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GEOLOGY AND CHARACTERISTICS OF Pb–Zn–Cu–Ag SKARN DEPOSIT AT RUWAI, LAMANDAU REGENCY, CENTRAL KALIMANTAN

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Abstract

This study is dealing with geology and characteristics of mineralogy, geochemistry and physicochemical conditions of hydrothermal fluid responsible for the formation of skarn Pb-Zn-Cu-Ag deposit at Ruwai, Lamandau Regency, Central Kalimantan. The formation of Ruwai skarn is genetically associated with calcareous rocks consisting of limestone and siltstone (derived from marl?) and controlled by NNE-SSW-trending strike slip faults and localized along N 70° E-trending thrust fault, which also acts as contact zone between sedimentary and volcanic rocks in the area. Ruwai skarn is mineralogically characterized by prograde alteration (garnet and clino-pyroxene) and retrograde alteration (epidote, chlorite, calcite and sericite). Ore mineralization is characterized by sphalerite, galena, chalcopyrite and Ag-sulphides (particularly acanthite and argentite), which formed at early retrograde stage. Geochemically, SiO_2 is enriched and CaO is depleted in limestone, consistent with silicic alteration (quartz and calc-silicate) and decarbonatization of the wallrock. The measured reserves of the deposit are 2,297,185 tonnes at average grades of 14.98 % Zn, 6.44 % Pb, 2.49 % Cu and 370.87 g/t Ag. Ruwai skarn orebody originated at moderate temperature of 250-266 °C and low salinity of 0.3-0.5 wt.% NaCl eq. The late retrograde stage formed at low temperature of 190-220 °C and low salinity of ~0.35 wt.% NaCl eq., which was influenced by meteoric water incursion at the late stage of the Ruwai Pb-Zn-Cu-Ag skarn formation.

Keywords: *Geology, skarn, mineralogy, geochemistry, Ruwai, Central Kalimantan.*

1 Introduction

1.1 Background

Geological framework and characterization in term of mineralogy, rock geochemistry and physicochemical conditions of responsible hydrothermal fluid of the Ruwai Pb-Zn-Cu-Ag skarn deposit has been investigated. This study is needed for a better understanding of the ore deposit, particularly on the genetic aspects including mineral assemblages, textures, geochemistry and natures of hydrothermal fluids involved. The genetic aspects combined with understanding of geological framework of the deposit could be guidance for the further exploration and mining development of the deposit. Some previous works in the area are reported, particularly emphasizing on the geology of the deposit for exploration, for instance, Ayson (1997), Baratang (1997) as well as Cooke and Kitto (1997). No studies in details on the mine geology and characterization of the deposit were previously conducted.

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Figure 1: Location map of the study area situated in Ruwai, Lamandau regency, Central Kalimantan

2 Regional Geology

The Ruwai Pb-Zn-Cu-Ag skarn deposit is a product of hydrothermal process resulted from Late Cretaceous dyke/stock, which intruded the Triassic-Middle Cretaceous volcanic and sedimentary rocks (Figure 2; Ayson, 1997; Baratang, 1997; Cooke and Kitto, 1997). Sedimentary rocks consist of siltstone, sandstone and limestone, which are included into Late Triassic-Middle Cretaceous Ketapang complex. Siltstone has been locally altered to skarn/hornfels, whereas limestone has been silicified. Two volcanic rocks are recognized in the field including felsic volcanic and acid intrusive rocks (dykes/stock). These volcanic rocks are a member of Late Triassic-Middle Cretaceous Matan complex. The youngest rock outcropped in the field is granodiorite, a member of Late Cretaceous-Early Tertiary Sukadana granitoid complex. Figure 2 also shows that the ore deposit prospects including Southwest Gossan, Ruwai, Central Gossan, Karim and Gojo are obviously localized between the lithological contact between volcanic and sedimentary rocks along N 70° E-trending fault. It is interpreted that the regional fault is of thrust type resulted from regional east-west compression during the late of Tertiary. In addition, other prominent structures are the NNE-SSW trending strike-slip faults.

