# ADVANCES ON TECHNOLOGICAL AND ECONOMIC FACTORS IN THE DEVELOPMENT OF THE DEEP-SEA POLYMETALLIC NODULES PROJECT OF THE INTEROCEANMETAL JOINT ORGANIZATION

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***ABSTRACT***
*Deep-sea mineral resources (polymetallic nodules, cobalt-ferromanganese crusts and polymetallic sulfides) attracted the attention of the world community since the early 2000s as a source of variety of metals, including many that are essential for emerging high- and green- technology applications. Interoceanmetal (IOM) as a contractor with the International Seabed Authority has exclusive rights for exploration for polymetallic nodules in the eastern part of Clarion-Clipperton Fracture Zone (NE, Pacific). This paper outlines framework of the value chain of nodules mining based both on the IOM's site-specific data obtained during the exploration activity and information of the new technological advances in extraction of valuable metals from nodules.*
***Keywords:*** *Deep seabed mining, polymetallic nodule, value chain, Interoceanmetal Joint Organization.*

## Introduction

Although the deep-sea mining (DSM) is not commercially viable at present, interest to explore deep seabed mineral resources (in particular, polymetallic nodules) rapidly increases in the last decade. As the largest known deposits are located in the international seabed area, called "The Area", the International Seabed Authority (ISA), made up of 167 member States, and the European Union, is mandated under the 1982 UN Convention on the Law of the Sea and the 1994 Agreement relating to the Implementation of its Part XI to organize, regulate and control all mineral-related activities for the benefit of mankind as a whole (www.isa.org.jm). Currently, the ISA has entered into 31 contracts for exploration for deep-sea minerals, thus 19 of these contracts are for exploration for polymetallic nodules in the Clarion-Clipperton Fracture Zone (CCZ), NE Pacific Ocean (17), Central Indian Ocean Basin (1) and Western Pacific Ocean (1). There are 7 contracts for exploration for polymetallic sulphides in the South West Indian Ridge, Central Indian Ridge and the Mid-Atlantic Ridge and 5 contracts for exploration for cobalt-rich crusts in the Western Pacific Ocean [1]. So far, no contracts for actual mining have been issued by the ISA but the process of preparing regulations for DSM is on the final phase of its agreement and approval [2].

The richest nodule deposits and, consequently, most exploration claims registered with the ISA are located in the CCZ. These deposits are considered alternatives to depleting land resources of strategic metals such as copper, nickel, cobalt, lead, zinc, molybdenum, platinum, and rare earths that are required for various industrial purposes [3-5]. The metals found in polymetallic nodules are critical for clean energy technologies such as wind turbines, solar panels, electric vehicle batteries and other energy storage devices [6].

Development of polymetallic nodules from the seabed beyond the limits of national jurisdiction is still in uncertain terms; perhaps the most important barrier is economic. However, the recent research indicates that deposits of polymetallic nodules and other marine minerals have the potential to be economically feasible for exploitation in the presence of favorable metal prices on the world market, as well as in accordance with the technological improvement of the mining and processing systems [7-9].

This study presents results based on the currently available synthesis of knowledge on the valuation of polymetallic nodule deposits as well as on the mining and processing technologies applied to the deep-sea mining project of the Interoceanmetal Joint Organization (IOM). The IOM, an intergovernmental consortium sponsored by governments of six states (Bulgaria, Cuba, the Czech Republic, Poland, the Russian Federation, and Slovakia), was among the first "pioneer investors", which in 2001 concluded with the ISA a contract for exploration for polymetallic nodules in 75,000-km$^2$ seafloor claim area, situated in the eastern part of the CCZ, of the northern equatorial Pacific (Fig. 1). The structure of the IOM investment project in general contains the analysis of the financial flow and technological developments of commercial phases of the project implementation, namely, deep-sea mining operations, metallurgical processing, and economic criteria investigations.

