frontiers | Frontiers in Marine Science

TYPE Editorial
PUBLISHED 25 September 2025
DOI 10.3389/fmars.2025.1702761

OPEN ACCESS

EDITED AND REVIEWED BY
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RECEIVED 10 September 2025
ACCEPTED 15 September 2025
PUBLISHED 25 September 2025

CITATION
Ren J, Jiang X, González FJ and Dong Y (2025) Editorial: Biogeochemical cycling and depositional processes of critical metals in the deep sea and their constraints on global changes.
Front. Mar. Sci. 12:1702761.
doi: 10.3389/fmars.2025.1702761

Editorial: Biogeochemical cycling and depositional processes of critical metals in the deep sea and their constraints on global changes

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KEYWORDS

polymetallic ferromanganese nodules, cobalt-rich ferromanganese crusts, polymetallicsulfides, sediments, seawater, giant diatoms, black shales

Editorial on the Research Topic
Biogeochemical cycling and depositional processes of critical metals in the deep sea and their constraints on global changes

1 Introduction

Critical metals—notably cobalt (Co), nickel (Ni), and rare earth elements (REE)—demonstrate pronounced enrichment in deep-sea sedimentary environments, particularly within polymetallic ferromanganese nodules, Co-rich ferromanganese crusts, and hydrothermal polymetallic sulfide deposits. These metalliferous phases represent strategic resources essential for sustainable technologies and decarbonization economies (Jiang et al., 2023; Sakellariadou et al., 2022). The sediment–water interface functions as a critical biogeochemical reaction front governing metal fluxes between oceanic and sedimentary reservoirs (Ren et al., 2024a; Du et al., 2025). Nevertheless, metal cycling dynamics across this interface are modulated by interconnected environmental forcing: (1) productivity-driven organic matter fluxes, (2) redox oscillations, (3) bottom-current reworking, (4) volcanic-hydrothermal inputs, and (5) climatic-tectonic controls on depositional architectures.

A mechanistic understanding of critical metal transport pathways, enrichment processes in mineral phases, and post-depositional preservation states is fundamental for both elucidating deep-sea ore genesis and reconstructing paleoenvironmental proxies. Integrating metal deposition systems within biogeochemical cycling frameworks under global change scenarios involves two imperatives: advancing earth system science and enabling predictive resource exploration models.

This Research Topic (*Biogeochemical Cycling and Depositional Processes of Critical Metals: Implications for Global Change*) synthesizes 9 pioneering studies examining ferromanganese nodules, sulfide deposits, giant diatom tests, and black shales across Pacific, Indian, and South China Sea basins and the Yangtze platform continental margin (Figure 1). These findings provide novel insights into metal cycling and paleoceanographic evolution.

2 Summary of Research Topic contributions

Ren et al. investigated Co enrichment in ferromanganese crusts, identifying key controls such as diffusion flux, seawater Co concentration, and MnO_2 dilution. It innovatively integrates these factors into a quantitative model to explain Co variations with water depth, offering a framework for resource assessment. This work highlights the role of biogeochemical processes in deep-sea metal deposition.

He et al. revealed that bacterial communities and biological structures facilitate metal enrichment and mineralization, with regional variations in polymetallic ferromanganese nodule formation linked to redox conditions and productivity. Li et al. demonstrated spatial variability in nodule composition within the Clarion-Clipperton Zone, attributing differences to hydrogenetic vs. diagenetic processes driven by plate motion and Antarctic bottom water dynamics. These studies explore the biogeochemical cycling and depositional processes of critical metals in deep-sea polymetallic nodules, highlighting microbial roles and environmental controls.

Lai et al. investigated microbial driven polymetallic ferromanganese nodule formation in the South China Sea, revealing how heterogeneous marine environments influence metal deposition. An analysis of microbial communities and geochemical conditions across three regions revealed distinct nodule formation mechanisms: diagenesis in suboxic settings and hydrogenesis in oxygen-rich areas. This work highlights microbial roles in metal cycling and nodule genesis, offering novel insights into deep-sea biogeochemical processes and their global implications.

Yang et al. investigated the biogeochemical cycling and deposition of critical metals in the Duanqiao hydrothermal field on the Southwest Indian Ridge. The analysis of mineral textures, trace elements, and $^{230}Th/U$ dating reveals multistage mineralization driven by seawater-hydrothermal fluid interactions. This study identifies enrichment mechanisms for Zn, Pb, As, Ag, and Cd in pyrite, chalcopyrite, and sphalerite, advancing the understanding of metal deposition in ultraslow-spreading ridges.

Yang et al. investigated metal regeneration dynamics in polymetallic nodule areas through *ex-situ* sediment disturbance experiments, revealing synchronized metal behaviors (e.g., Li, V, Co) linked to ferromanganese oxides and sediment texture. Key innovations include quantifying short-term metal release and identifying physicochemical controls, offering critical insights for deep-sea mining ecological risks. Shen et al. explored the middle Pleistocene ventilation history in the Magellan Seamounts via magnetic coercivity, metal enrichment, and grain size, linking weakened ventilation post-430 ka to reduced Antarctic bottom water formation. This work innovatively integrates multiple proxies to disentangle eolian inputs from circulation-driven redox changes, advancing the understanding of deep-sea biogeochemical cycles and their climate connections. Both studies highlight the interplay between metal mobility, sedimentation, and global change.