3 Methods of Study

Two 'normative' methods were used in this study including geological fieldwork and laboratory analysis of selected samples taken. A total of 21 rock and quartz vein samples were selected for analyses of petrography (6 samples), ore microscopy (6 samples), rock geochemistry (4 samples) and microthermometry of fluid inclusion (5 samples), respectively. Petrographic analysis on thin section and ore microscopic analysis on polished section were conducted at Department of Geological Engineering, Gadjah Mada Unversity. Bulk rock geochemistry was analysed using XRF (X-Ray Fluorescence) at Kyushu University, Japan. Microthermometric analysis of fluid inclusion was performed using LINKAM THMS 600 freezing and heating stage at Centre of Research and Development of Geotechnology, National Institute of Sciences (LIPI), Bandung.

4 Results and Analysis

4.1 Geology of Ruwai Skarn Deposit

As outlined before, Ruwai Pb-Zn-Cu-Ag skarn deposit is localized along the contact between volcanic rocks in the south and sedimentary rocks in the north. The lithological contact is also interpreted to be a N 70° E-trending thrust fault, which caused the volcanic rocks emplaced overlying the sedimentary rocks (Figure 3).

Stratigraphically, volcanic rocks are the oldest rocks, but in the field the rocks are emplaced on top of the sedimentary rocks due to fault movement. The type of volcanic rocks is difficult to be identified due to strongly weathering. However, according to previous workers (e.g. Ayson, 1997), there are two groups of volcanic rocks have been recognized, i.e. Late Triassic-Middle Cretaceous Matan volcanic complex and Late Cretaceous-Early Tertiary

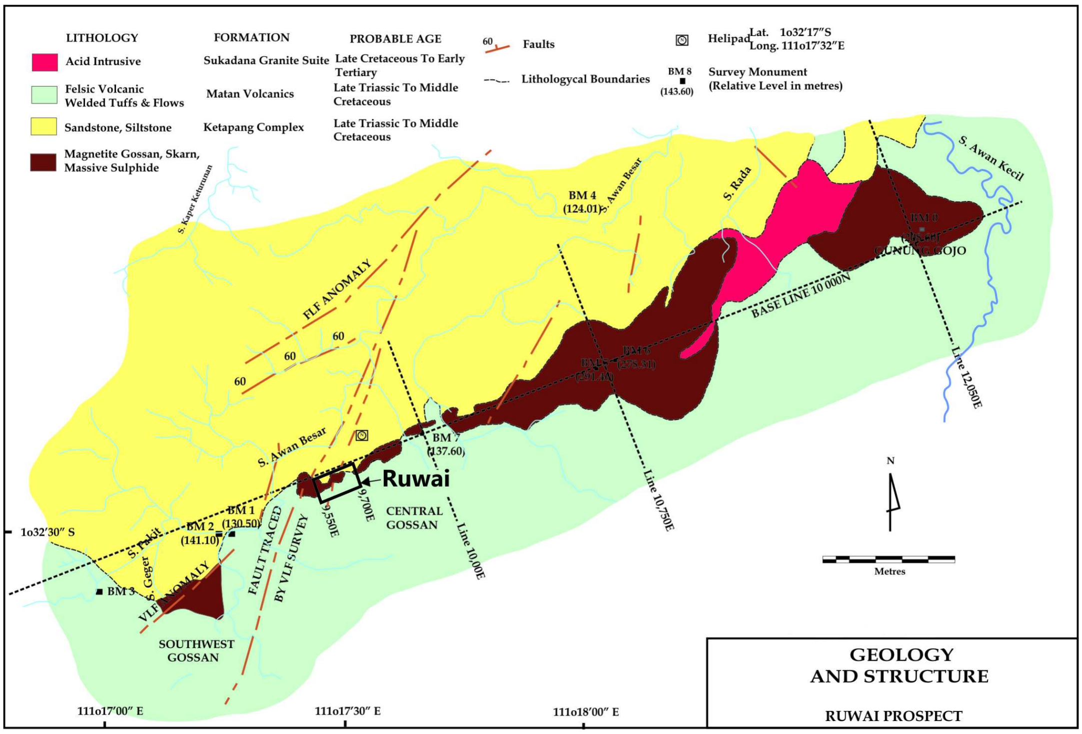

Figure 2: Map of regional geology of Ruwai area and its vicinity (after Ayson, 1997; Baratang, 1997; Cooke and Kitto, 1997)

Kerabai volcanic complex. The Matan complex is characterized by felsic volcanic rocks, whereas Kerabai complex is typified by basic volcanic rocks.

