minerals

MDPI

Editorial

Exploration of Polymetallic Nodules

Pedro Madureira [1,2,*] and Tomasz Abramowski [3,4,*]

[1] Estrutura de Missão para a Extensão da Plataforma Continental (EMEPC), 2770-047 Paço de Arcos, Portugal
[2] Department of Geosciences, Institute of Earth Sciences, University of Évora, 7000-671 Évora, Portugal
[3] Interoceanmetal Joint Organization, Cyryla i Metodego 9, 71-541 Szczecin, Poland
[4] Faculty of Navigation, Maritime University of Szczecin, Wały Chrobrego 1-2, 70-500 Szczecin, Poland
* Correspondence: pedro.madureira@emepc.mm.gov.pt (P.M.); t.abramowski@iom.gov.pl (T.A.)

The use of mineral resources has always been critical for human development. Mineral resources are critical for a sustainable economy, and cobalt, nickel, and manganese are among the strategic metals that play a crucial role. These three metals, plus cop- per, are found in one promising type of high-tonnage mineral deposit: polymetallic nod- ules.

Polymetallic nodules are known to occur in the vast abyssal plains at water depths greater than 4000 m. They have been particularly well identified in the Pacific Ocean, where they were targeted for commercial extraction during several pilot-mining initiatives that took place in the 1970s. Most current exploration activities searching for these deposits are concentrated around the international seafloor, named "the Area" by the United Nations Convention on the Law of the Sea (UNCLOS), where the activities are carried out under the jurisdiction of the International Seabed Authority (ISA). Since 2001, the ISA has granted 19 contracts for exploration of polymetallic nodules, 18 in the Pacific and 1 in the Indian basin. According to the ISA regulations, the term "Exploration" means the search for extractable concentrations of polymetallic nodules in the Area. The contracts provide companies with exclusive rights to carry out studies on the environmental, technical, economic, commercial, and other appropriate factors that must be taken into account in the future exploitation of these nodules. Some of the challenges of the exploration work are addressed in this Special Issue, which is focused on the geological assessment of this particular marine mineral resource.

The paper by Parianos et al. [1] focuses on the estimation and reporting of nodule resources, which are mainly dependent on the determination of the abundance of nodules. The issues related to determining the abundance of nodules are also addressed by these authors from lessons learned in the TOML (Tonga Offshore Mining Limited) exploration area in the Clarion-Clipperton Zone (CCZ). The study by Kuhn and Rühlemann [2] focuses on resource assessment from extensive datasets acquired during exploration activities in the BGR (Federal Institute for Geosciences and Natural Resources) area. They use an artificial neural network approach with a multivariate statistical correlation between nodule abundance derived from box-cores and hydroacoustic sources. Wasilewska-Błaszczyk and Mucha [3,4] demonstrate the need to increase the reliability of the results of photographic surveys of the seabed. These authors propose the use of a statistical linear model that includes quantitative variables, such as the abundance and spatial variation of nodules. In addition, their model includes ordinal variables that are estimated visually from photographs of the seafloor. Gordon and Parianos [5] propose an empirical statistical method to improve nodule resource estimation based on predictions and field measurements of nodule abundance and nodule seafloor coverage. Their method may be able to help improve the efficiency of the design and configuration of mining equipment. Gazis and Greinert [6] address the possible use of machine learning modeling to map the distribution of polymetallic nodules in an area of the Peru Basin. They presented the results of a quantile regression forests model, which is able to provide good results in morphologically similar areas with similar seabed morphologies.

Citation: Madureira, P.; Abramowski, T. Exploration of Polymetallic Nodules. *Minerals* **2022**, *12*, 1483. https://doi.org/10.3390/min12121483

Received: 31 October 2022
Accepted: 18 November 2022
Published: 23 November 2022

The paper by Tsune [7] focuses on the determination of a mathematical expression to quantify the burial of polymetallic nodules. Buried nodules may have an impact on resource assessment, and their estimation may be particularly relevant in some areas of the abyssal plains. Skowronek et al. [8] present a detailed mineralogical and microgeochemical study of nodules collected in the IOM (the Interoceanmetal Joint Organization) exploration area in the CCZ. Their data contribute to a better understanding of nodule growth and zo-nation, particularly for nodules resulting from diagenetic processes where hydrogenous processes only have a minor influence. The paper by Kim et al. [9] provides the geochemical characterization of fine particles produced through the degradation of polymetallic nodules. The discharge of fluid and fine-particle mixtures may cause serious disturbances to the marine environment.

