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### Genesis of Pb-Zn-Cu-Ag Deposits within Permian Carboniferous-Carbonate Rocks in Madina Regency, North Sumatra

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**Abstract** - Strong mineralized carbonate rock-bearing Pb-Zn-Cu-Ag-(Au) ores are well exposed on the Latong River area, Madina Regency, North Sumatra Province. The ore deposit is hosted within the carbonate rocks of the Permian to Carboniferous Tapanuli Group. It is mainly accumulated in hollows replacing limestone in the forms of lensoidal, colloform, veins, veinlets, cavity filling, breccia, and dissemination. The ores dominantly consist of galena (126 000 ppm Pb) and sphalerite (2347 ppm Zn). The other minerals are silver, azurite, covellite, pyrite, marcasite, and chalcopryrite. This deposit was formed by at least three phases of mineralization, *i.e.* pyrite and then galena replaced pyrite, sphalerite replaced galena, and pyrite. The last phase is the deposition of chalcopryrite that replaced sphalerite. The Latong sulfide ore deposits posses Pb isotope ratio of  $^{206}\text{Pb}/^{204}\text{Pb} = 19.16 - 20.72$ ,  $^{207}\text{Pb}/^{204}\text{Pb} = 16.16 - 17.29$ , and  $^{208}\text{Pb}/^{204}\text{Pb} = 42.92 - 40.78$ . The characteristic feature of the deposit indicates that it is formed by a sedimentary process rather than an igneous activity in origin. This leads to an interpretation that the Latong deposit belongs to the Sedimentary Hosted Massive Sulfide (SHMS) of Mississippi Valley-Type (MVT). The presence of SHMS in the island arc such as Sumatra has become controversial. For a long time, ore deposits in the Indonesian Island Arc are always identical with the porphyry and hydrothermal processes related to arc magmatism. This paper is dealing with the geology of Latong and its base metal deposits. This work is also to interpret their genesis as well as general relationship to the regional geology and tectonic setting of Sumatra.

**Keywords:** Latong, base-metal, galena, Mississippi Valley Type, Kuantan Formation

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#### INTRODUCTION

The presence of base metal (Pb - Zn - Cu) deposits by a sedimentary process known as Sedimentary Hosted Massive Sulphide (SHMS) in the island arc such as Sumatra has become controversial. For a long time, ore deposits in the Indonesian Island Arc are always identical with the porphyry and hydrothermal processes related to arc magmatism. Hence, the presence

of the SHMS in Indonesia which is an island arc region may be interesting to discuss.

SHMS type of deposit is restricted to a fairly limited stratigraphical range within the strata of a particular region in the continental crust. The largest known SHMS deposits belong to a continental margin arc in Naica Mexico (Evans, 1993; MacIntyre, 1995; *in* Abidin, 2008). The other places are northwestern Australia, Europe (Ireland, Alps, Poland, and England) and the

United State of America (Appalachian, Missouri, Oklahoma, Kansas, and Upper Mississippi District). In Indonesia, such deposit is mainly found in a continental margin arc of Sumatra, in which the deposits are hosted within the sediments of the Pre-Tertiary Tapanuli Group (Digdowirogo *et al.*, 2000; Mulya and Hendrawan, 2014; Utoyo, 2015 in press). A large size of base metal deposits (Pb-Zn) hosted in the marine sedimentary environments has been discovered in two places, *i.e.* Kelapa Kampit in Belitung Island (Schwartz and Surjono, 1990; Digdowirogo *et al.*, 2000; Yadi, 2014) and Dairi in northern Sumatra (van Bemmelen, 1949; Mulya and Hendrawan, 2014). Small scale base-metal deposits have also been reported in several places (Abidin, 2008; Abidin, 2010; Idrus *et al.*, 2011; Utoyo, 2015 in press).

In the Mississippi Valley Region and the British deposits, the ore fields are present in positive areas. Such positive areas are often underlain by older granitic masses, and Evans and Maroof (1976; *in* Evans, 1993) suggested that these very competent rock fractures are easy to produce channel ways for uprising solution which, on reaching the overlying limestone, gave rise to the mineralization. The geologic setting of Latong River area has a similarity to the above regions where ore deposit is hosted by carbonate rocks that are probably underlain by Lower Carboniferous granitic rocks. Sediment hosted massive sulfide is a sulfide ore deposit of Pb, Zn, and Cu with structures of stratiform and stratabound. Mineralization with stratiform structure that was deposited syn-genetically with carbonaceous argilic rocks is called Sedex (Sediment Exhalative). Mineralization with stratabound structure deposited epigenetically within carbonate rocks is called Mississippi Valley-Type (MVT). This ore deposit was not or less influenced by a magmatic activity, and the thermal current came from the overburden sediments above the deposits and tectonism (Goodfellow and Lydon, 2007).

The study area is located in the northern equator or on the northwestern part of Sumatra (Figure 1). Administratively, it belongs to the Siabu District, Madina Regency, North Sumatra Province.

The study of base-metal deposits in the area was part of the research programme on *Mineral Bijih Busur Magmatic (MBBm)* financially supported by the Geological Research and Development Centre - GRDC (now the Centre for Geological Survey - CGS) project. The first author was appointed as a project coordinator which was also responsible for the petrology and economic geology aspects. There is no previous geo-scientific investigation regarding to the presence of base-metal deposits and gold in the Latong River area. The information of the presence of galena ore deposits in this area was obtained from the local people.

The fieldwork investigation aims to study the geology of the Latong galena ore deposits, emphasizing on the geological framework including stratigraphy, sedimentation, magmatism, and structure as well as characteristic features of mineralogy, rock geochemistry, and geochronology. This study is necessary in order to better understand ore deposits, particularly on the genetic aspects including mineral assemblages, texture, geochemistry, age dating, and isotopic characteristics. The genetic aspects combined with geological framework of the deposits could be an important guide for a further study and economic importance. Pb isotope is very useful in detecting the origin or source of Pb elements within the metals themselves, and also in identifying the tectonic environment of the deposits. The earth has three main Pb reservoirs, *i.e.* the upper part of the continental crust, the lower part of the continental crust, and the upper part of the mantle (Doe and Zartman, 1979; *in* Rollinson 1993). In addition, this paper is dealing with geology of Latong and its base metal deposits, and also interpreting their genesis as well as general relationship to the regional geology and tectonic setting of Sumatra.

## METHOD OF STUDY

The geological fieldwork was conducted along the rivers, roads, tracks, and the ore deposit to observe the lithology outcrop followed by hand



Figure 1. Geographic sketch map of North Sumatra showing the research location and road access.

specimen descriptions, photographs, sketchings, and samplings. The location of the sample was recorded by using Global Positioning System (GPS). The laboratory work for the samples was done in accordance with the geoscientific purposes including ore mineragraphy, petrography, Atomic Absorption Spectrometry (AAS), K-Ar age dating, and Pb isotope. All sample treatments were conducted in the *Geol-Lab* of the CGS. The result of chemical analyses of the AAS, K-Ar age dating, and Pb isotope is tabulated in Table

1, 2, and 3 respectively. Ore mineragraphic and petrographic descriptions were observed under reflected-light and polarized-light microscopes respectively.

## REGIONAL GEOLOGY

The regional geology of the Latong deposit area is based on 1:250,000 geologic map of Lubuksikaping Quadrangle (Rock *et al.*, 1983).

