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Dairi Zn-Pb±Ag Deposit, North Sumatra, Indonesia: Preliminary Study on Host Rock Petrology and Ore Mineralogy

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Abstract
Dairi Zn-Pb±Ag deposit is outlined along the eastern limb of the Sopokomil dome. As an initial step in a comprehensive study of the deposit, characterization of host rocks and orebodies is necessary. Hand-specimen and petrographic observations reveal that the orebodies are hosted by siltstone-shale and dolostone sequences termed as Julu and Jehe units, respectively. In Julu unit, the orebodies are concordant and comprise massive, layering, and breccia ores. Conversely, the orebodies in Jehe unit are discordant and consist of vein, breccia, and disseminated ores. Within these orebodies, ore minerals comprise sphalerite, galena, chalcopyrite, arsenopyrite, pyrite, pyrrhotite, tetrahedrite, tennantite, freieslebenite, bournonite, unnamed Ag-Sb-S and Pb-Sb-S minerals associated with coarse-grained quartz and dolomite. Textural characteristics suggest that the ore mineral precipitation is likely to occur in early diagenetic and epigenetic stages with reference to the host rocks in Julu and Jehe units, respectively. The orebodies are then deformed along with the host rocks. It is postulated that the discordant and concordant orebodies have formed from the same mineralizing fluid. Stable isotope, mineral phase relations, and geochronology are essential to confirm this interpretation.

1. Introduction

Dairi Zn-Pb±Ag deposit is located in Dairi Regency, North Sumatra, Indonesia, approximately of 290 km to the southwest of Medan City. This deposit lies on the Sibumasu Block portion of Sumatra originating from Australia. The block was separated from Australia in Permo-Carboniferous and subsequently drifted toward Cathaysia Block and collided with East Malaya Block. The West Sumatra Block slid along Medial Sumatra Tectonic Zone to be emplaced toward the west of the Sibumasu Block in Triassic. Closing of Meso-Tethys Ocean led to the collision of these amalgamated blocks with the Woyla Arc in Cretaceous.[1] During its tectonic evolution, the Sibumasu Block has undergone extensional and compressional settings since its separation from Australia.

The deposit is hosted within a basal formation of Sumatra so-called the Kluet Formation. This formation consists of slates, metawackes, phyllites, metaquartzose arenite, and metalimestones[2],[3] representing seaward sedimentary deposits during the separation from Australia.[1] The area in which Dairi Zn-Pb±Ag deposit is located was deformed to form the Sopokomil dome. From bottom to top, the stratigraphy comprises dolostone (Jehe unit), interbedded siltstones and shales (Julu unit), and interbedded siltstones and sandstones with minor shales (Dagang unit). The deposit is hosted in the eastern flank of the dome within Julu unit and Jehe unit and divided into 4 prospects from SE to NW: Anjing Hitam, Basecamp, Lae Jehe, and Bongkaras (Fig. 1).

To the best knowledge of the authors, this deposit is the only sediment-hosted Zn-Pb deposit that has been discovered in Sumatra. It formed in Paleozoic age syn-genetically with the host sedimentary formation.[4] Therefore, a thorough research is essential to elucidate the nature of the deposit which can be further used to guide exploration in the Island. In this paper, we would like to present our latest petrological and mineralogical results and interpretation on Dairi Zn-Pb±Ag deposit as the initial stage of this research.

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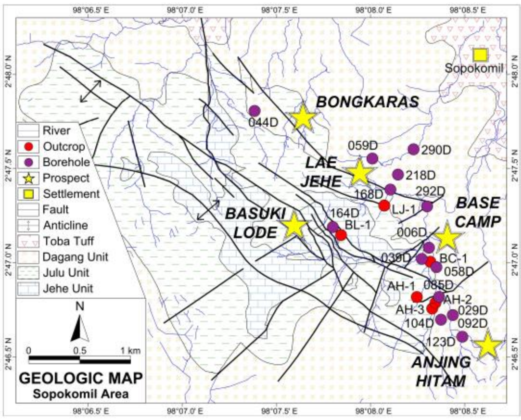


Figure 1. Geologic map and sample distribution in Dairi Zn-Pb±Ag deposit.

2. Materials and Methods

Samples used in this preliminary research were selected from 14 drillholes distributed in Dairi Zn-Pb±Ag deposit (Fig. 1). More than 130 polished sections and 25 doubly polished thin sections were analyzed under Polarizing Microscope ECLIPSE E600POL. Of this number, chemical composition of sulfosalts from 13 polished sections were then determined by SEM-EDS. In addition, XRD analysis was also performed to examine carbonate minerals in 17 samples.