The paper by Abramowski et al. [10] focuses on the economic assessment of polymetallic nodules, taking into account the financial flow of operating and capital expenses and the challenges imposed due to unexpected economic conditions, such as those imposed by the COVID-9 pandemic. Li et al. [11] provide their view on the payment mechanism related to the future exploitation of polymetallic nodules in the Area. Importantly, the possible impacts of deep-sea polymetallic nodule mining on land-based metal markets are also highlighted in their study.

One of the challenges for the future economic extraction of polymetallic nodules is the assessment of mineral reserves. This Special Issue addresses fundamental questions related to the determination of abundance nodules and proposes new approaches to improve mineral resource estimation. Another major challenge is found in the use of technology and sampling strategies that could ensure the effective protection of the marine environment from harmful effects caused by exploitation activities. This is certainly one of the topics that will require more focus and further research in order to develop sustainable models for commercial extraction of nodules in the Area. The mineral resources of the Area are considered to be the common heritage of mankind by UNCLOS, and future exploitation activities should be carried out for the benefit of mankind as a whole. An important contribution of this Special Issue also relies on the discussion of economic models and payment mechanisms that constitute the first steps toward the development of equitable mechanisms for sharing financial and other economic benefits derived from activities in the Area. The co-Editors would like to thank all the authors who contributed to this Special Issue on the exploration of polymetallic nodules.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Parianos, J.; Lipton, I.; Nimmo, M. Aspects of Estimation and Reporting of Mineral Resources of Seabed Polymetallic Nod- ules: A Contemporaneous Case Study. *Minerals* **2021**, *11*, 200.
2. Kuhn, T.; Rühlemann, C. Exploration of Polymetallic Nodules and Resource Assessment: A Case Study from the German Contract Area in the Clarion-Clipperton Zone of the Tropical Northeast Pacific. *Minerals* **2021**, *11*, 618. [CrossRef]
3. Wasilewska-Błaszczyk, M.; Mucha, J. Possibilities and Limitations of the Use of Seafloor Photographs for Estimating Polymetallic Nodule Resources—Case Study from IOM Area, Pacific Ocean. *Minerals* **2020**, *10*, 1123. [CrossRef]
4. Wasilewska-Błaszczyk, M.; Mucha, J. Application of General Linear Models (GLM) to Assess Nodule Abundance Based on a Photographic Survey (Case Study from IOM Area, Pacific Ocean). *Minerals* **2021**, *11*, 427. [CrossRef]
5. Yu, G.; Parianos, J. Empirical Application of Generalized Rayleigh Distribution for Mineral Resource Estimation of Seabed Polymetallic Nodules. *Minerals* **2021**, *11*, 449. [CrossRef]
6. Gazis, I.-Z.; Greinert, J. Importance of Spatial Autocorrelation in Machine Learning Modeling of Polymetallic Nodules, Model Uncertainty and Transferability at Local Scale. *Minerals* **2021**, *11*, 1172. [CrossRef]
7. Tsune, A. Quantitative Expression of the Burial Phenomenon of Deep Seafloor Manganese Nodules. *Minerals* **2021**, *11*, 227. [CrossRef]
8. Skowronek, A.; Maciąg, L.; Zawadzki, D.; Strzelecka, A.; Baláž, P.; Mianowicz, K.; Abramowski, T.; Konečný, P.; Kraw- cewicz, A. Chemostratigraphic and Textural Indicators of Nucleation and Growth of Polymetallic Nodules from the Clarion- Clipperton Fracture Zone (IOM Claim Area). *Minerals* **2021**, *11*, 868. [CrossRef]
9. Kim, M.G.; Hyeong, K.; Yoo, C.H.; Lee, J.Y.; Seo, I. Characterization of Fines Produced by Degradation of Polymetallic Nod- ules from the Clarion–Clipperton Zone. *Minerals* **2021**, *11*, 205. [CrossRef]

10. Abramowski, T.; Urbanek, M.; Baláž, P. Structural Economic Assessment of Polymetallic Nodules Mining Project with Updates to Present Market Conditions. *Minerals* **2021**, *11*, 311. [CrossRef]
11. Li, Y.; Liu, C.; Su, S.; Li, M.; Liu, S. Analysis of the Effect of Payment Mechanism on Exploitation of Polymetallic Nodules in the Area. *Minerals* **2021**, *11*, 211. [CrossRef]