Table 1. Ore Chemical Data of Galena Analyzed by AAS (in ppm)

No.	Sample No.	Ag	Cu	Pb	Zn	Au
1	05 SH 08 A	151.1	59.7	4306.7	2346.7	-
2	05 SH 15 A	-	-	-	-	<0.005
3	05 SH 17 B	1.6	54.9	23	61.8	-
4	05 SH 19 A	224.8	6.2	528.3	707.7	-
5	05 SH 23 A	3	63.1	250.7	47.4	-
6	05 SH 27 A	208.8	734.9	126000	753.5	-

Table 2. K-Ar Age Dating of the Granitic Rocks from the Latong River Area

No	Sample No.	Rock Type	Mineral	K (%)	$^{40}\text{Ar}/^{40}\text{K}$ Frac.*	Age (Million Years/Ma)	Period (Relative Age)
1	05 RK 15 B	Biotite granite	Biotite	7.040 7.063	0.007134	$118.76 \pm 0.62$	Early Cretaceous/ Aptian
2	05 RK 16 A	Hornblende granite	Hornblende	0.420 0.419	0.021286 0.976	$333.49 \pm 2.49$	Early Carboniferous/ Viséan
3	05 SH 28 A	Biotite granite	Biotite	7.030 7.018	0.007165 0.999	$119.27 \pm 0.58$	Early Cretaceous/ Aptian

Table 3. Pb-Isotopic Data of Galena Ore, Vein, and Altered Rocks from the Latong River Area

No.	Sample No.	Ore	Isotope (ppm)	Isotope Ratio
1	05SH17B	Galena ore	$^{204}\text{Pb} = 124.40$ $^{206}\text{Pb} = 25.70$ $^{207}\text{Pb} = 33.02$ $^{208}\text{Pb} = 53.70$	$^{206}\text{Pb}/^{204}\text{Pb} = 20.72$ $^{207}\text{Pb}/^{204}\text{Pb} = 17.29$ $^{208}\text{Pb}/^{204}\text{Pb} = 42.92$
2	05SH19A	Vein	$^{204}\text{Pb} = 8126.00$ $^{206}\text{Pb} = 1598.70$ $^{207}\text{Pb} = 2048.02$ $^{208}\text{Pb} = 3300.00$	$^{206}\text{Pb}/^{204}\text{Pb} = 19.72$ $^{207}\text{Pb}/^{204}\text{Pb} = 16.41$ $^{208}\text{Pb}/^{204}\text{Pb} = 40.35$
3	05SH23A	Altered rocks	$^{204}\text{Pb} = 505.50$ $^{206}\text{Pb} = 96.58$ $^{207}\text{Pb} = 125.40$ $^{208}\text{Pb} = 207.40$	$^{206}\text{Pb}/^{204}\text{Pb} = 19.16$ $^{207}\text{Pb}/^{204}\text{Pb} = 16.16$ $^{208}\text{Pb}/^{204}\text{Pb} = 40.78$

The oldest rocks exposed in the area are Permian to Carboniferous metasediment and carbonate rocks assigned to be the Tapanuli Group (Figure 2). This group is formally further divided into two formations (Kuantan and Kluet Formations) plus two undifferentiated units (undifferentiated Mesozoic and/or Paleozoic limestone and undifferentiated Mesozoic and/or Palaeozoic strata). The Kuantan Formation is mainly composed of meta-sediments (interbedded shale, siltstone, and

quartz sandstone) and metamorphic rocks (phyllite, schist, quartzite, and marble). The Kluet Formation consists of metaquartz sandstone and shale. They are turbidite deposits related to the *rift* on the continental margin (Cameron *et al.*, 1980; Pulunggono and Cameron, 1984). The undifferentiated Palaeozoic and/or Mesozoic limestone comprises metalimestone and marble. While, the undifferentiated Mesozoic and/or Palaeozoic strata are composed of meta-

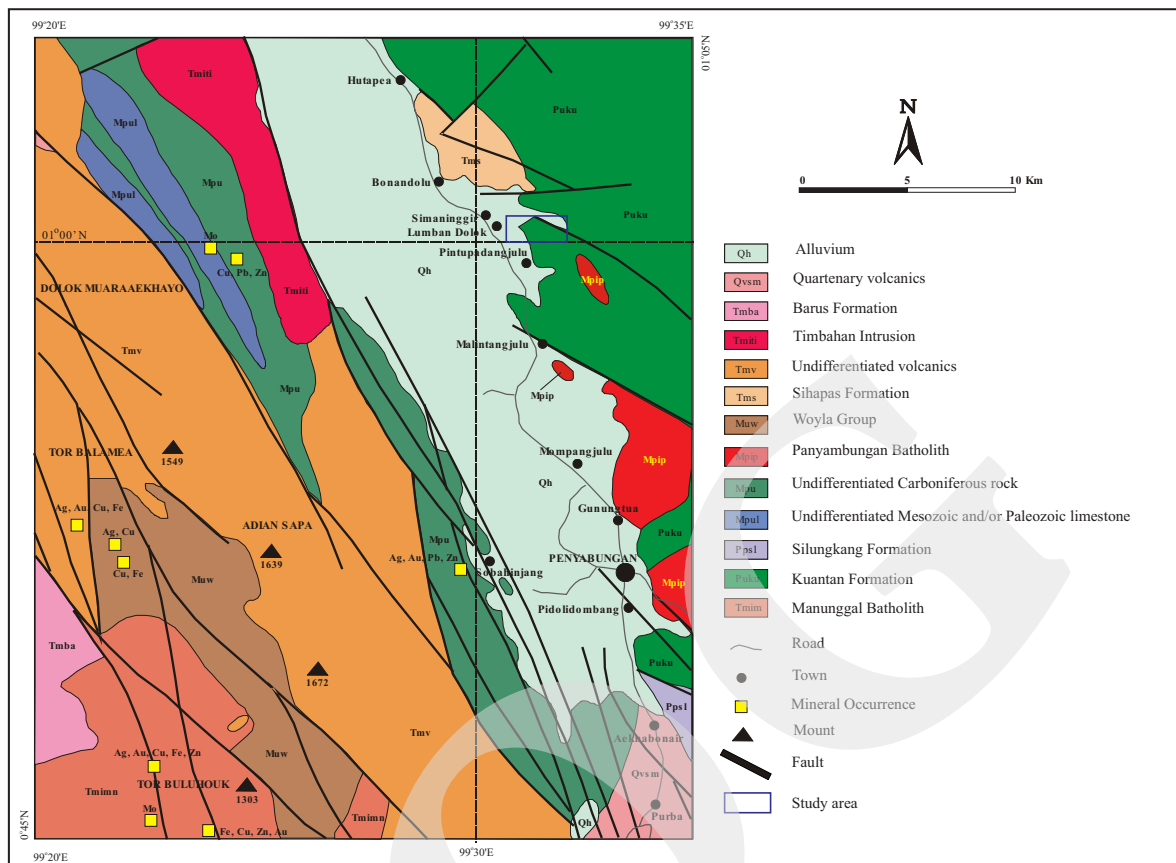


Figure 2. Regional geological map of the Latong area (modified from Rock *et al.*, 1983).

volcanics, slate, and metalimestone. This group is unconformably overlain by Permian Peusangan Group which is broadly divisible into two formations: Silungkang and Telukkido Formations. The Silungkang is composed of limestone, basic meta-volcanics, metatuffs, and volcanoclastic sandstone. The Telukkido comprises pyritic feldspathic metaquartz sandstone and shale with thin coals and plant remains. These two groups intruded by Paleozoic to Mesozoic Granitoid (Panyabungan Intrusions) are in a fault contact with the Woyla Group. The Woyla Group in this region formed as an oceanic assemblage which consists of serpentinites, amphibolite gabbros, pillow basalts, hyaloclastites, cherts, and deep sea sediments. It is interpreted as imbricated segments of an ocean floor and its underlain mantle (Cameron *et al.*, 1980). Those three groups and the granitoid are unconformably overlain by sediments (Sihapas and Barus Formations) and intruded by granitic to granodioritic rocks of Ter-

tiary age (Timbohan and Manunggal Intrusions). The whole of Pre-Tertiary and Tertiary rock units are unconformably overlain by Quaternary volcanics and alluvium.

## RESULTS AND ANALYSES

### Lithologic Descriptions

The Latong area is drained by two main rivers, Siancing and Latong Rivers (Figure 3). The lithology in the area mainly consists of clastic sedimentary rocks and less carbonate rocks with a few intrusions in the form of dyke (Figure 4). The galena ore deposits that will be discussed further are hosted within the carbonate rocks.