3. Results

3.1. Host Rocks

The sedimentary sequence in the Sopokomil dome downward stratigraphy consists of an interbedded dolomitic siltstones and sandstones with minor carbonaceous shales (Dagang unit), an interbedded dolomitic siltstones and carbonaceous shales as well as pyritic, dolomitic, carbonaceous shales (Julu unit), and arenaceous massive and breccia dolostones (Jehe unit). This sequence order occurs in all prospects except Lae Jehe which shows the repetition of Dagang unit below Julu unit.

3.2. Orebodies and Ore types

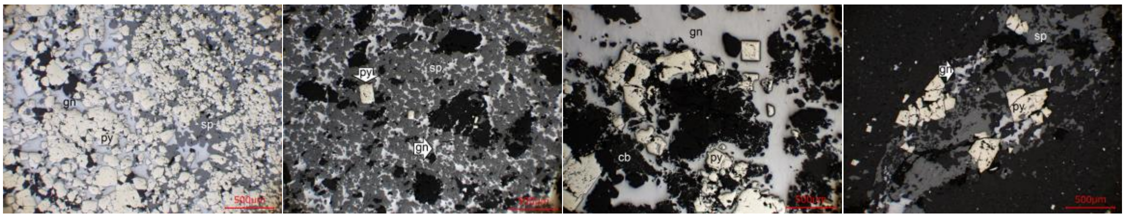
In Anjing Hitam and Bongkaras, the orebodies are hosted by Julu unit while in Lae Jehe and Basecamp, the orebodies are present within Julu and Jehe units. The orebodies hosted in Julu unit are concordant, multi-layers, and strata-bound with thickness of up to 30 m. In contrast, those are hosted in Jehe unit are discordant although they are strata-bound and multilayers in deposit-scale with the maximum thickness of 15 m. In terms of ore types, the Julu-hosted orebodies comprise pyritic massive sulfide (PyMs), sphalerite-rich massive sulfide (SpMs), galena-rich breccia (GnBx), sulfide layer (SL), and vein (V-Ju; Fig. 2). On the other hand, the Jehe-hosted orebodies consist of vein (V-Je), breccia (Bx), and disseminated (Ds; Fig. 3).

PyMs is predominated by euhedral pyrite with sphalerite-galena intergrowth filling its interstices. Fine-grained pyrite was disaggregated from larger pyrite grains in which densely interconnected quartz veinlets occur. Toward northwest, quartz-dolomite fillings in pyrite interstices tend to be more abundant. Overgrowth texture of two pyrite generations also exists. Galena and sphalerite replaced pyrite of the first generation. Additionally, pyrrhotite is present and forms intergrowth with sphalerite and galena as well as pyrite. This intergrowth is ubiquitous in the deep portion of Lae Jehe.

SpMs is predominated by the sphalerite-galena intergrowth. Pyrite and chalcopyrite occur in minor amount. Toward northwest, pyrrhotite is more abundant and intergrown by sphalerite and galena. The intergrowth abundance decreases as the incorporated rock fragments and lenses increase. In some portions, sphalerite aligns parallel to the sedimentary bedding. The alignment was disrupted by small-scale faults filled by quartz veins containing the sphalerite-galena intergrowth.

GnBx is characterized as an ore which irregular rock fragments are cemented by galena. Pyrite is euhedral with size is up to 3 mm. Galena chadacrysts is abundant within pyrite. Pyrite was intensely fractured and disaggregated. The fractures were healed by chalcopyrite, bournonite, tetrahedrite, galena, sphalerite, quartz, and dolomite. Additionally, as fracture healing minerals, chalcopyrite, bournonite, and tetrahedrite appears to exist in the innermost portion followed by galena, sphalerite, quartz, and dolomite.

SL is defined as an ore with mm-thick sulfide-rich layers intercalated by shale and siltstone layers. SL consists of two subtypes: sphalerite-galena-rich SL and pyrite-rich SL. In the first subtype, the sulfide-rich layers are predominated by the sphalerite-galena intergrowth while coarse-grained, euhedral pyrite is predominant in the second subtype. Toward northwest, pyrite is intergrown by pyrrhotite. Together with other sulfides, this intergrowth was cut by late quartz veinlets. In addition, folded and piercing ore layers were observed and abundant in Basecamp, Lae Jehe, and Bongkaras.



(a) (b) (c) (d)

Figure 2. Representative photomicrographs of (a) pyritic massive, (b) sphalerite-rich massive, (c) galena-rich breccia, and (d) sulfide layer ores.

