Establishing the ferromanganese crust ocean-climate mineral system

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Project Highlights:

- Explore the highly controversial topic of deep-sea mineral deposits and their critical metals enrichment (Co, Ni, Cu, Mo, V, REE, Te, Pt)
- Research the intimate link between ore geology and the ocean-climate dynamics
- Develop advanced desirable geochemical analytical skills, including new methods in micro-XRF analysis alongside Bruker GMBH, laser-ablation ICP-MS, and machine learning application for prospectivity analysis.

Overview:

Demand for critical metals (CM) is expected to increase 4- to 10-fold by 2040, exerting enormous pressure on complex supply chains and the environment. Access to CM is a global issue and diversification a strategic priority. With terrestrial mining increasingly constrained by environmental regulations, geopolitical tensions, and social concerns, the deep ocean has become a controversial but potentially important new frontier for CM extraction.

Deep-sea mineral deposits include polymetallic nodules, seafloor massive sulphides and ferromanganese crusts (FMC). Precipitating from ambient seawater, FMC are widespread, forming pavements tens of centimetres thick on rocky seafloor in low sedimentation areas. This class of deposits is considered to host one of the world's largest combined repositories of cobalt, nickel, tellurium, rare earths and other minor metals essentials for metal-intensive societies undergoing major changes in their energetic and technologic landscape.

FMC accumulate slowly (1-5 mm/Ma), producing a fine-scale stratigraphic layering, extending as far back as 85 Ma. Their stratigraphic metal composition and isotopic signature reflect the chemistry of seawater from which they precipitated. Thus, the FMC mineral system – the set of interconnected geological processes controlling the formation and preservation of FMC – is intimately connected to the evolution of the ocean-climate system and remain poorly characterised to this date.

Defining the FMC mineral system requires access to large volumes of geochemical and stratigraphic data from numerous locations, with enough resolution to derive statistically significant relationships between environmental parameters and FMC geochemistry. Achieving a better understanding of this system would allow more accurate predictive modelling and resource potential estimation.

This project aims at exploiting new methods for fast acquisition of high-resolution compositional and isotopic data through micro-XRF and laser-ablation ICP-MS to analyse a set of historical FeMn crust and polymetallic nodule samples from the Pacific Ocean. The project's main steps can be summarised as:

- Establishment of FMC correlated stratigraphic framework through isotopic analysis and age modelling
- Characterisation of the mineral system of FMC, exploring interaction through time of paleoclimate, oceanography and FMC mineral textures and critical metal content.
- Develop and optimise machine learning approaches to prospectivity mapping and quantification of mineral potential.