Sedimentary rocks recognized in the Ruwai prospect consist of siltstone, sandstone and limestone, which are correlated to Late Triassic-Middle Cretaceous Ketapang complex. Ore mineralization is closely associated with siltstone and limestone. Siltstone is probably derived from marl that has been undergone decalcification and silicification. Limestone also has been partially changed to marble and outcropped obviously in the centre of Ruwai prospect. Locally, the rock has been silicified to form calc silicate alteration.

Granodiorite is outcropped in Rada River situated between Karim and Gojo hills. The intrusive rock is correlated with Late Cretaceous-Early Tertiary Sukadana granite. Genetically, this intrusion is probably related to the formation of the Gojo and Karim skarn Fe deposits. In Ruwai mine (prospect), strong altered monzonite is recognized, which may be related to the formation of the Pb-Zn-Cu-Ag skarn deposit. In the Ruwai mine, some young intrusions in form of dyke and sill including microdiorite, andesite, basalt and rhyolite cross cut the ore body (Figure 4).

4.2 Mineralogical Characteristics

Ore minerals

Field observation and ore microscopy of six selected samples indicates that the Ruwai skarn ore body is characterized by the presence of pyrite (FeS_2), galena (PbS), sphalerite (ZnS), lesser chalcopyrite ($CuFeS_2$) as well as Ag-bearing sulphides particularly acanthite (AgS) and argentite (AgS). Iron oxides minerals such as magnetite and hematite are also present. Sphalerite is predominantly observed and microscopically often exhibits reddish brown internal reflection (Figure 5). Galena is the second abundant ore mineral within the ore body and showing a typical texture of triangular pits (Figure 5B).

Pyrite is mostly present in form of subhedral grain and locally it replaces the margin of sphalerite. However, occasionally pyrite is replaced

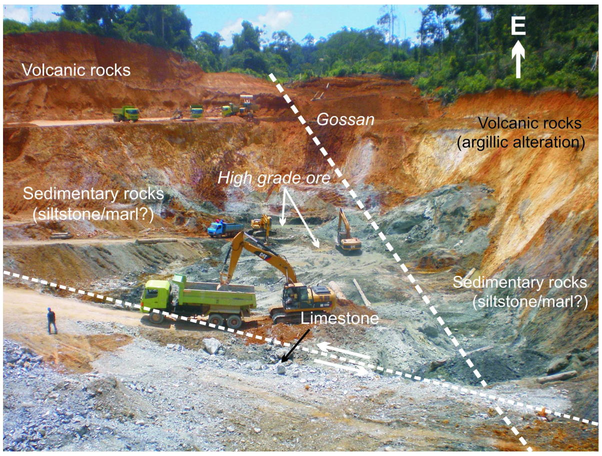

Figure 3: Mine of Pb-Zn-Cu-Ag skarn at Ruwai showing ore mineralization localized along the contact between volcanic rocks and sedimentary rock. Dashed line indicates suspected fault zone

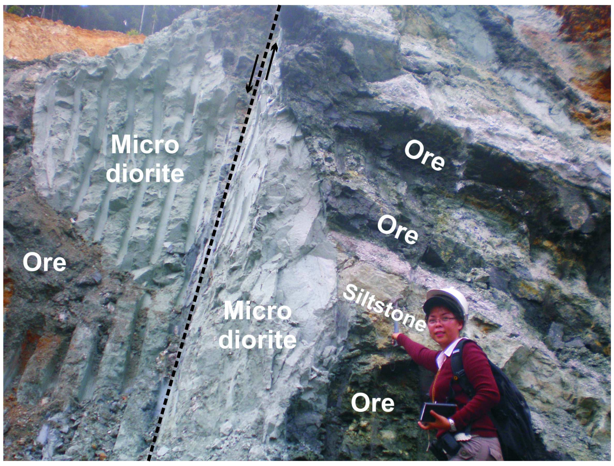

Figure 4: Micro-diorite cross cutting sedimentary rock bedding and Pb-Zn-Cu-Ag skarn ore body

by sphalerite suggesting that pyrite occurs in the broad stability conditions. Chalcopyrite is rarely present and it seems that the mineral formed in the early stage in term of paragenesis sequences. Silver-bearing sulfides (probably acanthite and argentite) mostly occur as inclusion and micro fractures filling in sphalerite (Figure 5C). The measured reserves of the deposit are 2,297,185 tonnes at average grades of 14.98 % Zn, 6.44 % Pb, 2.49 % Cu and 370.87 g/t Ag.

