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Economic Geology and Geomet for Ocean Resources: Sustainable Seafloor Metals

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The economic geology of deep-sea polymetallic nodules includes understanding ore deposit formation, characterization, and financial development in a regional geological context, just as it does for on-land deposits. Similarly, geomet models for these resources link geological understanding with process development for developing sustainable operations. It is generally appreciated that Ni, Cu, and Co deposits are of increasing importance given the projected demand curves for electric vehicles, battery energy storage, and other 21st-century technologies. While seafloor nodules have been known to be potential resources for these metals for decades, the economic geology and geomet of these deposits is less well understood because spatial metal deportment variability and processibility is not well constrained.

Seafloor polymetallic nodules from 13 sites across a 25,160-km^2 economic zone of the CCZ have been characterized for metal content, mineral deportment, and variability in terms of site-specific bathymetry, proximity to volcanic cones, fracture zones, abyssal plains, slope, relative crustal age, and nodule size classification. Micro-XRF analysis at the Cornell High Energy Synchrotron Source (CHESS) was conducted on nodules from each of the 13 sites in order to develop a better understanding of nodule mineral structure and element deportment variability. Data processing and cluster analysis reveal spatial and temporal distribution patterns within and among nodules, including hydrogenetic and diagenetic mineral species present across sequential layered growth structures (LGS). Fe-, Pb-, and potentially Co-rich hydrogenetic minerals (Fe-vernadite) follow finely laminated growth structures characteristic of turbostratically aligned phyllomanganate sheets around the exterior rims of multiple LGSs. Ni- and Cu-rich zones contain diagenetic minerals (7 À vernadite, 10 À vernadite, and todorokite) in repeated, delicate colloform accretionary growth textures radiating out from a central nucleus toward the interior of LGS zones. Todorokite is a topotactic transformation of 10 À vernadite when high levels of interlayer Mg+ cations are present. Characterizing todorokite within nodules is important because the microporous tunnels in todorokite are associated with edge-site Ni and Cu substitution for Mn3+ and Mn4+. The extent of topotactic transformation from 10 À vernadite to todorokite thus serves as a proxy for related metal distribution in a geomet framework for improved processing, since current flowsheets rely on bulk crush and metallurgy in the absence of understanding ore variability across the seafloor. Additional outcomes include parameters for environmental impact and potential remediation solutions.

These data assist in reducing some of the uncertainty surrounding deep-sea mining, which has seen a multidecadal regulatory holding period conducted by the International Seabed Authority (ISA) as designated in the UNCLOS. With finalization of the official ISA mining code set for 2024, such technical studies help to drive sustainable development of seafloor resources for the needs of society in the 21st century.