The lithology in the areas is partly metamorphosed to meta-sandstone, meta-siltstone, slate, phyllite, marble, metadolerite, and metagranite. The clastic sedimentary rock is divided into two units, *i.e.* interbedded sandstone and siltstone unit



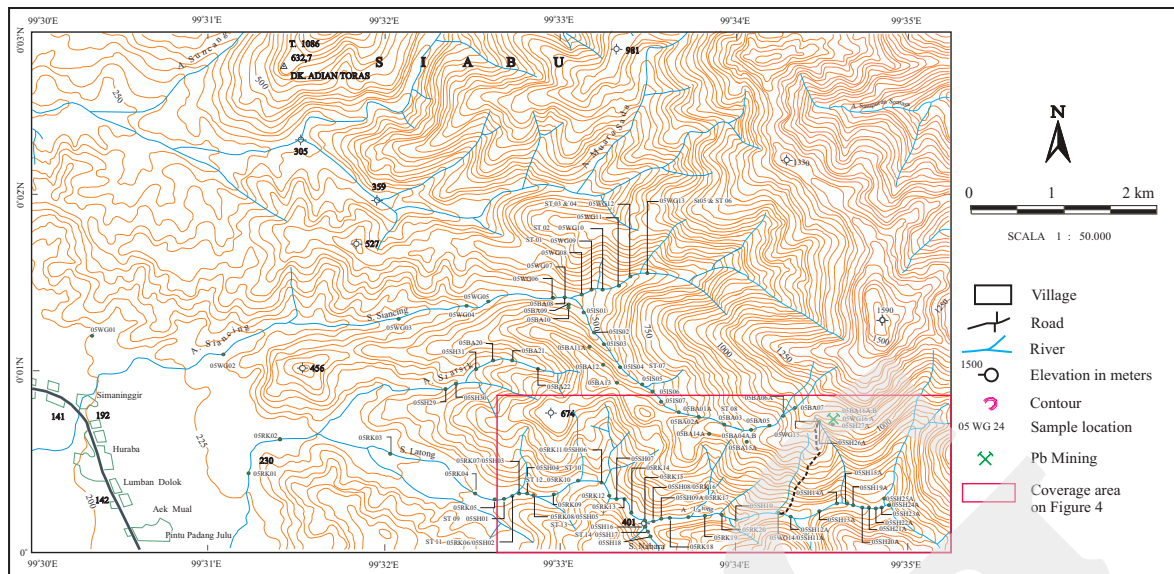


Figure 3. Map of Latong River area showing the location of lithologic outcrop observation and sampling.

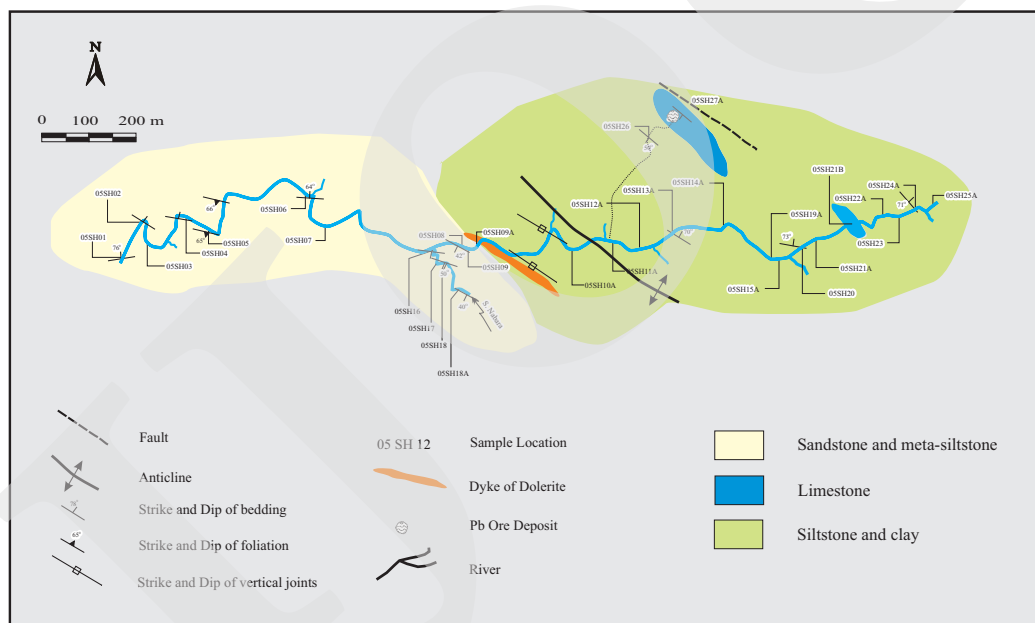


Figure 4. District geologic map of the Latong River area.

and interbedded siltstone and clay unit. While, the carbonate is more often as an intercalation within the sandstone and siltstone units. The metasandstone is mainly consist of quartzite and metaquartz sandstone, well bedded, very hard, jointed (Figures 5a, b). The slate is medium- to dark grey with quartz grains and carbonaceous materials as groundmass (Figures 6a, b). It is intercalated with phyllite and marble, and more often jointed with pyrite minerals.

The unmetamorphosed part of the sedimentary rocks mostly crops out in Siarsik River area (Figure 3). The primary structures such as parallel laminations, cross-beddings, and horizon of pyrite minerals are well developed. The sedimentary rocks are generally well bedded, folded, and faulted in some places (Figures 7a, b).

In the Siancing River, the limestone or marble is present as lenses and undulated bedding within the slate and occasionally interfingers

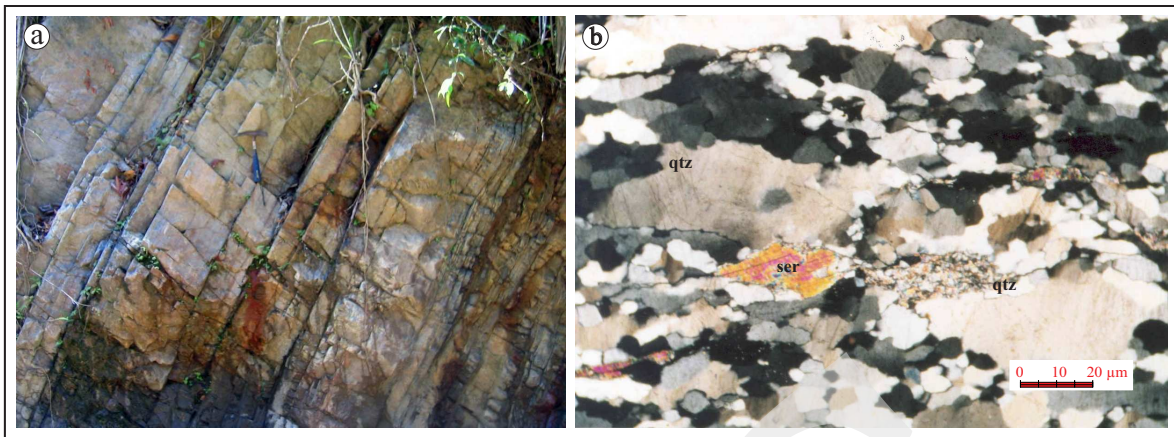


Figure 5. a. Photograph of well-bedded metaquartz sandstone of the Kluet Formation in the Latong River. Location 05RK09; b. Photomicrograph of quartz sandstone showing microcrystalline and super individual quartz grain growth with orientation parallel to the schistosity structures, mosaic, and interlocking. Some parts are filled by sericite. Sample 05 RK 09A. 40x, x-nicol. qtz= quartz, ser= sericite.