Hydrothermal alteration minerals

Two groups of hydrothermal alteration minerals are identified on the basis of field investigation, handspecimen description and petrographic analysis, including (1) prograde alteration minerals, and (2) retrograde alteration minerals. Prograde alteration minerals are represented by typical calc-silicate minerals particularly garnet and clino-pyroxene.

Prograde alteration minerals are commonly recognized in the country rocks of meta-limestone and meta-siltstone (marl?). Prograde minerals were also found in many other skarn deposit types worldwide, for instance, King Island, Sheelite (Kwak, 1986) and Batu Hijau, Sumbawa (Idrus *et al.*, 2009). Garnets in the Ruwai skarn deposit are mostly identified in massive form with coarse crystal grains filling in the fractures of meta-limestone (Figure 6A) and meta-siltstone. However, in some cases garnets are locally disseminated as fine-grained crystals in the sedimentary rocks. Optically, garnets frequently reveal a keliphytic structure, i.e. a zoned structure developing in the rims of garnet (Figure 6B). Garnets are mostly light brown in color and they are interpreted as andradite (Ca-Fe-rich garnet type). Megascopically, clino-pyroxenes are present as greenish fine-grained crystals together calcite, layering in siltstone and limestone (Figure 6C). Microscopically, clino-pyroxenes are disseminated (Figure 6D) and occasionally occurred as vein/veinlet in the sedimentary rocks and locally in monzonite. We interpret that the clino-pyroxene is of wollastonite type.

Retrograde alteration minerals are characterized by the presence of epidote, chlorite, calcite and sericite. Epidote exhibits a yellowish green in color, whereas chlorite is dark green, both minerals are identified in sedimentary rocks overlapping with prograde mineral phases. The retrograde minerals also widely occurred in young intrusions such as micro-diorite and andesite. Calcite commonly occurred as 'white layer' in the sedimentary rocks and partly formed as vein/veinlet. Sericite replacing plagioclase in volcanic rocks and intrusion is the latest stage of the hydrothermal min-

