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# Editorial: Ore formation and critical metal deposits: geological contribution to the clean energy transition

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Editorial on the Research Topic
Ore formation and critical metal deposits: geological contribution to the clean energy transition

Many chalcophile (sulfur-loving) and siderophile (iron-loving) elements are defined as critical metals based on their economic importance and potential supply risks. For these metals, demand already exceeds or is expected to exceed supply. Critical metals are associated with high technology and clean energy. The most prominent example is undoubtedly the elements required for the transition to low-carbon emission technologies and the electrification of transportation. Additionally, critical metals enter the composition of superalloys and other high-tech materials for the manufacture of high-technology applications in medicine, aerospace, and telecommunications.

Humanity faces serious problems such as global warming, pollution, and poverty. Earth sciences cover a wide range of research studies to address these problems. Scientists have recently started investigating the metallogenesis of critical metal deposits and the metallurgy of related minerals, but the essential information is still lacking. Chalcophile and highly siderophile metals fractionate in magmatic and hydrothermal processes to form different types of ores. The partitioning of metals between silicate melts, minerals, and fluids is strongly dependent on intensive parameters, such as temperature, pressure, oxygen, and sulfur fugacities, and the composition of melt, fluid, and sulfide phases, all of which can change significantly during the evolution of magmatic-hydrothermal systems. As a result, partitioning behavior varies in tectonic settings, such as mid-ocean ridges, oceanic islands, subduction zones, flood basalt provinces, and continental rift zones, leading to differences in metallogenic processes and ore types. Furthering our understanding of metal speciation and partitioning behavior can provide new insights into large-scale geodynamic processes and the concentration of strategic metals at local scales. This Research Topic collects interdisciplinary papers that contribute to various aspects of these processes, including petrology, experimental petrology (Helmy et al.), mineralogy, geochemistry, ore geology, economic geology (Bertrandsson Erlandsson et al.; Boucher et al.; Robb et al.), and planetary geology (Ciazela et al.).

Platinum-group elements (PGEs) form an important group of critical raw materials. Contributions to this Research Topic related to PGEs were provided by Helmy et al., Boucher et al., and Robb et al. The major hosts of Pt and Pd in magmatic and hydrothermal Cu-Ni sulfide ores are sulfides, arsenides, antimonites, tellurides, and bismuthides. To better understand which and when Pt or Pd phases form from Ni-Cu sulfide melts doped with different amounts of semimetals (As, Te, Bi, and Sb), Helmy et al. have designed an experimental approach consisting of slow cooling from 1,100°C to room conditions of these sulfide melts and then observing and analyzing the coexisting phases at different programmed temperatures. Boucher et al. present a large volume of data on the distribution of PGEs in pyrite in the New Afton alkali porphyry Cu-Au deposits in the Canadian Cordillera complemented by extensive trace element and sulfur isotope data in pyrite. They set the stage for the companion paper by Robb et al., which addresses the geochemical controls on PGE deposition and spatial distribution in the same deposit. Robb et al. present the first comprehensive look at the distribution of Pd and Pt in a porphyry deposit with grade shells in a resource model, and are the first to present a thermodynamic model for the co-precipitation of PGEs with pyrite in hydrothermal systems.

Cobalt is another element in rapidly growing demand. New alternative sources will soon be needed to satisfy this demand. Many expectations are connected to the mining of polymetallic nodules on the seafloor. Polymetallic nodules from the Clarion-Clipperton basin alone contain three to six times more cobalt than all land-based reserves, according to the 2021 reports of the International Renewable Energy Agency and World Ocean Review. However, environmental concerns related to seabed life and technical concerns related to post-processing on the vessel still hamper these endeavors, and new land-based sources will be needed before we can start exploring the oceans. Sphalerite hosts many critical metals, including Ga, Ge, and In. Nevertheless, Co has not been found in such high concentrations as in the sediment-hosted copper-cobalt Dolostone Ore Formation deposit, Namibia, which was investigated by Bertrandsson Erlandsson et al. Hence, it is vital to understand the mode of occurrence of this cobalt and to better understand the geological processes responsible for its formation.

Space mining also requires critical metals on Earth to develop the spaceship and space habitat infrastructure that will be sent into space. More importantly, local resources of critical metals will be needed on the Moon to avoid costly transportation from Earth. Due to the high cost, importing iron and copper from the Moon will be impractical. However, their *in situ* presence for future human activities will conserve Earth's resources for climate action rather than sending them into space in large amounts for exploration and other purposes. Despite the growing interest in space mining of asteroids and planetary bodies, directly detecting sulfides and oxides from orbit has been an unexplored field as they have not been detectable from orbit with the previously developed near-infrared (NIR) spectroscopy. However, currently developed far-IR (FIR) spectroscopy may offer rich possibilities for detecting ore minerals from orbit, especially on the Moon, where interferences from atmospheric water is not an issue (Ciazela et al.).

Therefore, the contributions to this Research Topic, organized in cooperation with the Commission on Ore Mineralogy of the International Mineralogical Association, improve our understanding of ore-forming processes, metal distribution, and their role in solving global economic and environmental problems. We thank the contributors and reviewers who made this Research Topic possible.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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