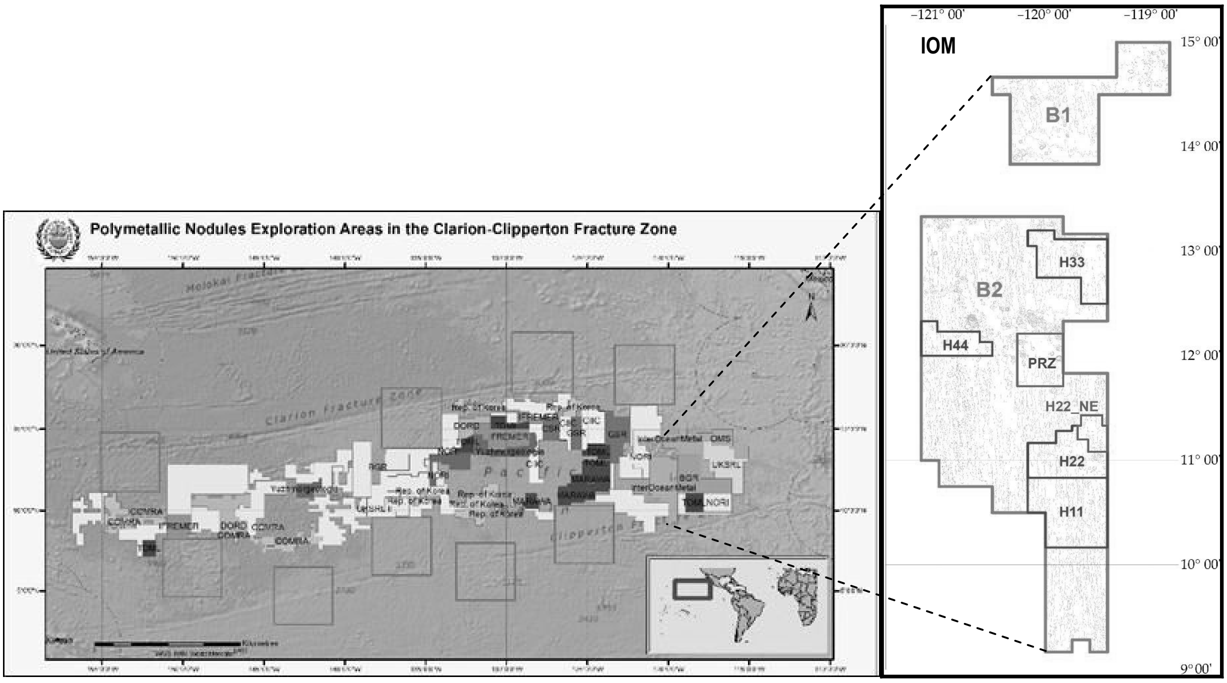


*Fig. 1: Map of exploration contract areas of polymetallic nodules in the Clarion-Clipperton Fractures Zone, NE Pacific Ocean (adapted from www.isa.org.jm); on the right, the IOM exploration area (sectors B1 and B2) with exploration and exploitable blocks, included in the resource estimation in this study*

## Materials and methods

The source of materials for this paper is based on extensive data and information obtained from more than 25 scientific expeditions and onshore investigation carried out by the IOM in the license area. The results of these comprehensive research, which included geological documentation, technology of nodule extraction and processing as well as research on the marine environment in the exploration area, were summarized in the IOM Preliminary Economic Assessment Technical Report prepared in 2018 and subsequently, the economic data were updated in 2019 taking into account changes in metal prices [10, 8]. Resource estimation is based on geostatistical data analysis of nodule samples collected during the above-mentioned expeditions carried out by the IOM.