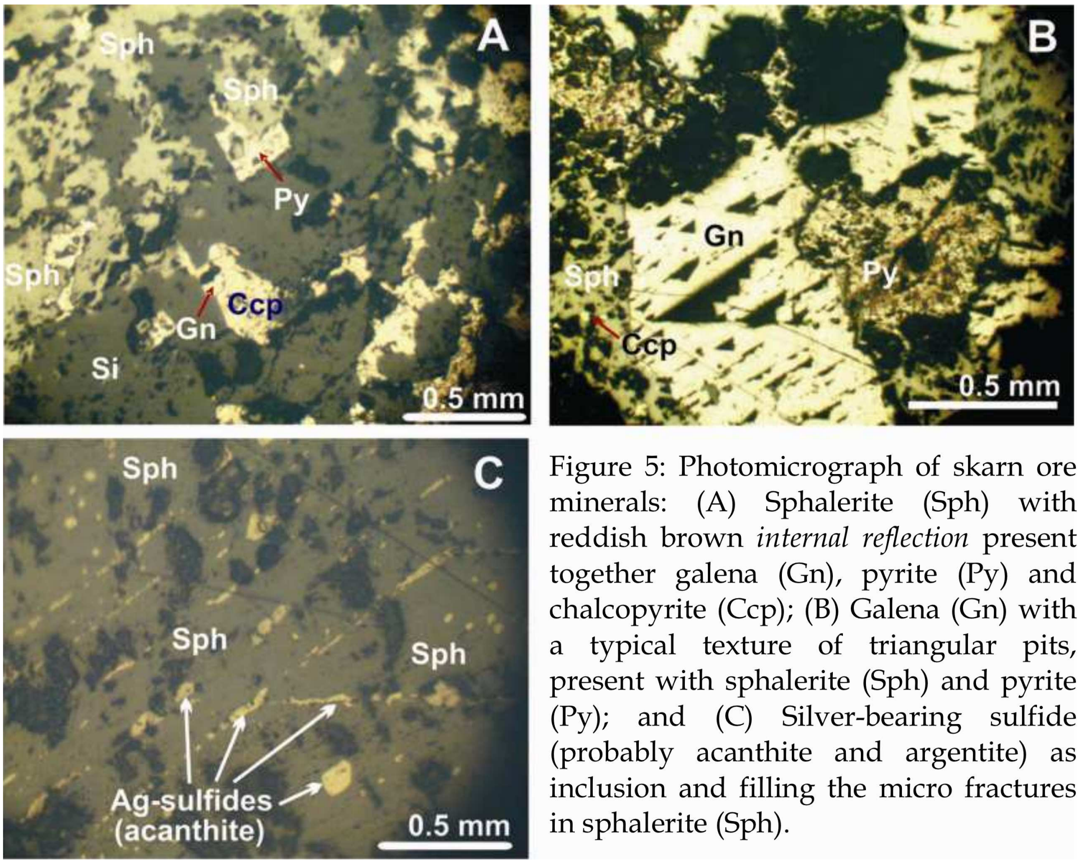

Figure 5: Photomicrograph of skarn ore minerals: (A) Sphalerite (Sph) with reddish brown *internal reflection* present together galena (Gn), pyrite (Py) and chalcopyrite (Ccp); (B) Galena (Gn) with a typical texture of triangular pits, present with sphalerite (Sph) and pyrite (Py); and (C) Silver-bearing sulfide (probably acanthite and argentite) as inclusion and filling the micro fractures in sphalerite (Sph).

eral formation in the deposit. It is formed as a product of hydration reaction between the mineral phase and meteoric water.

Ore mineralization is interpreted to be formed immediately post of prograde stage during the slightly decrease of temperature. This interpretation is proven by the occurrences of galena and sphalerite inclusions in massive garnet filling the fractures as well as in the form of base metal veins/veinlets crosscutting the fragments/crystals of massive garnet.

Rock geochemical characteristics

Geochemical characterization of meta-limestone and young intrusions is performed by XRF (X-Ray Fluorescence) as shown by the analysis result in Table 1. Limestone reveals a high SiO_2 content of 12.41 wt.% and low CaO content of 50.73 wt.% in average. The high concentration of SiO_2 and the low content of CaO compared to 'ideal' limestone composition are due to silicification and decarbonatization processes of the wall rock. Silicification and carbonatization may cause the volume lost of the rock. The chemical composition of young intrusion including micro-diorite and rhyolite was also analysed (Table 1). The young intrusions are slightly altered. This is proven by their chemical composition showing relatively high SiO_2 contents of 54.8 wt.% in diorite and 74.92 wt.% in rhyolite. The similar behavior is also shown by high total alkali (K_2O + NaO) contents of diorite (5.57 wt.%) and rhyolite (7.73 wt.%). Few trace elements are also included in Table 1.

Fluid inclusion microthermometry

Three quartz+ore samples, one barren quartz sample and one calcite sample were microthermometrically analysed using freezing and heating stages. In term of fluid inclusion phases present, there are petrographically no differences among the samples. The samples are dominantly composed of liquid-rich monophase and liquid-vapour-biphase fluid inclusions. The fluid inclusions are genetically categorized into primary and secondary types. The primary fluid inclusions are commonly