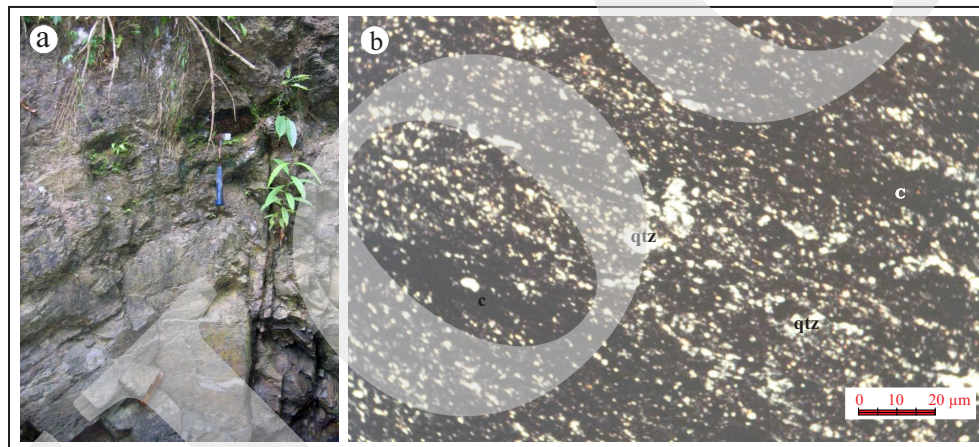


Figure 6. a. Photograph of slate showing cleavage structures and joints in Siancing River. Location 05WG12; b. Photomicrograph of slate showing quartz grains (white) lenses forming parallel orientation to the cleavage, set within the groundmass of carbon materials (black). Sample 05WG12A. 40x, x-nicol. c= carbon, qtz= quartz.

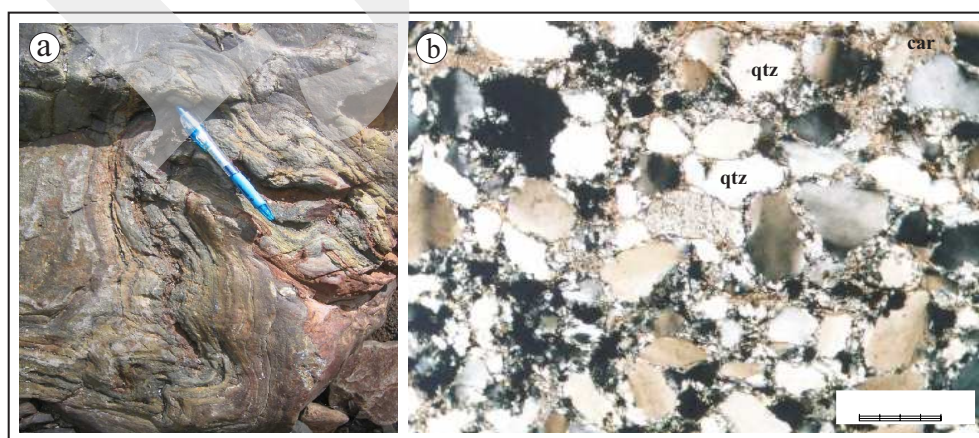


Figure 7. a. Photograph of strong to tightly folded meta-siltstone (slump structure) with pyrite minerals. It has very strong smell of sulfur. Location Latong River; b. Photomicrograph of siltstone showing quartz grains and iron sulfide cemented by carbonate. Location: Latong River, 40x, x-nicol. car= carbonate, qtz= quartz.



with siltstone. The limestone is brownish grey to dark grey, characterized by the development of calcite and quartz (Figures 8a, b). It is called neomorphic crystalline limestone. The limestone had been metamorphosed and recrystallized to become marble, consisting of calcite crystal (75%), quartz (20%), and micrite, with 0.005 - 1.00 mm in grain size. This rock is occupied by plenty of cross-cutting quartz and crystalline rock veins. Some parts of the crystalline calcite are sparry-calcite with diagenetic neomorphism as shown by suture on surface, rhombohedral, and polysynthetic twinning. The quartz veins are composed of anhedral quartz grains, equigran-

lar, long prismatic, and mosaic texture with comb structure in places.

The metadolerite dykes are brownish grey in colour, slightly deformed with granoblastic and nematoblastic textures (Figure 9a). The metadolerite comprises plagioclase (20%) and quartz (8%) as granoblast, hornblende (55%) and chlorite (15%) as nematoblast, uncontinuous foliated with grain size ranging from 0.10 to 1.25 mm (Figure 9b). The granite is pale brownish grey to dark grey, holocrystalline, and gneissic texture, composed of quartz (25%), plagioclase (30%), orthoclase (15%), biotite (20%), and muscovite (5%). Biotite and muscovite fill in space within

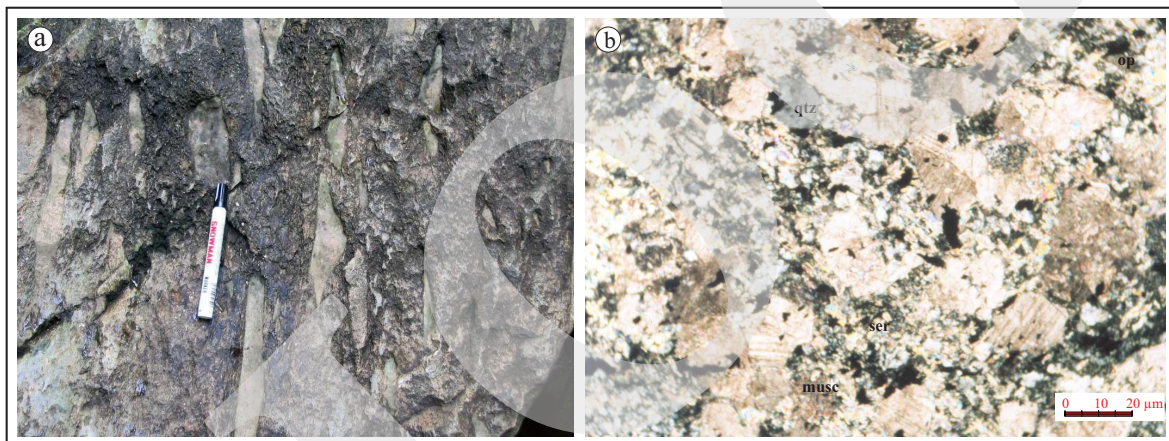


Figure 8. a. Photograph of crystalline limestone with elongate component of limestone parallel to the beds. Location: Siancing River (05WG09); b. Photomicrograph of crystalline limestone. It comprises calcite, quartz, sericite, muscovite, and opaque minerals, interlocking (intergrowth) and sutured. Opaques fill the space between minerals. The calcites is rhombohedral and polysynthetic twin/lamellar. Sample: 05 WG 09A . 40x, x-nicol. musc= muscovite, op= opaque, ser= sericite, qtz= quartz.

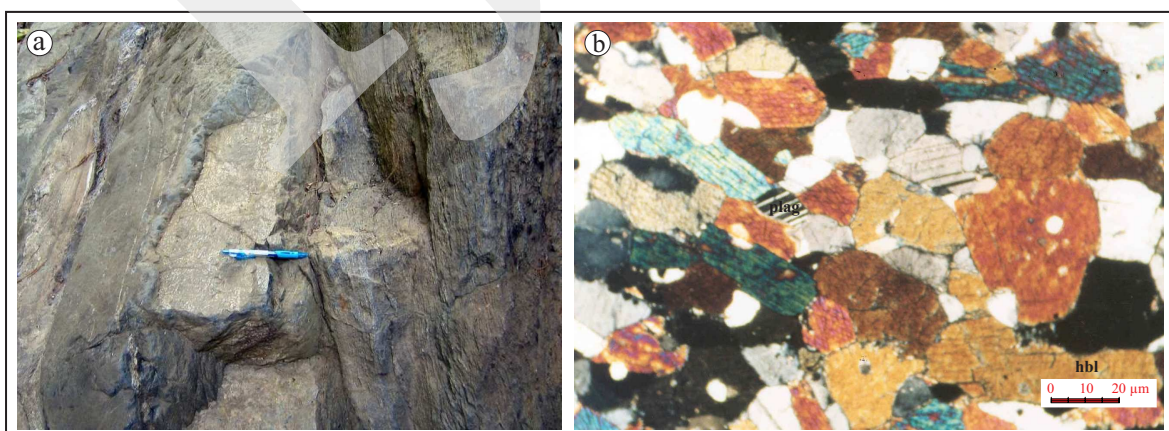


Figure 9. a. Photograph of dolerite dyke within metasedimentary rocks in Latong River (05RK18); b. Photomicrograph of the dolerite rocks showing mineral composition dominated by amphibole with slightly oriented schistosity structure. Sample 05 RK 18A. 40x, x-nicol. hbl= hornblende, plag= plagioclase.



the broken part of orthoclase and plagioclase, and form gneissic texture. The quartz forms mosaic and interlocking textures. Ore minerals of Fe- and Mg-oxides (5%) fill the broken space within other minerals.