V-Ju cut the host rocks and the orebodies in Julu unit. Galena and sphalerite is predominant. Fine-grained, euhedral pyrite is embedded on sphalerite while coarse-grained, corroded pyrite is present in galena-rich portion vein. Sphalerite hosts chalcopyrite disease. In Lae Jehe, pyrrhotite also exists in this ore type.

A crosscutting relationship between a 10-cm-thick vein and PyMs-SpMs in Julu unit was observed in Lae Jehe. Toward the vein, ore mineralogy is zoned according to mineral abundance and morphology. In the periphery, PyMs hosts chalcopyrite-bearing sphalerite. The amount of pyrite gradually decreases in the transition to SpMs. In SpMs, the chalcopyrite disease in sphalerite intensifies along with the initial appearance of pyrrhotite blebs. The pyrrhotite blebs become more abundant toward the vein. As the blebs form aggregate, pyrite embedded on sphalerite was replaced by pyrrhotite and started flowing. Pyrite is intergrown by pyrrhotite and sphalerite as well as Ag-Pb-Cu sulfosalts. In the vein edge, galena is predominant while the center of the vein is barren.

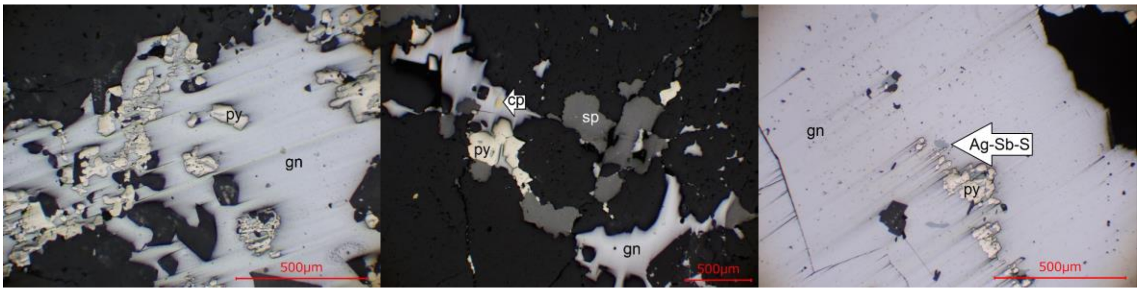
V-Je in Lae Jehe has similar ore mineralogy to V-Ju. In Basecamp, minor to abundant tetrahedrite, tennantite, arsenopyrite, and chalcopyrite coexist with sphalerite, galena, and pyrite. Locally, tennantite and tetrahedrite size can be up to 3 mm. In Bx ore, the sphalerite-galena intergrowth with minor chalcopyrite and pyrite occurs within quartz cementing arenaceous dolostones.

Different to other ores in Jehe unit, Ds in Lae Jehe does not contain galena. Sphalerite, chalcopyrite, and pyrite are present in the ore. In contrast, galena is abundant in Ds of Basecamp. Chalcopyrite, freieslebenite, Ag-Sb-S, and Pb-Sb-S minerals form intergrowth with galena.

4. Discussion

4.1. Sedimentary Basin

Evolution of Zn-Pb±Ag deposit-hosting sedimentary basins can be divided into rift-fill and sag-phase sequences.[5] The rift-fill consists of coarse-grained continental clastic sediments (e.g. conglomerates, red beds, sandstones, and turbidites) while the sag-phase comprises carbonate and fine-grained clastic rocks (e.g. shales and siltstones). The deposits are hosted by the sag-phase sequence whose 3-10% total organic carbon contents.[6],[7] In Dairi Zn-Pb±Ag deposit, the concordant ores are hosted by the interbedded dolomitic siltstones and carbonaceous shales as well as pyritic, dolomitic, carbonaceous shales of Julu Unit. The host rocks suggest that the deposit formed during the sag-phase of the basin in high organic carbon environment.



(a) (b) (c)

Figure 3. Representative photomicrographs of (a) vein, (b) breccia, and (c) disseminated ores.

The presence of the sag-phase sequence also plays an important role in generating metalliferous brines in the rift-fill sequence.[6] The trapped formational brines in the deep aquifer strata are compacted by the relatively impermeable overlying sag-phase strata resulting in heated brines[8] which convectively flow within the aquifer.[9],[10] During the free convection flow, metals are leached out and the brines become metal-rich. An extensional deformation resulting in deep-penetrating, syn-sedimentary faults provides permeable fluid conduits which enable the metalliferous brines to ascend to the near seafloor environments.[11] Dagang unit underlying Julu unit in Lae Jehe and Dang Takkas unit inferred in the deeper portion of the basin hosting Dairi Zn-Pb±Ag deposit are potential aquifer units in which the metalliferous brines could be produced.