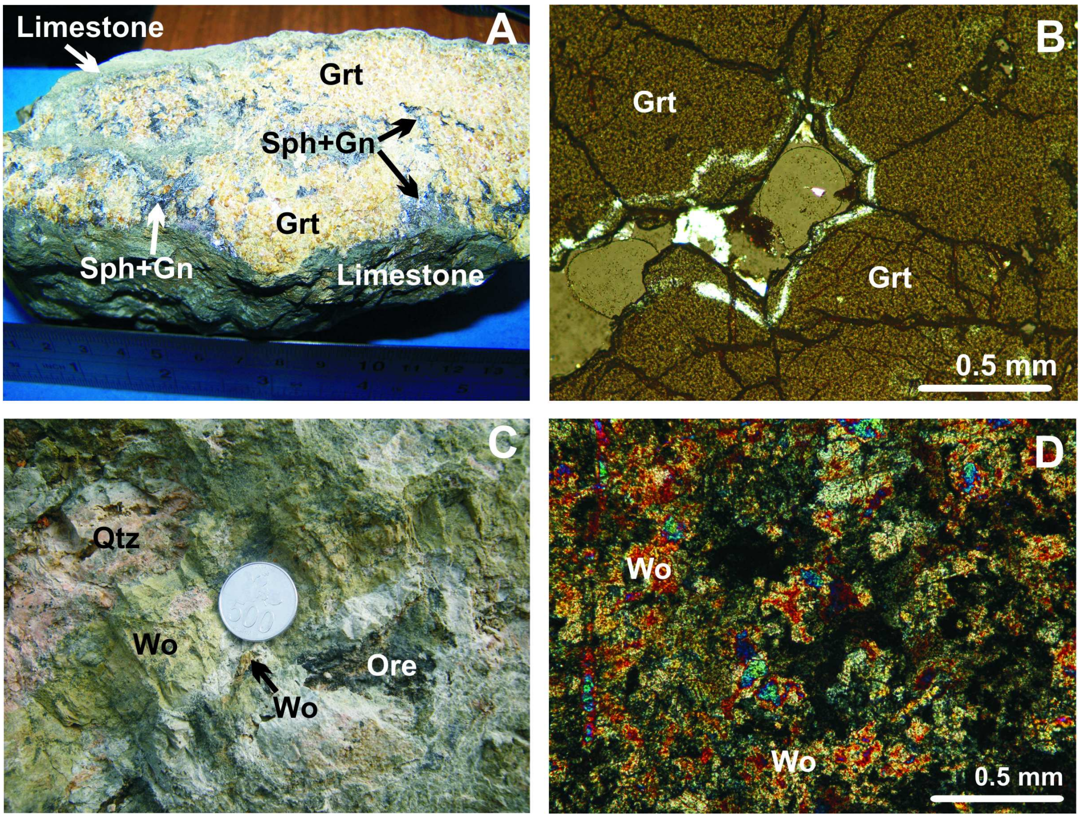

Figure 6: Prograde alteration minerals: (A). Handspecimen of coarse-grained garnet (Grt) hosted by meta-limestone. It is also shown that sphalerite and galena (Sph+Gn) stringers crosscut garnet crystals, (B). Photomicrograph of garnet (Grt) with a typical keliphytic structure, (C). Outcrop of silicified siltstone containing wollastonite (Wo), and (D). Photomicrograph of wollastonite (Wo)-enriched siltstone

Table 1: Geochemical data using XRF of meta-limestone as a host of ore mineralization and of young intrusion (micro-diorite and rhyolite)

Elements (wt.%)	GS01 Diorite	PK01 Rhyolite	GP01 Limestone	RW01 Limestone
SiO_2	54.80	74.92	8.77	16.04
TiO_2	1.11	0.23	0.13	0.11
Al_2O_3	17.12	13.42	2.30	1.56
FeO	7.78	1.08	1.20	2.56
MnO	0.15	0.03	0.06	0.50
MgO	6.03	0.57	1.46	1.50
CaO	3.92	0.72	50.42	51.04
Na_2O	2.90	4.57	0.78	0.00
K_2O	2.67	3.16	0.32	0.22
P_2O_5	0.35	0.08	0.03	0.03
H_2O	2.94	0.91	34.40	26.33
S	0.03	0.13	0.01	0.02
Total	99.80	99.82	99.88	99.91
ppm				
V	196	4	11	0
W	49	16	18	29
Rb	83	101	16	19
Sr	640	286	864	471
Ba	632	885	121	0
Y	32	18	11	12
Zr	181	144	25	31
Nb	9	14	2	3

represented by a negative crystal, tabular or prismatic forms, isolated, and mostly take place near the crystal growth zone. The secondary fluid inclusions are mostly placed on along micro fractures during their trapping.

Microthermometric analysis indicates that temperatures of homogenization (Th) of fluid inclusions in quartz+ore samples vary from 250 to 266 °C (moderate), temperature of melting (Tm) of -0.2 to -0.3 °C corresponding to salinity of 0.3 to 0.5 wt.% NaCl eq. Fluid inclusions in calcite sample reveals Th of 190–220 °C, Tm of -0.2 °C and averaging salinity of 0.35 wt.% NaCl eq. Fluid inclusions in barren quartz show Th of 180 °C, Tm of -0.8 °C and salinity of 1.42 wt.% NaCl eq. The temperature of homogenization is interpreted to be temperature of trapping and it doesn't need to be corrected. In general, the temperature and salinity of hydrothermal fluid are relatively low, and this may represent the physicochemical condition of hydrothermal fluid during the retrograde alteration of the Ruwai skarn deposit.

