

Characteristics and Provenance of the Dairi SEDEX Zn-Pb-Ag Deposit, Northern Sumatra, Indonesia

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論文題名 : Characteristics and Provenance of the Dairi SEDEX Zn-Pb-Ag Deposit, Northern Sumatra, Indonesia (インドネシア・スマトラ島北部のDairi SEDEX亜鉛-鉛-銀鉱床の特徴と起源)

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論 文 内 容 の 要 旨

The Dairi Zn-Pb-Ag deposit is located approximately 290 km to the southwest of Medan city, North Sumatra, Indonesia. The discovery of a massive sulfide outcrop hosted by Lower Carboniferous sedimentary rocks in the Lae Sopokomil creek, Dairi, has marked a milestone in the history of metal exploration in Sumatra; further exploration works suggest that mineralization style in Dairi accords with features of SEDEX (Sedimentary Exhalative)-type deposits, considered as a novel deposit type among mineral resources in the island. The giant metal resource in Dairi (25 Mt ore at 10.2 wt% Zn, 6.0 wt% Pb and 8.4 g/t Ag) has revealed a new metallogenic potential of Sumatra, therefore, underlining the importance and significance of a thorough investigation regarding its characteristics and provenance. The results of investigation on the Dairi Zn-Pb-Ag deposit are documented in a 6-chapter dissertation.

Chapter I introduces background, objectives and structure of the dissertation.

Chapter II reviews geologic background of the Dairi Zn-Pb-Ag deposit. The Dairi Zn-Pb-Ag deposit is hosted by the Lower Carboniferous Kluet-Kuantan Formation constituting the basement of the West Sumatra Block, and having an Indochina (Cathaysia) affinity. In a local scale, rocks in the vicinity of the Dairi Zn-Pb-Ag deposit, from top downward, are divided into the Dagang (interbedded dolomitic sandstones and siltstones), the Julu (interbedded dolomitic siltstones and carbonaceous shales) and the Jehe (massive and brecciated dolostones) units representing a sag-phase sequence. These rock units have undergone sub-greenschist facies metamorphism.

Chapter III focuses on petrographic features and geochemistry of the host rocks in Dairi. The Dagang and the Julu units are compositionally dominated by quartz, dolomite, muscovite and organic matter, with trace amounts of zircon, pyrite, sphalerite and rutile whilst the Jehe unit is dominated by dolomite. SEDEX Alteration Index (AI) and SEDEX Alteration Index based on the presence of hyalophane (AI-hp) systematically increase from the Dagang unit (SEDEX AI = 43-53, SEDEX AI-hp = 7-11) through the Julu unit (SEDEX AI = 51-75, SEDEX AI-hp = 9-73) to orebodies (SEDEX AI = 62-99, SEDEX AI-hp = 54-99) suggesting that geochemical halos around the orebodies are controlled by the presence of ankerite and hyalophane.

Chapter IV explains orebodies in Dairi, which are hosted by the Julu and the Jehe units. The orebodies hosted by the Julu unit are concordant to their sedimentary host unit, stratiform and multilayers consisting of the lower horizon (LH), the main horizon (MH) and the upper horizon (UH) whilst those hosted by the Jehe unit are discordant with respect to dolostones and stratabound at hand-specimen and deposit scales, respectively. Principal ore minerals are sphalerite and galena with trace tetrahedrite, bournonite and chalcopyrite in the orebodies hosted by the Julu unit, and with more abundant tetrahedrite and chalcopyrite as well as trace tennantite, arsenopyrite, pyrargyrite, acanthite, freieslebenite, boulangerite and diaphorite in the orebodies hosted by the Jehe unit. Iron