### Description of Ore Deposits

The main body of galena ore deposit is exposed in the hilly country of about 800 m above sea level. The ore is hosted within the neomorphic crystalline limestone, mainly accumulated in hollows in the shape of irregular lenses. The mineralization is in the form of colloform, veins, veinlets, cavity filling, and disseminations. It is dominated by the presence of galena (PbS) with minor sphalerite (ZnS), chalcopyrite (CuFeS<sub>2</sub>), covellite (CuS), and pyrite (FeS<sub>2</sub>). Megascopically, the galena shows euhedral coarse-grained crystal and anhedral very fine-grained crystal with irregular cleavage. Two different styles of deposit are detected, *i.e.* (1) Galena occurring within the massive limestone as hole filling deposits (Figure 10), brecciated limestone (Figures 11 and 12), brecciated quartz veins (Figure 13), and sericite quartz veins (Figure 14); (2) Iron sulphide especially pyrite occurring within the altered clastic sedimentary rocks (Figure 15a). The galena ore that is hole filling deposit is bright grey in colour with metallic luster, fine-grained, anhedral, and irregular cleavage. The galena within the brecciated limestone and quartz veins



Figure 10. Photograph of the neomorphic crystalline limestone. Pb ore was collected from the holes (Location Latong River).

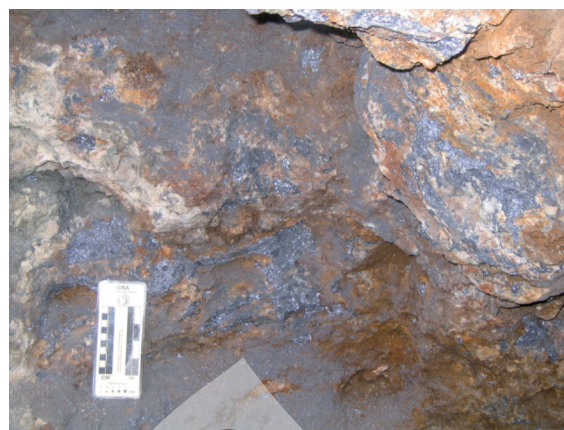


Figure 11. Photograph of brecciated limestone replaced by galena ore (grey in colour). Location Latong River.



Figure 12. Photograph of Pb-Zn ore in a neomorphic crystalline limestone.



Figure 13. Photograph of marcasite and galena within the altered sericite-quartz veins.

rocks is grey in colour, euhedral or good to perfect crystal forms and good cleavages. Other minerals embedded within the brecciated matrix of quartz





Figure 14. Photograph of marcassite and galena within an altered sericite-quartz vein.

and sericite are pyrite, marcassite, azurite, galena, and chalcopyrite (Figure 14).

In general, the galena contents in the ore bodies range from 5% to 80%. Others with minor amount are sphalerite, chalcopyrite, azurite, covellite, marcassite, and pyrite. Under a reflected light mode, the galena is typically characterized by the presence of “triangular pit” (Figure 16), replacing the pyrite and containing chalcopyrite blebs. It is light grey in colour, anhedral, colloform, irregular form, massive, granular with grain size ranging from 0.01 to 0.13 mm. The paragenetic sequence shows that the galena generally replaces pyrite and chalcopyrite, and then is replaced by covellite.

Sphalerite ranging from 0.5% to 2% by volume, is commonly dark grey to grey in colour, replacement texture with internal reflection in

places, anhedral, 0.01 to 0.10 mm in grain size. It contains abundant of chalcopyrite blebs. Such inclusions are referred to as chalcopyrite disease (Eldridge *et al.*, 1988; in Abidin, 2008). Pyrite is formed earlier and followed by the formation of sphalerite and galena. Chalcopyrite is commonly yellow in colour, patches, and as inclusions in sphalerite, colloform texture, 0.01 - 0.05 mm in grain size. Covellite (1%) is a secondary copper, bluish grey in colour, granular, and colloform in texture, 0.02 - 0.07 mm in grain size. It occurs in places, derived from chalcopyrite weathering, and replaces the galena ore.

Pyrite is found in most samples, distributed throughout the outcrops ranging from 10% to 80% by volume (Figures 15a, b). Under the reflected-light microscope, the pyrite is typically light grey, pale, dull, and yellowish grey in colour, subhedral and euhedral, pseudocubic, coarse- (0.05 - 0.60 mm) and fine- (<0.01 - 0.04 mm) grained size, colloform, veins, replacement texture, sheeting and cavity filling, replacing the fine- grained pyrite and galena. Pyrite is formed earlier filling the holes or nests, and then followed by sphalerite and galena. Some pyrite is strongly oxidized with dirty surface, rainbow colour, and botryoidal texture.

## Geochemistry

### Atomic Absorption Spectrometry

A total of six galena ore samples has been analyzed by using Atomic Absorption Spectrom-

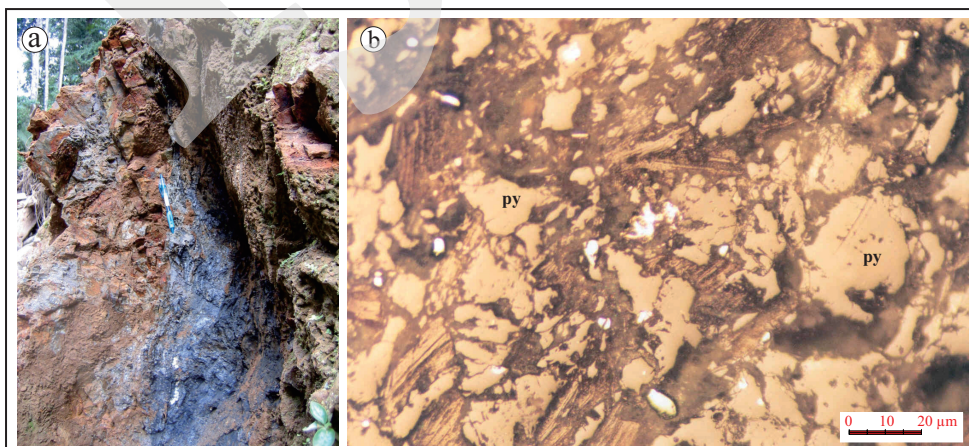


Figure 15. a. Photograph of strongly altered and mineralized rocks with sulfide minerals. Location 05RK17, Latong River; b. Photomicrograph of the rock on Figure 15a showing pyrite. Sample: 05RK17B. 40x, x-nicol. py= pyrite.