5 Discussion

5.1 Geological controls on the deposit formation

Two important geological aspects which control the formation of the Ruwai skarn deposit include lithology and geological structures. The Ruwai skarn deposit is originated by metasomatism process of calcareous wallrocks (limestone and siltstone/marl). Monzonite is interpreted to be mineralization-bearing intrusion in the area. Monzonite also acted as host of endoskarn mineralization, whereas limestone and siltstone/marl were the host of exoskarn mineralization. A NNE–SSW-trending strike-slip and N 70° E-trending thrust faults are interpreted to be pathway for the localization of the Pb-Zn-Cu-Ag skarn deposit. The Karim and Gojo Fe skarn deposits were also developed along the structures. Some minor N–E trending strike-slip faults formed during post-mineralization crosscutting the ore body and taking part to shape the current geometry of the deposit.

5.2 Mineral paragenesis

Generally, mineral paragenesis in the Ruwai skarn deposit is grouped into two stages i.e. prograde and retrograde as shown by Figure 7. Prograde stage formed at the temperature of more than 300 °C represented by garnet (andradite), clino-pyroxene (wollastonite), quartz, pyrite, chalcopyrite and possibly magnetite which occurred in both monzonite and wallrocks (limestone and siltstone). Garnet is typically characterized by keliphytic (coronas) structure, which is produced by a rim reaction of garnet crystals during postmagmatic stage/hydrothermal exsolution (cf. Williams *et al.*, 1982). Retrograde stage is typified by epidote, chlorite, quartz, calcite and sericite as well as pyrite, chalcopyrite, galena, sphalerite, hematite, acanthite and argentite. Pyrite and chalcopyrite possibly originated at the early retrograde stage, followed by galena, sphalerite and Ag-bearing sulfides, respectively. Ore mineralization occurred during the retrograde stage is common in the skarn deposit, for instance, Ertsberg (Meinert *et al.*, 1997) and Batu

Hijau (Idrus *et al.*, 2009). Quartz and pyrite are stable in a broad P-T condition, therefore, they are identified in both prograde and retrograde stages.

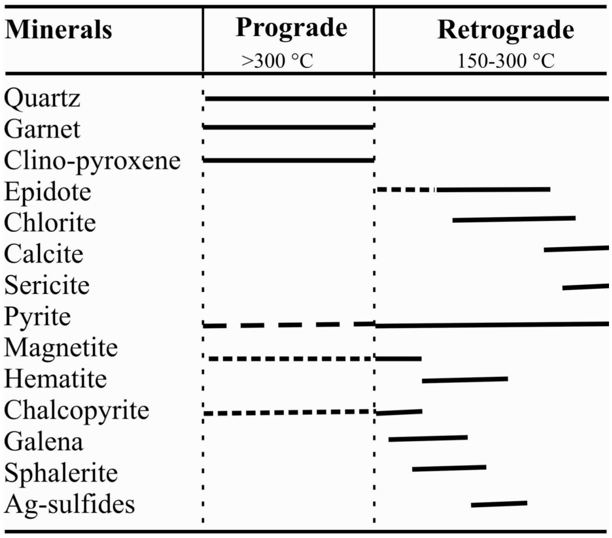

Figure 7: Mineral paragenesis in the Ruwai skarn deposit

5.3 Physicochemical conditions of ore formation

Physicochemical conditions consisting of temperature, pressure, salinity and depth of the ore formation is interpreted on the basis of fluid inclusion analysis in quartz and calcite vein samples. Ore mineralization is associated with quartz vein, hence, the fluid inclusion data represents ore formation at the early retrograde stage, whereas calcite vein is interpreted to form at the late retrograde stage. As a result, the Ruwai skarn ore deposit formed at a moderate temperature range of 250–266 °C with a relatively low salinity of 0.3–0.5 wt.% NaCl eq. The skarn mineralization and alteration is culminated at a low temperature and salinity of 190–220 °C and 0.35 wt.% NaCl eq., respectively during the late retrograde stage. The formation temperature and salinity are relatively lower in comparison to those of the Batu Hijau porphyry-related skarn, which formed at temperature of 340–360 °C and salinity of 35–45 wt.% NaCl eq. (early retrograde stage) as well as temperature of 280–300 °C and salinity of 1–10 wt.% NaCl eq (late retrograde stage) (Idrus *et al.*, 2009). On the basis of the temperature and salinity, it is interpreted that Ruwai skarn deposit originated at 'hydrostatic' pressure (P) of 0.05 kbar, corresponding to paleodepth of 0.5 km (cf. Hedenquist *et al.*, 1998).