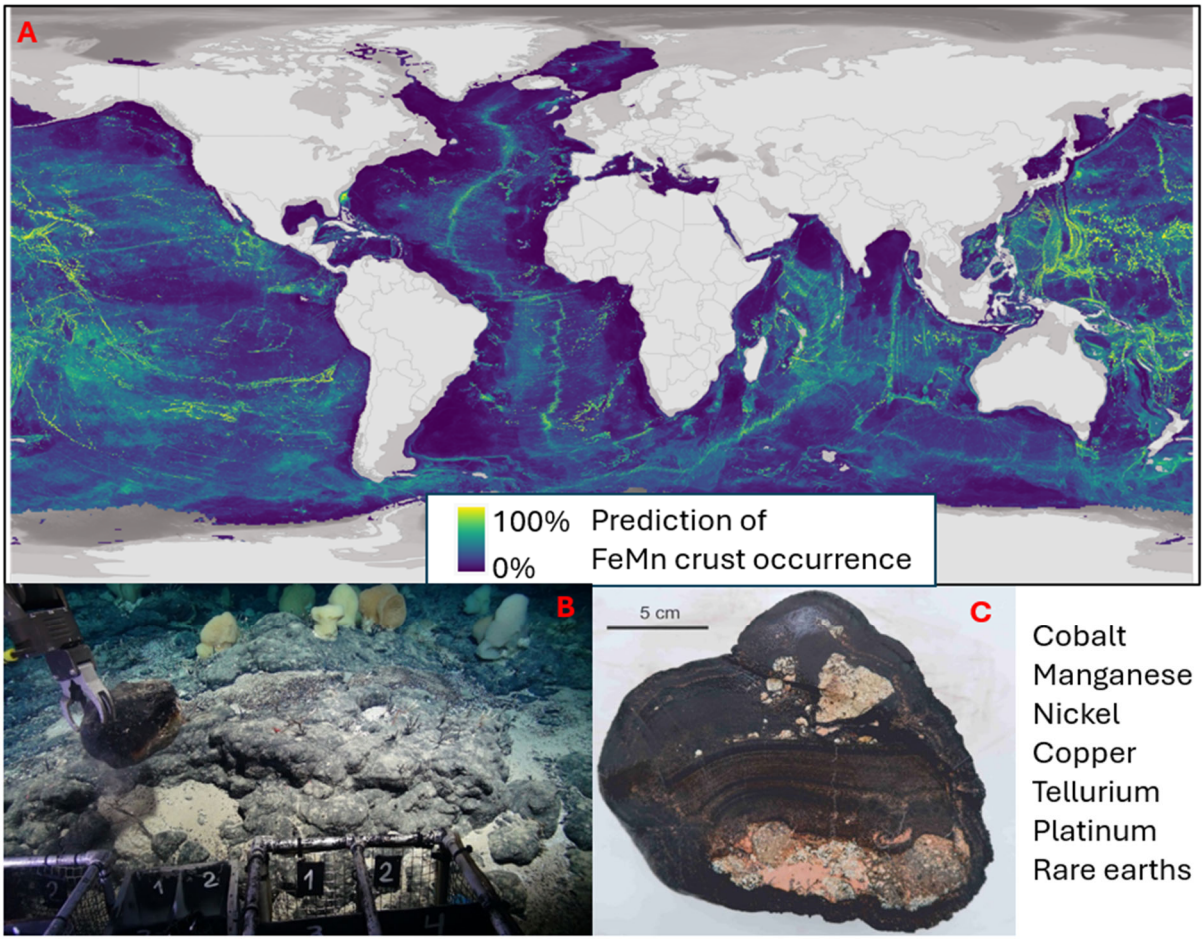

Figure 1: (A) Prospectivity map of FeMn crust occurrence in the world oceans (Josso et al., 2023). (B) FeMn crust outcrop at Tropic Seamount in the North Atlantic being sampled by Remotly operated vehicle. (C) Sampel cross section of a FeMn crust.

Methodology: 150 words

The successful candidate will work on Fe-Mn crust samples, have them prepared in thin sections for full imaging by SEM to provide key mineral texture observations and identify optimal target for laser-ablation ICP-MS (U-Pb dating, Pb isotopes). The student will be supported by instrument manufacturer and CASE partner Bruker for method development around acquisition and calibration of micro-XRF data on FeMn oxides matrices, with trips to their R&D facilities in Berlin.

All observational and acquired data will be integrated into the Geoactive Interactive Correlation Software for management, manipulation and visualisation of data sets as well as cross-sample correlation. Development of age models will allow to extract contemporaneous time slices of composition, mineral textures and environmental parameters to be interrogated through multi-variate statistical analysis for the development of the mineral system.

Machine learning algorithm (random forest and neural networks) will explore mineral prospectivity and characterise the potential mineral resource.

Possible Timeline

Year 1:

Literature review for familiarisation with topics of deep-sea mineral deposits, resource potential, oceanographic studies, age modelling and isotope systems. Familiarisation with samples and preparation of thin sections.

Development of NEIF proposal for acquisition of Be isotope data at SUERC, Glasgow and U-Th dating at BGS.

Training on M4 Tornado Bruker micro-XRF and BGS SEM instrument.

Training on R, Python, Geoactive IC.

High resolution micro-XRF and Pb isotopes data acquisition and development of sample correlated stratigraphy.

Active participation in public engagement.

Year 2:

Age modelling of the Pacific ferromanganese deposits through comparative analysis of (ii) Cobalt chronometry, (iii) Beryllium isotopes, (iv) U-Th dating.

Exploration of FMC mineral system: Statistical analysis of metal content variations and mineral textures with environmental parameters such as climate proxies, water depth, latitude, longitude, biological processes, water masses, distance gradient to land masses and hydrothermal sources.

Preparation of manuscript(s) and dissemination of results at conference(s). Active participation in public engagement.

Year 3:

Prospectivity analysis of the resource potential of Fe-Mn crusts:

- mapping of occurrences of deposit and confidence intervals using machine learning algorithm,
- Characterisation of the mineral potential of the region of interest by combining the FMC mineral system and prospective areas.

Preparation of manuscript(s) and dissemination of results at conference(s). Active participation in public engagement. Write-up of PhD thesis.

Training and skills:

TARGET researchers will participate in a minimum of 40 days training over the 3.5 years of study composed of:

- an annual one-week workshop dedicated to their year group, and tailored to that cohort's needs in terms of skills development – *for the first three years of their study*;
- an annual all-TARGET workshop with cross-year interactions, advanced training and opportunities to specialise in particular areas – *all years of study*;
- a number of one-day workshops;
- additional online events and in-person workshops attached to relevant conferences.

- Scanning electron Microscopy (SEM), laser-ablation MC-ICP-MS and micro-XRF analysis. Geochemical data quality assessment and quality check.
- Paper-writing skills. Paper and proposal writing skills, oral presentation at conferences and public engagement combining both education and outreach activities.
- Advanced data management, statistics, data analysis and visualisation in R, python or Matlab. Bayesian Regression modelling and Geochronology. Geoactive IC data management. Random forest and convoluted neural network machine learning.

Partners and collaboration (including CASE):

The student will be hosted at the British Geological Survey in Keyworth, Nottingham for about 70% of the time. The rest will be spent at the University of Leicester to work directly with the other members of the supervisory team on data acquisition and time series analysis.

The student will work closely with Bruker Instrument for the development of methods and calibration of micro-XRF data on FeMn oxide matrices. This will involve induction on instrument at their R&D facility in Berlin with continuous support throughout the project for work on instruments in Leicester, developing best-spoke methods and data analysis packages.

Further reading:

Josso, P et al., 2021. Controls on metal enrichment in ferromanganese crusts: Temporal changes in oceanic metal flux or phosphatisation? Geochimica et Cosmochimica Acta 2021 Vol. 308 Pages 60-74

Verlaan, P. A. and Cronan, D. S. Origin and variability of resource-grade marine ferromanganese nodules and crusts in the Pacific Ocean: A review of biogeochemical and physical controls. Geochemistry 2022 Vol. 82 Issue 1 Pages 125741

Mizell, K et al., 2020. Geographic and Oceanographic Influences on Ferromanganese Crust Composition Along a Pacific Ocean Meridional Transect, 14 N to 14S. Geochemistry, Geophysics, Geosystems 2020 Vol. 21 Issue 2 Pages e2019GC008716

Further details:

Please visit https://target.le.ac.uk/ for additional details on how to apply.

For further information, please contact Dr. Pierre Josso, piesso@bgs.ac.uk