The financial analysis of the considered project's scenarios was conducted using the discounted cash flow (DCF) method. DCF is a valuation method that values a business case (project) by projecting its future cash flows and then using the net present value (NPV) method to estimate those cash flows. The DCF approach in project assessment enables suitable net return indicators to be calculated (i.e., NPV, IRR—internal rate of return, PI—profitability index, dPP—discounted payback period). NPV is a mathematical technique to translate projected annual cash flow amounts into the present equivalent amounts using the discount factor (weighted average cost of capital, WACC). The discount factor determines the present value of future cash flows. Different scenarios and analyses for a better understanding of the impact of the changes on project results were evaluated.

## Deep seabed mining value chain: the IOM case study

Within the value chain concept of DSM, seven main stages from prospecting to sales can be identified [11]: (1) Prospecting and application, (2) Exploration, (3) Resource assessment, evaluation and mine planning,

(4) Extraction, lifting and surface operations, (5) Offshore and onshore logistics, transport operations, (6) Metallurgical processing stage, and (7) Distribution and sales. Whereas within prospecting, exploration and resource assessment phases the value is added generally to intangible assets of a project, for the extraction, processing and distribution phases the value increases with relation to product processing. There is an intermediate phase (3-4) the pilot mining test which could be considered to be an inevitable step in the shift from "resources" to "reserves" classification, where the value of a DSM project actually starts.

The current focus of the IOM mining project is aimed at exploration, evaluation and planning rather than exploitation. In these stages, the mining, extraction, lifting and surface operation techniques needed for the exploitation phase are now in planning or are tested on a small scale. This technology development value chain does not incorporate the regulatory, financial and environment protection stages which should facilitate the whole process of deep-sea mining.

### *Resources and reserves summary*

The exploration and exploitable blocks included in the IOM resource estimation with a more general view of the International Seabed Authority (ISA) exploration areas for polymetallic nodules are presented in Fig. 1. According to the CRIRSCO (Committee for Mineral Reserves International Reporting Standards) directives, the resources of polymetallic nodules in the IOM license area can be categorized as „inferred" in B1 and B2 exploration sectors, as „indicated" in H11 and H22 exploration blocks, and as measured in the H22_NE exploitable block (Fig.1).

The current status of mineral resource estimate of wet polymetallic nodules in the entire IOM exploration area and its first generation minable blocks/sites is shown in Table 1. No mineral reserve estimates in the IOM exploration area at present. Within the whole exploration area and blocks, the accuracy of nodule resource estimation is high, with the relative (kriging) standard error of the estimate of 3–8%. The accuracy of Cu, Co, Mn and Ni grade estimates is highly satisfying in areas of any size due to low variability of metal contents, resulting from stable chemical composition of polymetallic nodules.

Data on the metals contained in nodules presented in Table 1 were based on the results of geological samples, the number of which was statistically important for the purpose of the resource estimation. Therefore, the subject of this economic analysis was primarily focused on the metals shown in Table 1, also for the purpose of developing metallurgical processing methods.

*Table 1: Mineral resource estimate of wet polymetallic nodules in the B1 and B2 sectors of the IOM exploration area. Cut-off abundance 10 kg/m$^2$ of wet nodules, without volcanoes, outcrops, seabed areas free of nodules, and areas sloped over 7$^0$*

| Mineral Resource Classification | Mean abundance (wet kg/m$^2$) | Mn (%) | Ni (%) | Cu (%) | Co (%) | Resources (Mt)* |
|---|---|---|---|---|---|---|
| Measured (H22_NE block) | 14.6 | 29.19 | 1.31 | 1.25 | 0.18 | 12.2 |
| Measured total | | | | | | 12.2 |
| Indicated (H11 and H22 blocks) | 12.4 | 31.37 | 1.30 | 1.29 | 0.16 | 77.0 |
| Indicated total | | | | | | 77.0 |
| Inferred (B1 sector) | 13.4 | 27.84 | 1.21 | 0.90 | 0.21 | 62.6 |
| Inferred (H33 block) | 12.0 | 32.35 | 1.41 | 1.2 | 0.18 | 21.8 |
| Inferred (H44 block) | 11.5 | 30.71 | 1.32 | 1.19 | 0.19 | 13.6 |
| Inferred (B2 sector other) | 11.6 | 30.90 | 1.32 | 1.21 | 0.18 | 85.3 |
| Inferred total | | | | | | 183.3 |
| Grand total | | | | | | 272.5 |