5.4 Recommendation for exploration

On the basis of geological field data, the development exploration of the Ruwai skarn mine is directed to southwest (N 250 °E) and northeast (N 70 °E), parallel to lithological contact between sedimentary and volcanic rocks. Moreover, the extension and geometry of ore body to south and north is still open. Therefore, exploration program including detailed geological mapping, geophysics and drilling are proposed. Geophysical exploration e.g. IP (Induced Polarization) and geomagnetic survey could be applied. In addition, lithological distribution and mineralogical characteristics including calc-silicate alteration and ore mineralogy could be a controlling factor in directing exploration activities particularly geological mapping and drilling.

Ruwai skarn tends to be categorized into exoskarn type rather than endoskarn, although few endoskarn indications were recognized in the field. Ore mineralization and calc-silicate alteration are associated with meta-limestone and siltstone (marl?). The understanding and recognizing of diagnostic minerals of calc-silicate alteration particularly garnet (light brown, commonly crystalline), clino-pyroxene (light green, fine-grained crystals) and epidote (yellowish green, fine-medium grained crystals) are crucial during exploration in the field. Ore-bearing sulfides (sphalerite, galena, chalcopyrite and Ag-sulfides) are intimately related to the calc-silicate occurrences.

Rock-geochemical data including ore chemistry is useful to interpret the trend of Pb, Zn, Cu and Ag grades upon alteration and mineralization zone in the field. The ore chemical data could also be used for isograde mapping and ore body modeling. Fluid inclusion data (T, P, depth, salinity) are mostly applied for 'reconstruction' of genetic model of ore deposit in term of physical and chemical properties of hydrothermal fluids responsible for the formation of the Ruwai skarn deposit.

6 Conclusions

1. Geological aspects which predominantly controlled the formation of the Ruwai Pb-Zn-Cu-Ag skarn deposit consist of lithological type (limestone and siltstone/marl) and the presence of structural elements i.e. NNE–SSW-trending strike-slip fault and N 70 E-trending thrust fault, which also acts as lithological contact between sedimentary rock and volcanic rock. The economic ore body is mostly localized along the thrust fault zone and associated with calc-silicate-altered wallrocks consisting of siltstone (marl?) and limestone, thus, the ore deposit is categorized into calcic-exoskarn type. However, some evidences for the presence of minor endoskarn hosted by the causative monzonite intrusion have also been recognized in the field.
2. On the basis of mineral paragenesis, the Ruwai skarn deposit is genetically grouped into 2 mineral assemblages, which consist of prograde-related mineral assemblages (high temperature), and retrograde-related mineral assemblages (low temperature). Prograde-related mineral assemblages are typically characterized by the presence of andraditic garnet (Ca-Fe-rich type) and clino-pyroxene (wollastonite), whereas retrograde-related mineral assemblages are represented by epidote, chlorite, calcite and sericite which formed during the decrease of temperature. Ore minerals typified by sphalerite, galena, chalcopyrite and Ag-bearing sulfides (acanthite and argentite) may be formed during early retrograde stage. Chalcopyrite was precipitated in the first occasion, followed by galena, sphalerite and Ag-bearing sulfides, consecutively. Pyrite is interpreted to be formed from early to late retrograde stage of the skarn formation.
3. Silicification and decarbonazation of wallrocks particularly limestone has caused an increase of SiO_2 content (˜12.41 wt.%) and a decrease of CaO content (˜50.73 wt.%) of the rock, respectively. The elemental concentration change in limestone reveals the presence of calc-silicate minerals particularly garnet and clino-pyroxene replacing calcite. In addition, the alteration processes may also decrease the volume (volume-loss) of the rock.
4. Microthermometric fluid inclusion data indicate that the Ruwai skarn ore body originated at a moderate temperature of 250-266 °C and a relatively low salinity of 0.3-0.5 wt.% NaCl eq., which corresponds with a hyrostatic presssure of 0.05 kbar and depth of 0.5 km below of paleosurface. The moderate temperature of formation coincides with petrographic/ore microscopic data suggesting the ore body formation during the early retrograde stage. The origin of Ruwai skarn deposit is culminated at low temperature and salinity of 190–220 °C and 0.35 wt.% NaCl eq., respectively during the late retrograde stage. The relatively low temperature and salinity of hydrothermal fluid as shown by fluid inclusion data and the presence of sericite in altered wall rocks may imply a significant contribution of meteoric water in the Ruwai ore body formation during the retrograde stage.

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