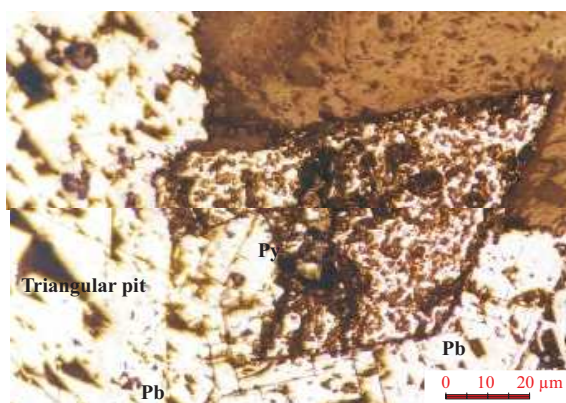


Figure 16. Photomicrograph showing triangular pit texture within galena. 40x, x-nicol. Pb= galena, Py= pyrite.

etry (AAS) for base metals and Au. The result is tabulated on Table 1. Sample 05SH27A is a galena ore with sphalerite, chalcopryite, and covellite, containing up to 12.6% of Pb. The highest zinc content is shown on sample 05SH08A which is up to 2346.7 ppm. It is brecciated galena ore with abundant pyrite. Sample 05SH19A is a mineralized breccia or brecciated quartz vein containing pyrite, azurite, galena, and chalcopryite in the matrix or groundmass. It contains up to 224.8 ppm of Ag. Sample 05SH23A is an altered rock where galena ore occurs as a cavity filling. It contains pyrite and sphalerite. The chalcopryite occurs only as inclusions in sphalerite. One sample (05SH15A) shows a trace of gold mineralization. It is quartz veins within the metamorphic rocks.

From the data, it seems that there is a good correlation between Pb, Zn, and Ag. The ore sample with high lead also contains high zinc and silver. Copper does not follow the trend of zinc and silver grade. Pb grade from this area is extremely high which is up to 12,6% compared with general nature of major metalliferous skarn types which is 6% (Einaudi *et al.*, 1981, *in* Evans, 1993; Einaudi and Burt, 1982; *in* Evans, 1993). Silver with the value of up to 224 ppm is also high, compared with that of the skarn types which is of 171 ppm in average.

### K-Ar Age Dating

The potassium Argon (K-Ar) isotopic age determination was carried out on three samples, con-

sisting of two samples of biotite granites and one sample of hornblende granite. The result of K-Ar age dating analyses based on calculation using the MINIKAR programme is shown on Table 2.

The sample 05RK15B yields an age of  $118.76 \pm 0.62$  Ma (Early Cretaceous) and sample number 05SH28A gives an age of  $119.27 \pm 0.58$  Ma (Early Cretaceous). The third sample (05RK16A) produces much older age of  $333.49 \pm 2.49$  Ma (Early Carboniferous). The first two samples are referred to the Panyabungan Granite that formed as granite stocks in the area intruding the Permian to Carboniferous Tapanuli Group. The intrusion has a contact metamorphism producing metasediments with a hydrothermal process as shown by the presence of clay or fibrous minerals surrounding quartz minerals as previously mentioned.

The hornblende granite is a dyke of 2.5 m wide. It intrudes quartz sandstone of the Permian to Carboniferous Kluet-Kuantan Formations of the Tapanuli Group. The far different age of the two types of granite is that Early Carboniferous age for the hornblende granite and Early Cretaceous for the biotite granite can not be further explained, due to very limited data. However, the presence of a magmatic activity as old as Carboniferous has been reported from Bukit Barisan in the central part of Sumatra (Tobler, 1919; *in* Hartono *et al.*, 1996).

### Pb Isotope

Pb isotope of ore, vein, and altered rocks from the Latong River area were analyzed by using ICP-MS technique. The result is shown on Table 3. Atomic elements of Pb are starting from 204, 205, 206, and 208. The Latong sulfide ore deposit posses Pb-isotope ratio of  $^{206}\text{Pb}/^{204}\text{Pb} = 19.16 - 20.72$ ,  $^{207}\text{Pb}/^{204}\text{Pb} = 16.16 - 17.29$ , and  $^{208}\text{Pb}/^{204}\text{Pb} = 42.92 - 40.78$ . The Pb ores are categorized on rather high radiogenic compositions ( $^{206}\text{Pb}/^{204}\text{Pb} > 19.1$ ). According to Zartman (1974; *in* Cox *et al.*, 1979) a high  $^{206}\text{Pb}/^{204}\text{Pb}$  isotope ratio (*ca.*  $>19.1$ ) is tentatively identified as a mantle source similar to that of oceanic basalt. It shows that they belong to field II of Cox *et al.* (1979). Additionally, Pb from sample 05SH17B has been found to notably enrich in radiogenic lead (*i.e.*  $^{206}\text{Pb}/^{204}\text{Pb}$  ratios of 20.72) compared to ordinary lead. They



are all J-types. On Figure 17, the Pb ratio values of two samples (05SH19A and 05SH23A) fall on the upper crust field which is similar with the Dairi (Middleton, 2003). These facts suggest that the Latong Pb deposit was derived from a crustal source relatively high in uranium and thorium, which could have provided it with anomalous amount of radiogenic lead.

## DISCUSSIONS

The genesis model of Sediment Hosted Massive Sulfide (SHMS) deposit has been a controversial and widely discussed subject for many years, but there is still no agreement about its origin. It is generally accepted that the sedimentary basin with rift system is the main source of massive sulfide

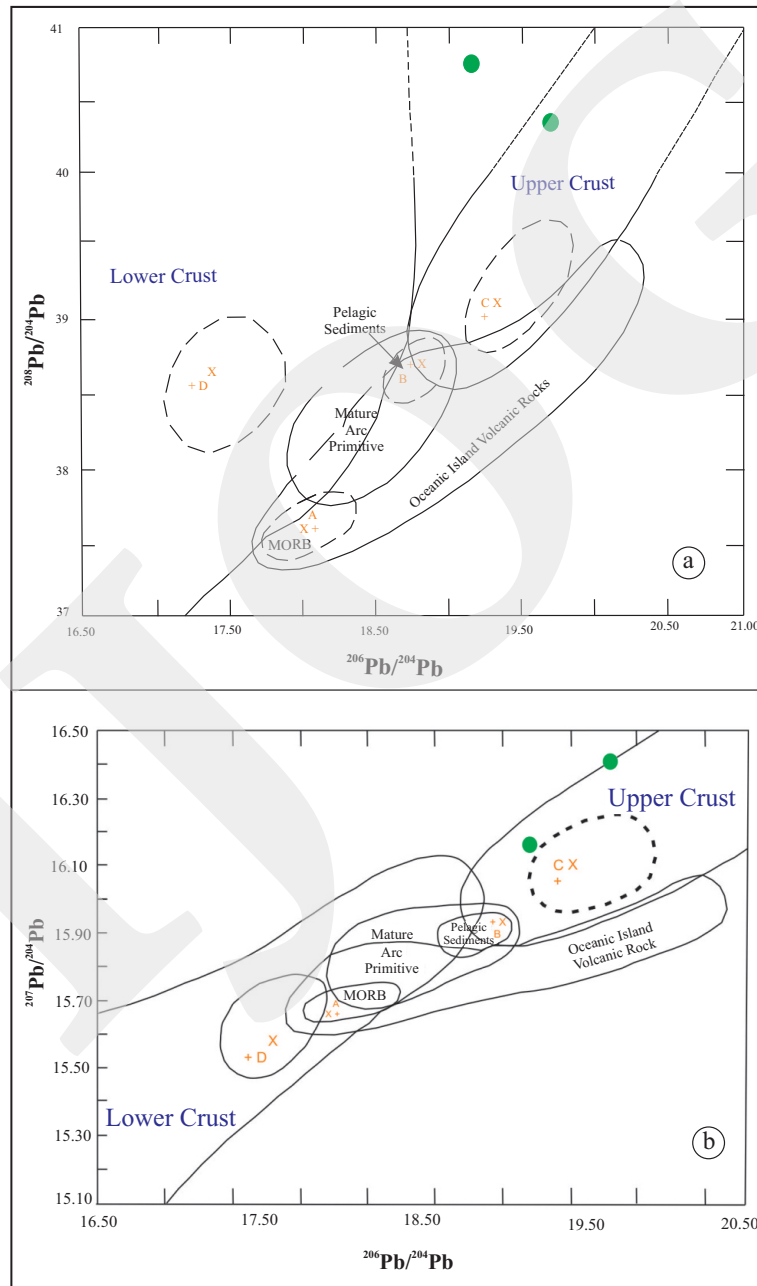


Figure 17. Diagrams of lead-isotopic ratio of the two samples (05SH19A and 05SH23A) from Latong Deposits (green spots) modified from Zartman and Doe (1981); a. One sample (05SH23A) lies between upper crust and lower crust field, while another one (05SH19A) falls under upper crust area; b. Both samples are situated on the upper crust field. Detailed explanation of these two figures can be referred into the Zartman and Doe's original paper (1981, p.137).

formation (Goodfellow, 2000). Block faulting movement within the basin had caused a pressure and thermal increase where the fluid within the sediments became hot. Here, the hydrothermal fluid and metal migrated into the lower pressure area like fracture zones that end at sea floors.