Lin et al. advanced the understanding of biogeochemical cycling and deep-sea deposition by revealing that Ethmodiscus rex diatom

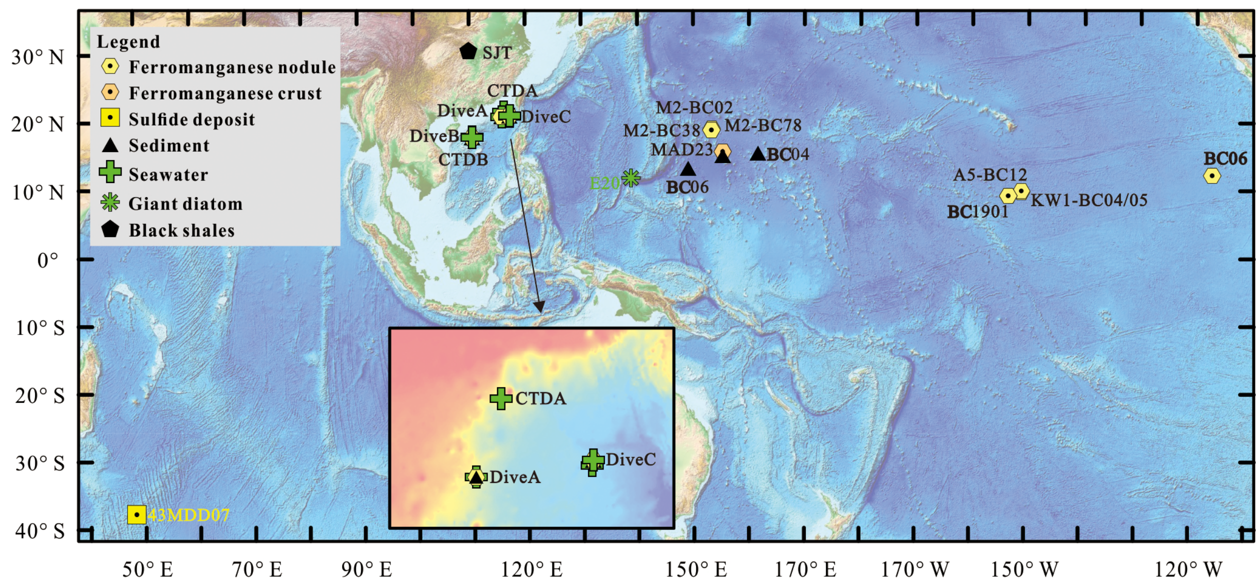

FIGURE 1
Schematic map of sample locations for the 9 studies in the Research Topic. Data sources: Ferromanganese nodules (Lai et al.; Li et al.; He et al.), ferromanganese crusts (Ren et al.), sulfide deposits (Yang et al.), sediments (Lai et al.; Shen et al.; Yang et al.), seawater (Lai et al.), giant diatoms (Lin et al.), and black shales (Wang et al.). The topography dataset available at https://www.ngdc.noaa.gov.

blooms (last glacial maximum to early Holocene) were driven by deep-water upwelling and volcanic nutrient fluxes, not solely eolian dust. Key innovations include linking diatom mat formation to intensified deep currents and topographic upwelling, highlighting the role of deep-ocean processes in carbon sequestration and global climate dynamics. Notably, the Figure 7 in the original publication contained an error, which has been addressed in a subsequent Correction notice (Lin et al.).

Wang et al. investigated the biogeochemical cycling and deposition of critical metals (V, Cr, Ni, U, Sr, Ba) in Cambrian black shales of the Shuijingtuo Formation, highlighting their enrichment mechanisms under anoxic conditions, high productivity, and hydrothermal activity. Key innovations include linking metal enrichment to organic matter affinity, redox-sensitive deposition, and submarine hydrothermal influences, providing insights into paleoenvironmental controls on metal cycling in deep-sea settings.

Author contributions

JR: Conceptualization, Funding acquisition, Visualization, Writing – original draft, Writing – review & editing. XJ: Writing – review & editing. FG: Writing – review & editing. YD: Writing – review & editing.

Funding

The author(s) declare financial support was received for the research and/or publication of this article. This work was supported by the National Natural Science Foundation of China (U2244222), the Project of the Geological Survey of China (DD20240091) and the European Union HORIZON CL4-20022-RESILIANCE-01, TRIDENT Project (101091959).

Acknowledgments

As the topic editors of this Research Topic, we would like to express our sincere gratitude to the Editors-in-Chief, especially Prof. Eric 'Pieter Achterberg, for their expert guidance and the editorial team for their invaluable support throughout the preparation of this Research Topic. We are also deeply grateful to all the reviewers for their time and effort in providing constructive feedback, which has been instrumental in enhancing the quality of the contributions. Our sincere thanks also extend to all the authors for their excellent research papers.

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 potential conflicts of interest.

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