sulfides are dominated by diagenetic, hydrothermal and metamorphic pyrite, except in LH where pyrrhotite is abundant. Gangue minerals include quartz, dolomite and minor hyalophane; trace barite and calcite are locally present. These minerals occur in pyrite-rich massive ore, sphalerite-rich massive ore, bedded sulfide ore, galena-rich breccia ore and vein ore types within the orebodies hosted by the Julu unit whilst the orebodies hosted by the Jehe unit are divided into vein ore and disseminated ore types. Ore minerals in Dairi were precipitated in diagenetic, hydrothermal and metamorphic stages. The diagenetic stage was marked by precipitation of diagenetic pyrite in top few centimeters of sub-seafloor unconsolidated sediments. Hydrothermal pyrite, sphalerite, galena, tetrahedrite, bournonite, chalcopyrite and pyrrhotite were precipitated on the seafloor during the hydrothermal stage. Hydrothermal pyrite, sphalerite, galena, tetrahedrite, tennantite, chalcopyrite, arsenopyrite, pyrargyrite, acanthite, freieslebenite, boulangerite and diaphorite were precipitated in open spaces and reactive dolostones in the Jehe unit – conceptually understood as feeder zones to the stratiform orebodies. The metamorphic stage was characterized by pyrite transformation to pyrrhotite during its prograde sub-stage whilst metamorphic pyrite formed from pyrrhotite during its retrograde sub-stage. The latter was accompanied with microscopic-scale brittle deformation of pyrite and remobilization of soft sulfides into fractures in pyrite.

Chapter V discusses characteristics of the ore-forming fluid responsible for the formation of the Dairi Zn-Pb-Ag deposit. Fluid inclusions in the orebodies hosted by the Julu and the Jehe units were homogenized at 109.8°-349.5°C and 116.8°-195.2°C, respectively. The wide range of temperature recorded in the Julu units may have resulted from fluid inclusion stretching due to post-mineral metamorphism. On the other hand, the narrower temperature range in the Jehe unit is likely to reflect unmodified homogenization temperatures. Fluid inclusion salinity indicates a saline ore-forming fluid (18-25 wt% NaCl eq.) capable to leach metals from the rift-fill rocks, and to transport them as metal-chlorides to the depositional sites. Mixing with descending, less saline seawater – resulted in a less saline fluid (3-7 NaCl wt% eq.) – led to precipitation of metal sulfides and sulfosalts in the open spaces in dolostones. Acidity generated from the in-fracture metal precipitation dissolved reactive dolostones that extended mineralization to the wall rock, and released CO₂ to the remaining fluid. After being discharged to the seafloor, the ore-forming fluid dispersed (from SE to NW) at the bottom of seawater column due to its high density (1.02-1.09 g/mL). Mixing with a vast amount of seawater resulted in the formation of ore mass on the seafloor.

The rift-fill sequence of the Dairi basin is inferred to consist of similar rocks to the host rocks of the Dairi deposit. The dominance of reduced rocks in the rift-fill sequence – consisting of micas, clays and diagenetic pyrite – buffered the ore-forming fluid to reduced and acidic conditions. The coexisting pyrite-pyrrhotite assemblage in the absence of hematite and magnetite reinforces the reduced nature of the ore-forming fluid ($m\text{H}_2\text{S} > m\text{SO}_4^{2-}$). The reduced condition is also implied by sulfur isotope ratios of sulfides from the orebodies hosted by the Jehe unit ($\delta^{34}\text{S} = +5.0 \pm 1.2\text{‰}$), distinct from and narrower than those from the orebodies hosted by LH ($\delta^{34}\text{S} = +11.5 \pm 4.1\text{‰}$), MH ($\delta^{34}\text{S} = +23.7 \pm 3.5\text{‰}$) and UH ($\delta^{34}\text{S} = +22.0 \pm 2.7\text{‰}$). Higher $\delta^{34}\text{S}$ of sulfides in the orebodies hosted by the Julu unit signifies basin isolated from open ocean and anoxia development in the Dairi basin. Although hydrothermal sulfur is dominant in the feeder zones, bacterially reduced sulfur (BRS) in the orebodies hosted by the Julu unit contributes to >90% of metal resource in Dairi; hence, BRS is essential to the formation of the giant Dairi SEDEX Zn-Pb-Ag deposit.

Chapter VI presents conclusions of this study, emphasizing on descriptive aspects of (1) host rocks and geochemical halos, (2) orebodies, (3) and ore-forming fluid. A genetic model is provided as one of the conclusions formulated from these descriptive aspects. Recommendations for future works in Dairi are also included in this final chapter.