Genetically, there are two well known types of base-metal deposit occurrences related to the SHMS, *i.e.* sedimentary exhalative (sedex) and Mississippi- Valley Type (MVT). Mineralization with stratiform structure was deposited syn-genetically with carbonaceous argillitic rocks known as sedex. The sedex deposits are associated with deep sea syn-rift deposits typically carbonaceous and cherty rocks (Evans, 1993). The sedex is hosted by carbonaceous shales and dolosiltstones. Mineralization with stratabound structure was deposited epigenetically within carbonate rocks and most commonly in dolomite known as MVT. The MVT is in the form of ore rich quartz vein, breccias, replacement matrix, brecciated oxidation of sulfide minerals in limestone (Middleton, 2003). The MVT and vein-type mineralization is confined to a sequence of shelf carbonates which are in a sharp contact with overlying sedex-bearing argillites (Middleton, 2003).

In Indonesia, the largest zinc-lead deposit is known as the Dairi cluster at Sopokomil Village, Karo Regency, North Sumatra (Middleton, 1993; Crow and van Leeuwen, 2005; Mulya and Hendrawan, 2014). This deposit is related to the sedex and MVT, where recently identified in the Permian to Carboniferous Kluet Formation (Aldis *et al.*, 1983; Middleton, 2003), a continental margin arc of Sumatra. The Dairi cluster is believed to be formed by the reaction of volcanic fluids with sediments, and supergene mineralization. The latter was presumably deposited recently from decending metal-rich solutions derived from the weathering of the sedex mineralization (Middleton, 2003). According to Middleton (2003), the Pb source rock of Dairi was originated from the Sumatra basement rocks, which could be correlated to the age of 1800-2000 Ma (Precambrian) radiogenic rich basement in Hall Creek of north-western Australia. This rock was the source rock of Sorby Hill deposit and other MVT deposits in

Bonaparte and Canning Basins. The Dairi deposits have an average Pb ratio of  $18,977 \pm 0,034$  for sedex type and  $19,263 \pm 0,085$  for MVT type which is similar to the MVT Sorby Hill deposit. However, an ore rich hydrothermal fluid of the Dairi MVT was mixed with hydrothermal fluid rich in more radiogenic Pb, before being deposited in the site of ore deposition.

Pre-Cretaceous evolution of Sumatra has been summarized by Metcalfe (1996). In general, the Pre-Tertiary geological framework of Sumatra comprises several small continental fragments, including the Sikuleh and Natal Blocks, now located along the southwest margin of Sumatra that were accreted to Sundaland in the Cretaceous called the Woyla terranes by Cameron *et al.* (1980) and Pulunggono and Cameron (1984). Stratigraphic studies of part of the Woyla terranes in the Padang area (Yancey and Alif, 1977; *in* Metcalfe, 1996) reveal similarities with the stratigraphy of the Exmouth Plateau of the NW Australia Shelf (Gorur and Sengor, 1992; *in* Metcalfe 1996). Limited paleomagnetic data from the Sikuleh Block (Haile, 1979; *in* Metcalfe, 1996) suggest paleolatitudes of 26°S for the Late Triassic and 10°S in the Late Mesozoic which is consistent with a NW Australian region of these terranes.

Cameron *et al.* (1980) suggested that the Tapanuli Group represents a continental margins sequence deposited on a rifted passive margin. They further suggested that turbiditic sandstones and shales were deposited in rift basins, while limestone of the Kuantan Formation formed carbonates bank on horst blocks of uplifted basement. The rifting process in the region was followed by magmatic activities as shown by the presence of several intrusions of Early Cretaceous to Triassic ages that were distributed in the Muarasipongi, Madina, and Sibolga areas (Rock *et al.*, 1983; Zulkarnain, 2009). The clastic sediments in the Latong River area had been metamorphosed to become metasediments, and they had also undergone hydrothermal processes as indicated by the presence of clay or fibrous minerals (sericite and muscovite) surrounding quartz minerals. The metasediments are characterized by granoblastic, lepidoblastic, and mosaic textures with

intergrowth and interlocking. The limestone is characterized by the growth of calcite, neomorphic crystalline, and silica. This rock is full of cross-cutting veins with the comb structure. In general, the limestone has been affected by regional metamorphism, and it was partly changed into marble. This is probably related to fluid from the magmatic activity of Early Cretaceous as a result of crustal melting that intruded the Kuantan Formations in the Latong River area. The presence of granitoid rocks in this area with K-Ar age dating result of  $330.49 \pm 2.49$  Ma and  $118.76 \pm 0.62$  -  $119.27 \pm 0.58$  Ma may be correlated with a basement high and rifting process respectively.

The ore body of Latong deposit is stratabound formed epigenetically in Limestone Member

of the Permo-Carboniferous Kuantan Formation. The structures found in this ore body are colloform, vein, veinlets, cavity filling, and ore matrix breccias. The body dominantly consists of galena, sphalerite, pyrite, and marcasite. On the basis of paragenetic study, the early phase of mineral deposition is pyrite, then, galena replaced pyrite. Sphalerite replaced galena and pyrite. The last phase is the deposition of chalcopyrite that replaced sphalerite. The Pb ore isotopes from Latong River are categorized on rather high radiogenic compositions ( $^{206}\text{Pb}/^{204}\text{Pb} > 19.1$ ) which is similar with the Dairi MVT type deposits.

Figure 18 shows a model to explain the genesis of MVT deposits as proposed by Evans (1993). The galena ore deposits are hosted within the

