately associated with compression due to oblique collision between Australian - Eurasian

Plates and the Indian Ocean Plate. The Arai granite which is assigned to be Cretaceous in age intruded the older formations (Peneta and Rawas). Therefore, this granite is expected to be a heat source for mineralization in the studied area.

Mineralization which is associated with the Arai granite is iron ore, Zn-Cu-Pb-Py-Fe-Ag and Au deposits. The deposits host within the Peneta and Rawas Formation. The iron ore deposit has been mined for magnetite and hematite ores by PT. MAJU but for the time being it is terminated. It is classified into indo-skarn type. In contrast, Zn-Cu-Pb-Py-Fe-Ag of the Tuboh deposit which is classified into exo-skarn is also mined for Zn ore by the locals while placer gold is mined by the locals in the Rawas River.

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