The fertility of sedimentary basin that hosts Dairi Zn-Pb±Ag deposit is also supported by regional dolomitization. This feature is recorded as extensive dolostone distribution in Jehe unit and dolomitic composition of sedimentary rocks in Julu unit. The regional dolomitization is a robust event for generating a higher transmissivity carbonate rocks (Large et al., 2002). Consequently, the ascending metalliferous brines could flow laterally in limited distance from the fluid conduits resulting in ore mineral precipitation within Jehe unit. In the overlying Julu unit, the brines flowed vertically through the syn-sedimantary faults. As the brine encountered unconsolidated sediment in the near seafloor environment, the brines flowed laterally resulting in the concordant ores.

4.2. Ore Paragenesis

In the concordant ores, the strata-bound morphology of the orebodies is an indicative of either hydrothermal fluid exhalation or sub-seafloor precipitation. The multilayer nature of the orebodies suggests multiple pulses of the metalliferous brines have reached the near seafloor environment. The sulfide precipitation was initiated by framboids. This early stage was then followed by the main stage of subhedral and euhedral pyrite as well as anhedral sphalerite, galena, chalcopyrite, pyrrhotite, tetrahedrite, and bournonite. Quartz and dolomite were also precipitated along with the main stage sulfides. In this stage, pyrite was precipitated slightly earlier than other sulfides and gangue minerals. Considering that the early stage is minor, textural characteristics suggest that the ore mineral precipitation occurred in sub-seafloor during early diagenetic stage is more predominant in Dairi Zn-Pb±Ag deposit.

In the discordant ores, the occurrence of Bx and V-Je ores indicate the escape of metalliferous brines and open-space fillings. Ds ore around veins and breccia occurs in high permeability portions of dolostones. Sulfide paragenesis in these ores is similar to that in the concordant ores with an exception that the early stage is absent in the discordant ores.

Euhedral pyrite was slightly earlier precipitated than galena, sphalerite, chalcopyrite, pyrrhotite, arsenopyrite, tetrahedrite, tennantite, freieslebenite, Ag-Sb-S, and Pb-Sb-S minerals.

It is postulated that the discordant ores acted as a feeder zone for the overlying concordant ores. Ag-sulfosalts and Pb-sulfosalts were mainly precipitated in the feeder zone. Above the feeder zone, massive ore commonly occurs and evolve to layer ore in distal.[5],[6] Stable isotope study, mineral phase relations, and geochronology are essential to prove this postulate.

As the Sibumasu block has experienced multiple compressional events[1], syn-diagenetic Dairi Zn-Pb±Ag deposit has undergone polyphase deformation and metamorphism.[12] The tilted layers of concordant ores are considered as a mega-scale indication. In hand-specimen and microscopic scales, the orebodies also record the deformation.

In hand-specimen scale, the deformation is indicated by the folded ore layers, their sulfide segregation, and pyrrhotite piercing veins. Pyrrhotite was concentrated in fold hinges and piercing veins as well as sphalerite-galena was concentrated in fold limbs suggesting that the sulfide remobilization occurred in ductile condition. An indicative of hand-specimen scale deformation and the sulfide remobilization are also present in the disrupted mineralized beds and offset fractures filled by the sphalerite-galena intergrowth.

In metamorphic environments, pyrite tends to recrystallize to form exceptionally coarse-grained, euhedral grains.[13] This recrystallization is also supported by the presence of rounded galena matrix inclusions in pyrite. Fractures formed resulting from the brittle behavior of pyrite. Additionally, pyrite can be rotated and disaggregated under low-grade metamorphic environment.[14] These pyrite characteristics could be observed in Dairi Zn-Pb±Ag deposit as an indicative of deformation documented in microscopic scale.

Another indication is the fracture-filling minerals of pyrite. Pyrite fractures in Dairi Zn-Pb±Ag deposit were filled by galena, sphalerite, chalcopyrite, bournonite, quartz, and dolomite. These soft sulfides can be remobilized into pyrite fractures. The order of fracture filling is in accordance with the readiness of soft sulfides to flow.[15] In addition, the presence of chalcopyrite as the fracture-filling mineral indicates that the remobilization occurred in fluid-state condition[14], although solid-state remobilization for galena could not be ruled out in local scale.[16]

5. Conclusions

Sedimentary basin hosting Dairi Zn-Pb±Ag deposit is filled by sag-phase rocks which are rich in organic carbon and have undergone regional dolomitization. The ore formation is predominated by precipitation during early diagenetic stage in sub-seafloor environment. The discordant ores in Jehe Unit and the concordant ores in Julu Unit may have been precipitated from the same mineralizing fluid. In addition, the ores have been deformed and remobilized in mega-, hand-specimen, and microscopic scales.

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