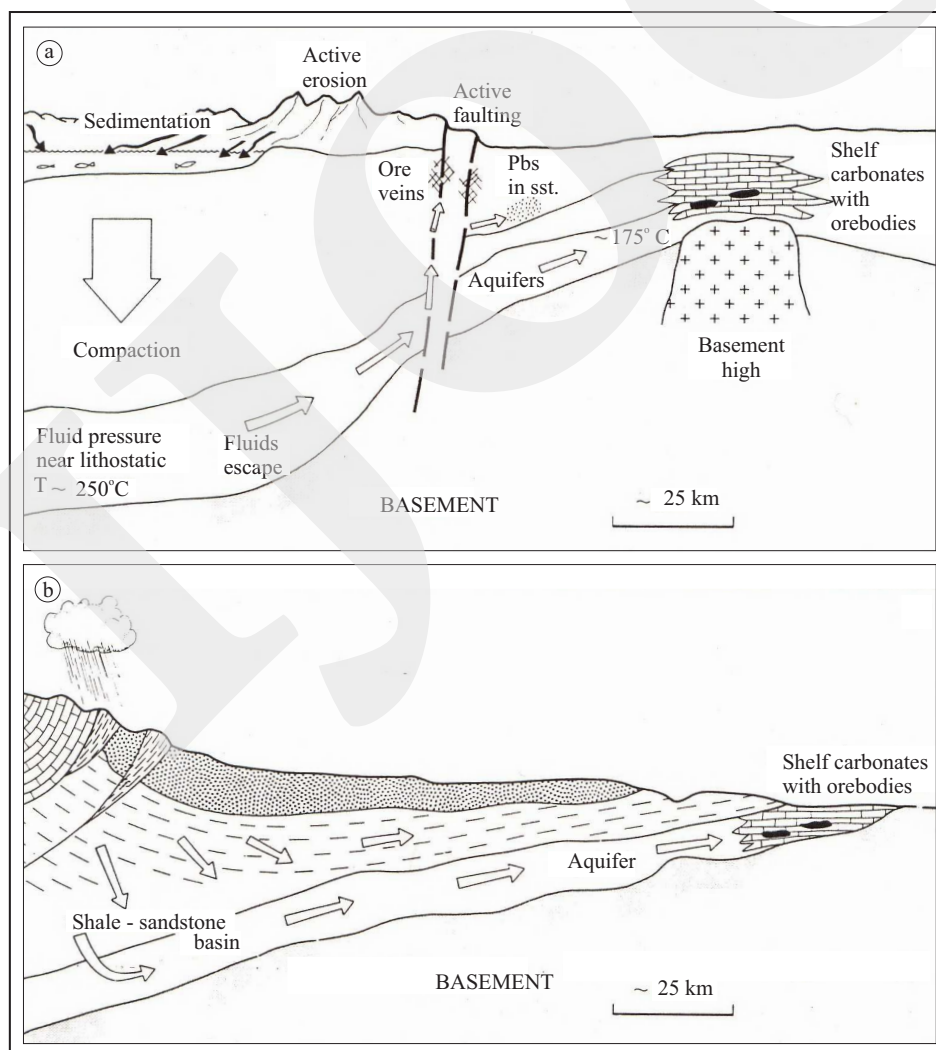


Figure 18. Model of the formation of Mississippi Valley-type deposits (Evans, 1993) which may be applied for ore deposit formation in the study area.



carbonate that are sitting directly on the basement rocks (Figure 18): (a) Over pressured, hot pore fluids escaped from a shale basin (perhaps aided by hydraulic fracturing) and made up aquifers to form deposits in cooler strata, filling fractures, or forming other type of ore body; (b) Gravity-driven fluids flowing from a hydraulic head in a highland area flush through a basin driving out and replenishing the formation of waters.

Although it is still too early to confirm the type or style of deposits in Latong River area,

one of the important point in this respect is that the Latong deposit has the same host rocks, age, texture, ore mineralogy, mineral alteration, Pb isotope (Table 4) with the Dairi MVT deposits in northern Sumatra. The Latong and Dairi MVT deposits are hosted within the limestone in platform carbonate sequences in the West Sumatra Block (Crow, 2005). Plots of the two samples on diagrams of lead-isotopic ratio (Figure 17a, b) confirm that they are derived from a crustal source relatively high in uranium and thorium.

Table 4. Comparison of a Genetic Component of the Latong Deposits with Other Deposits in the Sumatra Region and the Mississippi Valley Type

Cluster Name Genetic Components	Latong	Dairi (Middleton, 2003)	Kelapa Kampit (Crow & van Leeuwen, 2005)	Upper Mississippi Valley Mining District (Evans, 1993)
Host Rocks	Limestone	Limestone (MVT) and clastic sediments (sedex)	Metasediments and metavolcanics	Carbonate rocks
Age of host rocks	Permo-Carboniferous	Permo-Carboniferous	Triassic - Permian	Pre-Cambrian
Ore texture/ style of mineralization	Colloform, cavity filling, vein/vein lets, dissemination	vein, crackle breccia and ore matrix breccia	Massive, fine grained sphalerite, galena and pyrite; Brecciated quartz vein, mudstone with selvage of sulfides; disseminated sphalerite and galena in sandstone	Breccia (open space filling), fractures, and vugs. Crackle, mosaic, rubble, and rock-matrix breccia. The mineralized breccia
Ore minerals	Galena, phalerite marcasite and pyrite	Galena, sphalerite and pyrite	Sphalerite, galena and pyrite	Sphalerite, galena, pyrite and marcasite
Alteration mineralogy	Recrystallization, silicification	Silicification, recrystallization, dolomitization, sericite/muscovite	-	Hydrothermal brecciation, recrystallization, dissolution, dolomitization and silicification
Pb-Isotop ratio ( $^{206}\text{Pb}/^{204}\text{Pb}$ )	19.16 - 20.72	19,088 - 19,336 (MVT) 18,923 - 19,093 (sedex)	>19.00	20.00 or greater
Associated Igneous Rocks	Granite	-	Granite	Magmatic activity: Heat sources, such as buried intrusive rocks, are not present.
Source	-	Pre-Cambrian basement	-	Pre-Cambrian

## CONCLUSIONS

The lithology of the Latong deposit area mainly consists of low grade metamorphics such as metasandstone, metasilstone, quartzite, slate, phyllite, and marble. The intrusive rocks occur in places in the form of stocks and dyke comprising dolerite, hornblende granite, and biotite granite. K-Ar age dating of the granites indicates there are two periods of magmatic intrusions, *i.e.* Carboniferous ( $333.49 \pm 2.49$  Ma) and Early Cretaceous age ( $118.76 \pm 0.62$  Ma and  $119.27 \pm 0.58$ ). The geological aspect predominantly controlling the formation of the Latong Pb-Zn-Cu-Ag deposit consists of clastic rocks and carbonates. The ores, which are mainly accumulated in hollows and replaced limestone, are in the form of lensoidal, veins, veinlets, breccia, and dissemination. The ores dominantly consist of galena and sphalerite. The other minerals are silver, azurite, covellite, pyrite, and chalcopyrite. The early phase of mineral deposition is pyrite, then galena replacing pyrite. Sphalerite replaced galena and pyrite. The last phase is the deposition of chalcopyrite that replaced sphalerite.

Genetically, the Latong deposits belong to Sedimentary Hosted Massive Sulfide (SHMS) of Mississippi Valley- type. It is notably enriched in radiogenic lead with  $^{206}\text{Pb}/^{204}\text{Pb}$  ratio of  $>19.1$ . The ore body is stratabound and formed epigenetically in Limestone Member of the Kuantan Formation. It is interpreted that the limestone formed carbonate banks on horst block of the basement high. The formation system of galena ore mineralization in the Latong area was by fluid flow processing, where hot fluids escaped from a shale basin by hydraulic fracturing to form deposits in cooler strata, filling fracture, and/or forming an ore body in limestone. This evidence is shown by the occurrence of sulfide in fine clastic sediments as well as in the breccia or fractured rock which is probably related to the fault zone. The euhedral crystals of galena occur in the breccia, while the anhedral crystals within the carbonate rocks on the uppermost part of the stratigraphic succession.

The enrichment of radiogenic isotope ratio of the deposit ( $^{206}\text{Pb}/^{204}\text{Pb} = 19.16 - 20.72$ ), stratabound, carbonate-hosted sulfide bodies with mineral (*i.e.* assemblage of galena, sphalerite, pyrite and marcasite), and texture (*i.e.* breccia, fractures, and vugs) suggested that the Latong Deposits belong to the MVT. There is a positive correlation among the mineral grade content, and the high lead content is followed by high zinc and silver.

The magmatic activities including the Cretaceous granite, Tertiary granite, and Quaternary Volcanics in Latong River area are much younger than the galena deposits. These magmatic rocks only affected the country rocks in some places by a contact metamorphism resulted in the deposition of hydrothermal minerals, such as sericite, calcite, and quartz. In addition, the presence of tectonic structures, such as Sumatra Fault Zone which passed through this region, had affected the country rocks and resulted in a regional metamorphism and hydrothermal minerals as well.

It is suggested that more detailed studies about the deposit are necessary, including geological mapping, structural geology, sampling, and analytical laboratories. A drilling test is proposed to delineate the vertical distribution of the deposit. Geophysical methods (Induced Polarization, gravity, and magnet) should be carried out in order to know the distribution of the deposit laterally as well as the subsurface configuration of the deposit.

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conducted by Ir. Sam Permanadewi, M.M. The Pb isotope is conducted by using ICP-MS operated by Dr. Purnama Sendjaja, S.T., M.T. Last but not least, the authors greatly appreciate and thank so much to the locals, without them the team could not reach the deposits.

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