**Sector B2 includes exploration blocks H11, H22, H33, and H44 and exploitable block H22_NE.*

### *Economic evaluation*

Two economic modelling scenarios, including four different variants in total, were carried out. Scenario 1, or a CAPEX-heavy scenario, is a variant of the project which assumes extraction, transportation and processing of 4.5 million tons of wet polymetallic nodules. The processing part of the business case takes into consideration 3 technological options, which could be used to process nodules (HM- hydrometallurgy, PM – pyrometallurgy, HPAL – high pressure acid leaching). Three processing technologies are considered (Table 2): hydrometallurgy (HM), pyro-hydrometallurgy (PM), and hydrometallurgy with pressure (HPAL). HM technology supports selective leaching using sulfur dioxide, producing concentrates of Cu, Ni, Co, and $MnO_2$. PM technology furthers selective electro-reduction of nonferrous metals (ore-smelting in an electric furnace) producing SiMn and subsequent treatment of the complex Cu/Ni/Co alloy. HPAL technology by high-pressure acid leaching using pyrite as a reducing agent and producing concentrates of Cu, Ni, Co, Zn, and $MnO_2$.

For the purpose of this economic analysis, a technical study was carried out to evaluate the investment costs and operating costs of the three methods indicated above. In the case of the PM and HM methods, a green field investment was assumed in which a completely new metallurgical plants are being built. In the case of the HPAL technology, the costs were assessed assuming an investment to extend the existing metallurgical installations in Moa, Cuba. In this case, it was anticipated to reduce the high costs typical of HPAL technology, but it should be mentioned that they were still relatively high. Table 2 presents the features of the three analyzed technologies.

*Table 2: Comparison of the IOM alternative project implementation scenarios (as the end of 2019)*

| | Mining output (wet polymetallic nodules, Mt) | Processing input (dry polymetallic nodules, Mt) | Total CAPEX (MUSD) | Average annual OPEX (MUSD) | NPV (MUSD) WACC 20,5% | IRR (%) |
|---|---|---|---|---|---|---|
| Scenario 1 – HM | 4.5 | 3.0 | 2.508 | 1.293 | -1.565 | -5.38 |
| Scenario 1 – PM | 4.5 | 3.0 | 4.286 | 1.814 | -2.983 | - |
| Scenario 1 – HPAL | 4.5 | 3.0 | 2.535 | 751 | -705 | 13.10 |
| Scenario 2 | 1.5 | - | 513 | 110 | 52 | 24.58 |

Where: HM- hydrometallurgy, PM – pyrometallurgy, HPAL – high pressure acid leaching, NPV - Net Present Value, WACC - Weighted Average Cost of Capita, IRR -Internal Rate of Return.

The second scenario (1.5 million tons per year) is a CAPEX-light scenario, in which the case is limited to the extraction, lifting and sale of raw ore (Table 2). This option does not take into account the construction costs of the metal processing plant and operating costs of the process. In this scenario, all the mined polymetallic nodules volume would be sold to any buyer. The basic factor of profitability of such a scenario is the price and sales volume of raw ore.

Comparison of alternative project scenarios is shown in Table 2.

Analysis of the options for alternative project implementation indicates that the project requires optimization of the business concept. For scenarios that include a combination of a mining and processing part, the project results are negative regardless the chosen technology. This results from high both CAPEX as well as OPEX. Use of existing processing capacities or ordering the processing of metals as external service seems to be a better solution. This could require reconsideration of the optimal capacity of polymetallic nodules production and the sales structure.

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