学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Ore genesis and Environmental study of Pinpet Iron Deposit, southern Shan State, Myanmar.
(ミャンマーシャン州南部ピンペット鉄鉱床における鉱床形成と環境影響に関する研究)

Myanmar has great potential in a variety of metal and mineral resources, many of which have been poorly explored. The Pinpet deposit is the second-largest iron (Fe) deposit in Myanmar, located in the Shan Plateau, the eastern part of Myanmar. The probable ore reserve is estimated to be 10 million tons of hematite ore and 70 million tons of limonite ore, in which pilot-scale open-cut mining and beneficiation processes for low-grade ores began in 2003. However, the mine operations have been suspended since 2017, in part because of the possible contamination of heavy metals and hazardous elements into the surrounding aquatic environment and associated public concern. Despite the concerns, a scientific investigation of the source and degree of contamination in the streams near the deposit has not yet been conducted. Ore genesis in the Pinpet Fe deposit is not well understood, which also makes it difficult to assess the environmental risk because some Fe ore deposit types may contain a significant concentration of hazardous elements, such as arsenic (As) and uranium (U). Therefore, objectives of the dissertation are to reveal the ore-forming processes based on geological survey and mineralogical and geochemical analyses of ores and host rocks and to understand the environmental impact by Pinpet Fe mine's activities on the surface water qualities by quantifying heavy-metal and hazardous-elements concentrations of surface water and sediments in stream beds.

Chapter 1 provides the general background on Pinpet Fe deposit and its mining activities based on literature reviews, as well as the objectives of the dissertation. Chapter 2 focuses on the detailed geological mapping of the Pinpet deposit and the surrounding area. Based on the literature review, the study area is hosted by a lower Palaeozoic rock sequence (Silurian limestones), which is bounded by the NE-SW trend of major localized faults that trends parallel to regional faults (Kyaukkyan and Htam Sang faults). The other minor cross faults (WNW-ESE trending) are also found in the middle part of the ore zone related to hematite ore zones. Field survey indicates that the well-bedded (trending 40 to 65 degree) hematite ore zone was controlled by WNW-ESE faulting while limonite ore zones showed poor bedding nature due to intensely weathered condition. Hematite outcrops were also surrounded by magnetic anomalies caused by the presence of magnetite grains. However, Fe ore zones were constrained by the country rock (limestone) with sharp contacts. Therefore, the results of field survey suggest that the Fe enrichment in the over all ore zones occurred concordantly with sedimentation processes whereas mineralization of hematite ores was likely caused by later tectonic events.

Chapter 3 focuses on the mineralogical and geochemical characteristics of Fe ores. Petrographic observation and the whole-rock geochemical analysis indicate that the ores are primarily composed of hematite, goethite, magnetite and other minerals including manganese oxides and barite.

Arsenic was the most abundant trace element, containing up to 2.1 wt. percent although the As contents were variable. Sequential extraction results indicate that most (more than 90 percent) of the As in the As-rich ores is hosted in insoluble fractions (e.g., crystalline Fe hydroxides and clays). Other trace elements such as copper (Cu), zinc (Zn), and U were not significantly enriched in the ores. Stable isotope analysis of Fe in the ores indicates the variable isotope compositions, suggesting that Fe was precipitated from hydrothermal fluid in an open system. Fluid inclusion analysis of barite indicates that a low temperature (about 160 degree Celsius) hydrothermal fluid with salinity ranging from 0.2 to 6.6 wt. percent NaCl eq. was responsible for the formation. These results may suggest the hydrothermal fluid was formed by mixing of seawater with meteoric water.

Chapter 4 focuses on the geochemical characteristics of surface waters and sediments in a stream flowing near the Pinpet deposit. The result of major dissolved element analyses shows that all the surface water samples were dominated by calcium, magnesium, and bicarbonate ions, controlled by limestone bedrock in the study area. All the dissolved trace elements, including As, Cu, Zn, and Fe are in low concentrations, below the WHO standard as well as the proposed national drinking water quality standards in Myanmar. Bulk chemical compositions of the stream sediments indicate no significant past contamination by hazardous elements. Arsenic, Zn, and Cu concentrations in the sediments are similar to those in uncontaminated sediments, although some sediments in the tailings dam were probably transported to the middle reaches of the stream. However, arsenic in these sediments is mostly bounded in insoluble fractions.

Chapter 5 concludes the ore genesis model of the Pinpet Fe ore deposit and environmental risk associated with the development of the Pinpet mine. The sedimentary nature with bedding planes observed in the hematite ores zone suggests that ores were formed during sedimentation processes. The Fe isotope data of the hematite and limonite ores suggest that Fe was precipitated by oxidative precipitation of ferrous iron from a low-temperature hydrothermal fluid in seawater. On the other hand, the spatial distribution of hematite ores and As-rich ores is along with the WNW-ESE trend, according to minor faults in the area, suggesting that mineralization of hematite ores and addition of As into the limonite ores occurred during later tectonic activities. Therefore, it is concluded that the Pinpet Fe deposit was formed as a result of multiple hydrothermal activities during both sedimentation and faulting events. Geochemical characteristics of surface waters and sediments in a stream flowing near the Pinpet deposit indicate that no significant past and present contaminations of metals into the aquatic environments. Although As contents in some ores were high, sequential extraction results indicate that most of the As in this As-rich ore is hosted in insoluble fractions, probably in the crystal structure of Fe hydroxides and clays. Therefore, As is unlikely to be released into the aquatic environment by interacting with water during future ore beneficiation processes should mining be re-established at Pinpet.